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Abdelazim M. Negm
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Water Resources Management in Balkan Countries

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Abdelazim M. Negm · Gheorghe Romanescu ·
Martina Zelenakova
Editors

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Editors
Abdelazim M. Negm
Faculty of Engineering
Zagazig University
Zagazig, Egypt

Gheorghe Romanescu
Faculty of Geography and Geology
University “Alexandru Ioan Cuza”
Iași, Romania

Martina Zelenakova
Technical University of Kosice
Košice, Slovakia

Gheorghe Romanescu is Deceased (died on 3rd October 2018)

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Preface

Water resources management of a country is a national responsibility, and relevant activities should be proposed so that the specific needs of a country are met. Many of its component activities may be done at the local and regional levels. This national responsibility should be divided among neighboring countries in the case of cross-border water resources, and international programs and project may provide valuable help.

With respect to the importance of the assessed information on sustainable development and the maintaining the integrity of ecosystems, all countries are urgently called upon to achieve a level of assessment of water resources corresponding to needs as soon as possible.

The policy should be such that all national and international activities of assessing water resources are fully coordinated and financed over the long term. The approach to achieving this goal may differ in individual countries but will typically include the mandating of regulations and administrative decisions, especially in terms of allocating financial resources.

The assessment of water resources requires significant financial resources if the support of sustainable social–economic development is raised with this. These resources, however, represent only a small portion (e.g., 0.2–1.0%) of financial resources expended on investments and activities in the water sector as a whole. Governments are urgently called on to allocate national and international funds for priority assessment of activities in the area of water resources management.

This book presents an expert overview and knowledge on water resources management in Balkan countries—Slovenia, North Macedonia, Serbia, Croatia, Greece, Bulgaria, and Romania. The book will be useful to experts, professionals, researchers, scientists, practitioners, academics working in the field of water resources management. Water is a vital component of the natural environment, but it is also a basic prerequisite for all human economic and social activities in general. Water is a form of wealth which requires protection; its usage needs to be regulated, and its supply needs to be regenerated. Water may be continuously renewed in nature, but only on the precondition that the fundamental principles of its protection are respected. Anybody who is carrying out any activity which may affect the state and relations of surface and underground waters has the obligation to make all necessary efforts for their preservation and protection will be interested in this book. The book is devoted to a variety of water resources issues in Balkan countries. The book presents state-of-the-art knowledge that can be effectively used for solving a variety of problems in integrated water resources management.

The book has been treated as the product of teamwork of more than 40 distinguished researchers and scientists from different institutions, academic, and research centers with major concerns regarding water management from Balkan countries.

The *Water Resources Management in Balkan Countries* book consists of 17 chapters and is divided into nine parts. Part I, "Introducing the book," was prepared by editors Abdelazim M. Negm from Water and Water Structures Engineering Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt; Martina Zelenakova from Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia; and Ionut Minea from Department of Geography, Faculty of Geography and Geology, Alexandru Ioan Cuza University of Iasi, Iași, Romania.

It also contains the chapter which is devoted Danube River (DR) Delta. The DR is the biggest and the most significant river in the Balkan region, flowing through almost all Balkan countries. Chapter 2, "Danube Delta Biosphere Reserve—Long-Term Assessment of Water Quality," offers an overview over almost 25 years of the anthropogenic pressures in Danube Delta Biosphere Reserve in the last half-century accompanied by long-term water quality assessment in this area using legislations, physical–chemical (such as salts, nutrients, heavy metals) and biological parameters. It was prepared by Cristina Despina, Liliana Teodorof, Adrian Burada, Daniela Seceleanu-Odor, Iuliana-Mihaela Tudor, Orhan Ibram, Cristian Trifanov, Marian Tudor from Danube Delta National Institute for Research and Development (DDNIRD), Tulcea, Romania.

Part II of the book focused on "Water Resources Management in Slovenia." Chapter 3 of the book "Water Resources in Slovenia" outlines key facts about water resources of Slovenia, which is a country characterized by an abundance of water in a great variety of forms. The chapter was written by Mauro Hrvatin, Blaž Komac, and Matija Zorn from Research Centre of the Slovenian Academy of Sciences and Arts, Anton Melik Geographical Institute, Slovenia. Chapter 4 "Induced Riverbank Filtration (IRBF) for Managed Artificial Groundwater Recharge (MAR) in Slovenia" pays attention to the efficiency of managed artificial groundwater recharge system and consequently a water quality healthy aquifer in Slovenia. The chapter was prepared by Irena Kopač from Ecological Engineering Institute d.o.o., Maribor and Matevž Vremec from Faculty of Engineering, University of Maribor, Slovenia.

Part III of the book deals with "Water Resource Management in Croatia." Chapter 5 "Groundwater Resources in Croatia" is devoted the quantity and distribution of groundwater resources in Croatia which are determined primarily by hydrogeology and climate. The authors of these chapters are Danijel Orešić and Ivan Čanjevac from Department of Geography, Faculty of Science, University of

Zagreb, Croatia. Chapter 6 "Water Quality Status of Croatian Surface Water Resources" describes the status of water quality of small rivers, large rivers, and lakes in Croatia. It was written by Lidija Tadić and Marija Šperac from Josip Juraj Strossmayer University of Osijek, Faculty of Civil Engineering Osijek, Croatia, and Barbara Karleuša and Josip Rubinić from University of Rijeka, Faculty of Civil Engineering, Rijeka, Croatia. Chapter 7 "Surface Water Resources and Their Management in Croatia" focuses on water balance components and surface water resources in Croatia and analyses main water use sectors, water resources management system, and flood protection in Croatia. The authors of these chapters are Ivan Čanjevac and Danijel Orešić from Department of Geography, Faculty of Science, University of Zagreb, Croatia.

Part IV focuses on "Water Resource Management in Bosna and Herzegovina." Chapter 8 "Water Resources in Bosnia and Herzegovina" prepared by Emina Hadžić from Faculty of Civil Engineering, University of Sarajevo, Bosnia and Herzegovina, and Alma Imamović from Ministry of Agriculture, Water Management and Forestry of the Federation of Bosnia and Herzegovina deals with hydrological conditions and water resources management in Bosnia and Herzegovina.

Part V of this book is devoted to "Water Resource Management in Serbia." Chapter 9 "Water Resources of Serbia and Its Utilization" describes legislation, regulatory, and institutional framework for water utilization and provides the detailed data and information about natural conditions, as well as the latest monitoring data on water resources quantity and quality significant for water utilization in Serbia. The authors of this chapter, Borislava Blagojević, Marko Langović, Ivan Novković, Slavoljub Dragićević, and Nenad Živković, are from Faculty of Geography, University of Belgrade, Belgrade, Serbia. Chapter 10, "Microbial Quality of Irrigation Water in Serbia: Risks to Food Safety," deals with the detected water quality of sources used for irrigation in agricultural areas of Serbia and the potential risks if water of inadequate quality is used for irrigation. It was prepared by Željka Rudić, Igor Kljujev, Bojana Vujović, Mile Božić, and Vera Raičević from the Jaroslav Černi Institute for the Development of Water Resources, Serbia. The aim of Chap. 11 "Precipitation and Drought Analysis in Serbia for the Period 1946–2017" is to monitor and analyze precipitation and drought which cover various fields of influence in Serbia in some detailed and expedient manner. It was written by Milan Gocic, Slavisa Trajkovic, Mladen Milanovic Faculty of Civil Engineering and Architecture, University of Nis, Nis, Serbia.

Part VI is interested in "Water Resource Management in Bulgaria." Chapter 12 "Water Resource Management in Bulgaria" includes the information about the water resources in Bulgaria: for rivers, lakes, and damps, also information for water management and law in Bulgaria. The chapter was prepared by Rositsa Velichkova, Tsvetelina Petrova, Iskra Simova, and Detelin Markov from Technical University of Sofia, Sofia, Bulgaria; Georgi Bardarov from Sofia University "St. Kliment Ohridski," Sofia, Bulgaria; and Milka Uzunova from LR2A.Lab, ECAM-EPMI Cergy-Pontoise, France. Chapter 13 "River Systems Under the Anthropogenic and Climate Change Impacts: Bulgarian Case" is focused on the existing problems in the area with regard to the Bulgarian river system quantification status, and it was prepared by Mila Chilikova-Lubomirova from Fluid Mechanics Department, Institute of Mechanics—Bulgarian Academy of Sciences, Bulgaria.

Part VII is devoted to "Water Resource Management in North Macedonia." Chapter 14 "Water Resources Management in Republic of North Macedonia" introduces water resources in the country and points out demand for improvement of capacity, financials, and human resources for better water management. The chapter was written by Ivan Radevski, Svemir Gorin, Vladimir Zlatanoski from Institute of Geography, Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Skopje, Republic of North Macedonia. Chapter 15 "Water Quality and Pollution Status of the Main Rivers in the Republic of North Macedonia" prepared by Olgica Dimitrovska, Ivan Radevski, and Svemir Gorin from Institute of Geography, Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Skopje, Republic of North Macedonia emphasizes the main pressuring of the quality of the water resources in the Republic of North Macedonia, the pointing and diffusive sources of pollution as a result of the activities of the households, the industry and the agriculture through water quality indicators (BOD_5, total ammonium, nutrients).

Part VIII is focused on "Water Resource Management in Greece." Chapter 16 "Agricultural Water Management in Greece" concerns on problems in irrigation water management in Greece. It was prepared by Nicholas Dercas from Water Resources Sector, Department of Natural Resources Management and Agricultural Engineering, Agricultural University of Athens, Athens, Greece.

Part IX is "Conclusion," and Chap. 17 titled "Update, Conclusions, and Recommendations for Water Resources Management in Balkan" was prepared by editors of the book Abdelazim M. Negm, Martina Zelenakova, and Ionut Minea.

This book presents a real valuable source of knowledge in the field of water resources management of Balkan countries. We would like to express special thanks to all the authors for their contributions. Without their patience and effort in writing and revising the different versions to satisfy the high-quality standards of Springer, it would not have been possible to produce this volume and make it a reality. This high-quality volume sure will be a greatly appreciated source of information for the academics, researchers, practitioners, students, and scientists mainly from Balkan countries but not only for them. Much appreciation and great thanks are also owed to the editors of the Environmental Earth Science book series at Springer for the constructive comments, advice, and the critical reviews. Acknowledgments must be extended to include all members of the Springer team who have worked long and hard to produce this volume. The volume editors would be happy to receive any comments, feedback, suggestions for improvement, or new chapters for next editions are welcomed and should be sent directly to the volume editors. The emails of the editors can be found inside the books at the footnote of their chapters.

The book is especially devoted to University Professor Gheorghe Romanescu, Editor of this book, Eminent Teacher, and Researcher in the field of water geography, who unexpectedly has left us on October 3, 2018, during the processing of this volume. We appreciate his great effort in the invitation of the authors because without his contribution and hard work, the book would not arouse.

Košice, Slovakia — Martina Zelenakova
Iași, Romania — Gheorghe Romanescu
Zagazig, Egypt — Abdelazim M. Negm
March 2019

The original version of this book was revised: The country name “Macedonia” to “North Macedonia” throughout the book has been corrected. The correction to this book can be found at https://doi.org/10.1007/978-3-030-22468-4_18

Contents

Part I
Introducing the Book

Chapter 1
Introduction to “Water Resources Management in Balkan Countries”

Martina Zelenakova, Abdelazim M. Negm and Ionut Minea

Abstract This chapter presents the main features of the book titled “Water Resources Management in Balkan Countries” and their related topics. The covered topics are all about water resources management in Balkan countries. These countries includ Romania, Slovenia, Croatia, Bosna and Herzegovina, Serbia, Bulgaria, North Macedonia and Greece. The main technical elements of each of water resources management in each country are presented under its relevant theme.

Keywords Balkan countries · Water quality · Management · Romania · Slovenia · Croatia · Bosna and Herzegovina · Serbia · Bulgaria · North Macedonia and Greece · Albania · Montenegro

1.1 Balkan Countries: A Brief Background

The Balkan Peninsula has long been a bridge between Europe and Asia. There will be various civilizations, cultures, languages, traditions and religions. South-eastern Europe is situated in the Mediterranean and Black Sea area. The surface consists of mountain massifs of various ages and heights. In the west there are the Alps. The Balkan Peninsula is filled with Dinars, the Old Plains (Balkans) and Rhodopes. In the northeast of Romania there are the Carpathians. The lowlands lie along the

M. Zelenakova
Faculty of Civil Engineering, Department of Environmental Engineering, Technical University in Košice, Košice, Slovakia
e-mail: martina.zelenakova@tuke.sk

A. M. Negm (✉)
Faculty of Engineering, Water and Water Structures Engineering Department, University Zagazig, Zagazig, Egypt
e-mail: amnegm@zu.edu.eg; amnegm85@yahoo.com

I. Minea
Faculty of Geography and Geology, Department of Geography, Alexandru Ioan Cuza, University of Iasi, Iasi, Romania
e-mail: ionutminea1979@yahoo.com

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rivers Danube and Marica. The Balkan Peninsula includes a large number of islands mainly in the Adriatic, Ionian and Aegean seas. The climate at Balkan is predominantly Mediterranean, changing inland to continental, and mountainous in mountain ranges. The Balkan Peninsula consists of Slovenia, Croatia, Bosnia and Herzegovina, Serbia and Montenegro, Albania, North Macedonia, Greece, Bulgaria, and Romania. In the 20th century, the state of Yugoslavia was part of the Balkans, and after 1991 it broke up during a series of civil wars. The process of disintegration of the former Yugoslavia has not yet come to an end since the autonomous state of Kosovo has declared independence from Serbia, but most countries in the world have not recognized it. Figure 1.1 shows the geographical location of the Balkan Countries. In the next subsections, a brief background of each country is presented.

1.1.1 Romania

The center of the country is formed by the large Transylvanian Highlands, surrounded by the Carpathian Arch and the Venetian and Apusian Hills in the west. Lowlands with Hungary reach Romania, the Wallachian Plain occupies most of the south. The most

Fig. 1.1 Shows the geographical location of the Balkan countries https://www.naturalearthdata.com/downloads/

important rivers Danube and Prut are borderline. Romania is rich in oil, natural gas, coal, iron ore. Therefore, the state is focused on mining, engineering (Dacia), chemical (Rompetrol) and the food industry. Crop production includes cereals, corn, sunflower, fruit, potatoes, vine. Forests occupy one-quarter of the territory. The largest settlements of Romania include the capital Bucharest, Constanta, Timisoara, Satu Mare, and Ploiesti. Transport is mostly road and rail, with transport networks mostly outdated. Tourism is focused on the Black Sea coast with centers of Mamaia, Eforia, Mangalia. It is worth visiting the capital city Bucharest and Bukovina. For lovers of winter sports, there are also ski resorts in the Carpathians. The Danube Delta is a protected area with unique fauna and flora. The water resources management in Romania were covered in details in a separate book. In this book, only one chapter (Chap. 2) is presented which is related to Danube Delta.

1.1.2 Slovenia

This country extends in the northwestern part of the Balkan Peninsula. From Austria and Italy, it extends to the Alps and the Kras mountain range to the south. Slovenia has access to the Adriatic Sea; the largest rivers are Sava and Drava. 92% of the Slovenian population are Slovenes; the minorities are Croats and Serbs. The bulk of the population is Catholic. The Republic of Slovenia is the most industrialized part of the former Yugoslavia. Industrial production accounts for about 35% of gross domestic product. In the territory of Slovenia, the machinery, automotive and electrical industries, pharmaceutical and chemical industries prevail, as well as brown coal, polymetallic ores, mercury, oil, and natural gas. Slovenia also has advanced agriculture, producing grain, fruit, vegetables, and vines. The main economic centers are Ljubljana, Maribor, Cejle and the ports of Koper, Izola, and Piran. Slovenia has attractive winter sports and hiking resorts in the Alps. There are several therapeutic waters and spas. There are richly visited caves in Kras: Postojna jama and the Adriatic coast. Chapters 3 and 4 are presented about water resources management in Slovenia.

1.1.3 Croatia

In the west, the Adriatic Sea surrounds the country, most of the Croatian coast is in Dalmatia. The rugged coastline is located more than 600 islands, e.g. Brac, Hvar, Krk and others. In the northeast, the Dinare Mountains are being considered into the fertile lowlands between the Sava, Danube and Drava rivers. The population of the Republic consists of Croats (80%), Serbs, Italians, Hungarians, and other minorities. Mineral resources and hydropower have created the right conditions for industrial development. Black coal, bauxite, oil, and natural gas are mined. Industries such as engineering, chemical, textile and timber industries are also developed. Agriculture is developed on the lowlands, with grains, sugar beet, vines on the Adriatic coast, olives, figs, and citruses. Services account for the largest share of GDP, up to 2/3. Croatia is a very popular holiday destination, Zagreb, Dubrovnik, Split, Rijeka, Makarska Riviera (Istria and Dalmatia beaches) and Plitvice Lakes National Park are the most attractive destinations. The water resources management in Croatia were presented in Chaps. 5, 6 and 7.

1.1.4 Bosnia and Herzegovina

Most of the surface is mountainous, partly forested and partly consists of bare karst mountains. The soil is fertile in the valley of the Sava River, where there is a loess plain. The country was named after the river "Bosnia," which stems from Sarajevo. This state is rich in ores, coal, and energy. The economy is dominated by industry —engineering, metallurgical, timber, and food. In the valley of the Sava River, maize, wheat, vine, tobacco, and fruit are grown. In the mountains, cattle and sheep breeding predominate. Between 1992 and 1995, a civil war broke out that destroyed not only society but also the country and its economy. The water resources management in Bosnia and Herzegovina is covered in Chap. 8.

1.1.5 Serbia

This country is located in the central part of the Balkans; it includes Vojvodina in the north and Kosovo in the south. The territories in the south and southwest fill the hills; the north is lowland. The population is made up of Serbs, Albanians, Montenegro, Hungarians, Slovaks, and Romanians. The largest industrial and cultural center is the capital of Belgrade. Vojvodina is the main granary of the country, where cereals, sugar beet, vines, vegetables, fruits, and tobacco are grown. Sheep farming is predominant in animal production. The core of the industry is mining and quarrying, which is used to develop engineering, chemical, and textile industries. * Kosovo is the most backward part of Serbia, and is demanding for autonomy. It is under UN administration, and the largest center of the industry is the capital city of Pristina. Serbia is represented by Chaps. 9, 10 and 11.

1.1.6 Bulgaria

Bulgaria lies in the southeastern part of the Balkan Peninsula off the Black Sea coast. Most of the northern border with Romania is the Danube, around which is the fertile North-Bulgarian Plain. The middle of the country stretches the mountain system Old Plain, also known as the Balkans. Very mountainous, it is southwest, where mountains such as Rila, Pirin, and Rhodopes, which are separated from the Upper Plain Lowland by the Old Plain. The population is mainly made up of Bulgarians and Turks. Most residents live in cities. The capital is Sofia; the other major sites are Varna, Plovdiv, Ruse, and Burgas. Economy: Crop production dominates in agriculture. Growing of wheat, corn, sunflowers, cotton, tomatoes, peppers, vines and tobacco. Bulgaria”s specialty is rose growing and rose oil production. Engineering, metallurgical, petrochemical (Burgas), textile and food industries. The most visited is the Black Sea coast, e.g. Golden Sands or Sunny Beach. The water resources management in Bulgaria are covered in Chaps. 12 and 13.

1.1.7 North Macedonia

North Macedonia has a total area of 25,713 km^2. Republic of North Macedonia is country located in the central part of the Balkan Peninsula. The relief is predominantly hilly-mountainous, with an altitude range of 54 m amsl to 2764 m amsl. This landscape results with very complex climate conditions with variations from basin to basin. The richest part of the country with precipitation are mountain ridges across the border with Albania (maximum 1400 mm per year), the central part of the country is driest with annual precipitation sum of 370 mm, east part has a maximum average annual precipitation of 950 mm. North Macedonia is a small landlocked country; the surface is mostly mountainous, and more than one-third of the area is covered by forests. North Macedonia is a major economic and transport axis from Europe to Greece and Turkey. Only the mining of ores (iron) and wood is significant. The industrial center is the city of Skopje. The water resources management in North Macedonia is presented in Chaps. 14 and 15.

1.1.8 Greece

This country occupies the south of the Balkan Peninsula and adjacent islands. In the north, it borders on Albania, North Macedonia, Bulgaria, and Turkey. In the south, the Aegean and Ionian Seas form the natural boundary. Scattered islands make up about one-fifth of the country’s surface. The Ionian Islands are located on the western shores; the most famous are the Itaka and Corfu. Part of the Greek territory is also almost all the Aegean islands, eg. Eubia, Lesbos, Samos, Cyclades, Rhodes, Crete. South Mainland is the Peloponnese Peninsula. The mountains of Pindos and Olympia surround the Thessaloniki Plain. The area of the forests has been considerably reduced by the excavation from the past, and the machine grassland has expanded. Typical is the cultivation of citrus, olive, grape, cotton, tobacco, etc. The industry is dominated by the textile, tobacco, and food processing industries. The industry is concentrated in the capital Athens, which with the port of Piraeus form an agglomeration. In the north-east lies Thessaloniki, an industrial center and a port. In Greece, maritime and air transport is important. Greece water resources management is presented in Chap. 16.

1.1.9 Montenegro and Albania

The next two countries of the Balkan Peninsula are not covered in the book due to unavailability of the editor's experts-contacts in these two countries which we hope to cover this in the next edition. Therefore, we provide here an introduction about them with an emphasis on their water resources management. The main resource of this information is retrieved from www.climatechangepost.com.

1.1.9.1 Montenegro

Montenegro (Podgorica) is a mountainous country that has progressed to the sea. The main consumptive use of water in Montenegro is for the supply of settlements. Annual water abstractions in the last decades were 105 million m^3 respectively, whereas some 90% of total abstractions was from groundwater sources. The industry is the second largest user with an average annual consumption of approximately 50 million m^3. There are significant deposits of bauxite and expanded are metallurgical, engineering and woodworking industries. Industrial facilities predominantly rely on their own supply system (less than 3% of water used by industry is from public water supply systems) with roughly two-thirds of abstractions from the surface and one third from groundwater. Consumption of water by agriculture is extremely small; the total irrigated area growing slowly. Most of the irrigated area is used to produce table and wine grapes, fruits and vegetables in the area starting from around Podgorica and running to the coast. Mostly groundwater is used for irrigation. The most important economic use of water in Montenegro is to generate electricity by hydropower plants (Callaway 2010).

Montenegro is rich in water resources, although there are also arid karst areas in the country. The rivers of Montenegro drain into two basins: the Black Sea and the Adriatic Sea. Natural lakes are also an important water resource, the most significant of which are Biogradsko, Plav, Black, Šasko, and Skadar Lake. The largest artificial reservoir is Piva Lake with a total accumulation capacity of 880 million m^3. Other significant lakes are: Slano, Krupac, and Vrtac and the accumulation of Otilovići. The terrain of Montenegro is permeable carbonate rocks, so, precipitation quickly penetrates into the ground feeding karst aquifers that discharge into the zones of erosion bases, coastal sea, Skadar Lake and along the rim of the Zeta-Bjelopavlići plain, the Nikšić field and alongside the waterbeds (Ministry for Spatial Planning and Environment of the Republic of Montenegro 2010).

Is considered that the yield of water resources will be reduced, and some springs will dry up. The sources of water supply to cities will hardly have the capacity to meet the water demand. The capacity of accumulations used for industrial and commercial purposes will be reduced, as well as energy generation, whereby the imports of electricity will be increased. Generally speaking, climate change will certainly affect the condition of water resourcesin the country. The southern parts of Montenegro will be the most vulnerable to climate change (Ministry for Spatial Planning and Environment of the Republic of Montenegro 2010), (https://www.climatechangepost.com/montenegro/fresh-water-resources/).

1.1.9.2 Albania

Albania is a coastal state in the south of the Adriatic Sea. The climate is subtropical and Mediterranean. The natural increase is high, and most people live in the countryside. Larger cities are Tirana (capital), Durres, Skadar, and Elbasan. Albania is one of the most underdeveloped countries in Europe, with 50% of the population working in agriculture. The food and mining industries dominate.

The area surrounding Albania has relatively abundant fresh water resources. There are seven main rivers in Albania which run from east to west. The contribution of rivers discharges into the Adriatic Sea is very large (95%), compared to the discharge into the Ionian Sea (5%). The total volume of water flow is 39,220 × 106 m^3/year. There are two characteristic periods in the year, in terms of the water flow: from October to May is the wet period, and from June to September the dry one. 86% of the annual water flow is discharged during the wet period and 8% during the dry one. June is the transition period, accounting for 6% of the annual water flow. The agricultural sector is the biggest consumer of fresh water (60%) (Porej and Diku 2009).

It is predicted a decrease in the long term mean annual and seasonal runoff in Albania although this country should not experience significant socioeconomic impacts due to climate change reducing its water availability. Under the reduced surface water flow and increased evaporation, the storage of reservoirs will decrease, and that would affect the energy production by hydro power stations. Because of the reduction of stream flows in the wetlands, the western part of Albania would experience both increasing demands for water and reduced supply of water, which would decrease the wetland area. Vice versa the increase of the extreme events may lead an under-designed reservoir or spillway with potential flood risk (Ministry of Environment of Albania 2002).

Water quality is expected to degrade in Albania, not only due to the expected climate changes but also due to new industrial and agricultural development. The main hot spots for this problem are the districts of Tirana, Fier, Korçë, Kavajë, Durres, Vlorë, Elbasan, and Berat. Other consequences of climate change include the erosion of riverbeds, and modification of turbidity and sediment load in the water bodies. The following impacts of climate change include losses of soil moisture from increased evapotranspiration and this follows decreased percolation of water. Reduction in ground water supply in combination with the increase of salinity of the ground water supply will bring a shortage of adequate quality of drinking water. Moreover, the demand for drinking water and water use for social and economic purposes may be expected to increase because of population growth (Ministry of Environment of Albania 2002).

The transboundary Buna/Bojana Watershed is shared by Albania and Montenegro, as well as a long stretch of the coastal zone of the Adriatic Sea. The watershed is faced with a variety of pressures, including unsustainable agricultural methods, increased tourism, and altered hydrological regimes from hydropower generation and flood control measures. Albania and Montenegro, while similar socially and economically, differ in their administrative, legal, and institutional frameworks. Regardless, both countries have recognized the need to strengthen their cross-border cooperation through the development of an integrated water resource plan for the watershed (www.gwp.org and https://www.climatechangepost.com/albania/fresh-water-resources/).

1.2 Technical Aspects of Chapters Water Resources in Balkan Countries

1.2.1 Danube Delta Biosphere

Chapter 2 offers an overview on the surface water quality over 25 years in Danube Delta Biosphere Reserve, part of UNESCO's World Heritage List and List of the RAMSAR Convention on Wetlands of International Importance, especially as Waterfowl Habitat. A description of anthropogenic pressures that affected Danube Delta in the last half-century is presented. These threats refer to major discharges of untreated or insufficiently treated wastewaters coming from over 81 million people living in this basin, industrial sources, extensively agriculture especially in the communist era or even the lack of wastewater treatment plants along the Danube River. Situated in the exit from the entire Danube River Basin, downstream of all sub-basins, Danube Delta is particularly threatened by all this pollution. Also, the anthropogenic implications in the Danube Delta itself, strong economic development of this area which lasted 4–5 decades with forced agriculture/industrial development during 1970', without taking into account the laws of the evolution of natural ecosystems, have left behind negative marks for the environment and contributed to the disturbance of the deltaic area. Aspects related to water quality legislation over time were also introduced. An important sub-chapter treats water quality assessment in Danube Delta Biosphere Reserve, trends and evolution in physical-chemical parameters (as salts, nutrients, heavy metals) from the Danube River entrance into the Danube Delta to the River mouths over 25 years related to biological parameters and their trends and evolution.

To sum up, Danube River is the collector and the emissary to the Black Sea of all discharges from upstream riparian countries, affecting the environmental state of Danube Delta Biosphere Reserve and also the Black Sea coastal zone by various types of pollution. Therefore, as a part of the Danube Basin entire system, the aquatic habitats of the Danube delta depends on upstream conditions. Therefore, joint efforts are compulsory to be done by EU but also by Non-EU countries in order to diminish the problems created in water quality and quantity including environmental damage affecting the quality of life.

1.2.2 Water Resources Management in Slovenia

Chapter 3 presents the surface water availability in Slovenia which is a country characterized by an abundance of water in a great variety of forms. The river network comprises almost 28,000 km of watercourses (1.4 km/km^2). However, these are not equally distributed, as about 40% of Slovenia is karst and therefore almost without surface waters. Rivers from four-fifths of Slovenia territory flow several hundred kilometers to the Black Sea and from less than one fifth into the nearest Adriatic Sea. The few small natural lakes are either tectonic, glacial, or karst. The once-extensive swamps and marshes have shrunk significantly due to water regulation, and climate change has also caused the two Slovenian glaciers to shrink drastically. The population’s water supply relies heavily on groundwater, which is threatened by pollution. Slovenia also has a small share of coastal water. Many parts of the country are threatened by different types of floods. The right to drinkable water is mentioned in the Slovenian constitution as a fundamental right. Although Slovenia has an above-average quantity of water. However, because of climate change and pollution, these may change in the future.

In Chap. 4 the managed artificial groundwater recharge systems (MAR) coupled with induced riverbank filtration (IRBF) experience in Slovenia is presented. the authors present two examples of the use of MAR with IRBF in Slovenia, the deep aquifer of Vrbanski plato and the shallow aquifer of Apače field and both have shown to be a great step towards sustainable groundwater management. While the MAR in Segovci and Podgrad is constructed to prevent possible contamination of nitrates and recharge the aquifer in the summer months, the MAR in Vrbanski Plato is used to protect the pumping station from possible contamination from the city center and increase the overall capacity of the pumping station to maintain a constant water withdrawal throughout the year. The use of water resource management tools like FREEWAT have in both cases shown a significant role in the establishment, maintenance and optimization of an efficient MAR system with IRBF. The numerical models produced inside the FREEWAT hydrogeological environment can be used to analyze the MAR systems impact on the groundwater level, the change in the groundwater flow direction, the efficiency of the system against possible contamination and also for optimization of the MAR system to reduce the operating costs related to water pumps. In Slovania, the use of water resource management tools like FREEWAT have in both cases shown a significant role in the establishment, maintenance and optimization of an efficient MAR system with IRBF. However, the current practice with IRBF and MAR should be upgraded based on remote data acquisition and transmission, including GIS physically based fully distributed numerical modeling to continuously monitor and manage well fields, reducing costs and human-operated activities.

1.2.3 Water Resource Management in Croatia

Chapter 5 presents and discusses the quantity and distribution of groundwater resources in Croatia based on hydrogeology and climate. The first part of the chapter deals with the hydrogeological characteristics of Croatia, emphasizing the difference between the inland Pannonian region, where clastic sediments of various permeability prevail, and the predominantly karstic Dinaric region along the Adriatic coast. The second part of the chapter is focused on the groundwater bodies and their characteristics. Most importantly, renewable groundwater reserves and the groundwater withdrawal at the level of groundwater bodies are presented. In addition, the structure of registered and unregistered water withdrawal in Croatia is being analysed. Groundwater is of primary importance in high-quality mass water supply in general and in Croatia as well. Finally, a short strategic view on groundwater reserves in Croatia is presented, as envisioned by the Croatian Waters (Hrvatske vode), a legal entity for water management in Croatia.

The groundwater reserves are rather abundant and in general not overused. However, most important aquifers are vulnerable, due to their characteristics and exposure to potential threats. In addition, a considerable portion of the groundwater resources is shared with neighbouring countries.

The most important aquifers are under environmental pressure, but still mostly in good condition regarding their quantity and quality. In order to manage groundwater reserves in a sustainable way, it is highly important to protect and preserve them.

On the other hand, the Croatian territory is divided into two big river basins. Related to their geographical diversities, pressures on water quality are also different. In the continental part of the country, the main threats come from diffuse pollution of agriculture and farming. The Adriatic coast is mainly karst region vulnerable to any pollution (see Chap. 6).

Water quality analysis of different Croatian rivers and lakes (natural and artificial) shows an important influence of the catchment area including geographical features, hydrological regime, land use, population, etc. Besides the basic geographical characteristics of the Danube River Basin and Adriatic Sea Basin, impacts on water quality depend on the significance of anthropogenic activities and sizes of catchment areas. Smaller rivers are more exposed to pollution of any kind than large rivers what is presented by water quality analysis of several large, medium and small rivers. The proposed analysis of Croatian surface water quality status made on the basis of the recorded data shows improvement of the most analysed parameters.

Croatian lakes are also exposed to different sources of pollution. In recent time, climate change has also had some impact on water quality during periods of low discharges.

The author indicated that water quality is continuously improving as a result of comprehensive activities, especially the construction of sewage water treatment plants. There are also periodic occurrences of very high values of all parameters which coincide with dry hydrological conditions, which proves that water bodies are extremely vulnerable to pollution during drought periods.

A lot of effort has been made in establishing a very extensive monitoring network together with legislation and measures in order to improve water quality status. However, there are still some improvements which can be done.

Croatia is a middle-sized country in the south of Central Europe, ranked fourth in Europe by the Total Renewable Water Resources per capita (TRWR). Despite the size (56594 km^2), it has very heterogeneous physical-geographical characteristics and Chap. 7 is devoted to present the temporal and spatial variability of water resources in Croatia which may be due to heterogeneous physical-geographical characteristics. This well explained through the chapter by covering the aspects of two topics.

The first part is focused on water balance components and freshwater reserves in Croatia taking into account significant regional differences between karts and non-karst (Pannonian) area. Furthermore, surface water resources (river network and lakes) in Croatia are regionally presented. The second part contains analyses of water resources utilization, i.e., communal water supply (sources and systems), agriculture (irrigation), hydropower use (more than a half of countries’ electricity production) and navigation. In addition, water resources management system and flood protection in Croatia is presented.

Croatia is generally water-rich country with significant spatial and temporal differences. Water resources management has a long history in Croatia and is still mainly led by the civil engineering sector. With the progressive implementation of the WFD, Croatia is slowly changing management practice towards more sustainable solutions.

The authors emphasize that protection and sustainable management of rich water resources in Croatia presents a challenge and is a responsibility of all stakeholders in the water sector. This asks for a scientific cooperation, interdisciplinary and stakeholder participation which Croatia’s water management sector should accept in order to improve and manage fragile water resources in a more sustainable way.

1.2.4 Water Resource Management in Bosna and Herzegovina

Chapter 8 presents water resources management in Bosnia and Herzegovina by giving a historical overview of the water management, natural features, climate characteristics and basic characteristics of waters of Bosnia and Herzegovina.

Although the country is perceived as rich in water resources, the figures show a significant difference in annual rainfall in the territory and the distribution of runoff. The present conditions of water use and water quality protection in the country are given through the available facts and figures. Due to the complex administrative structure, water management sector seems to be inefficient and insufficient coordinated, what has been briefly explanted in the last part of the chapter. A number of challenges have been identified in order to harmonize the existing water management system with the requirements of policy and legislation of the European Union and improve the state of water resources management sector in Bosnia and Herzegovina.

Although a country with a historical tradition in managing water resources, Bosnia and Herzegovina is facing many challenges today in an effort to meet the EU's requirements and standards in the water sector, and to respond to the unevenness of the time and spatial availability of water resources in the country.

The author stressed that authorities in Bosnia and Herzegovina among the others should be primarily focused on the strengthening the institutional framework, improving coordination at all levels of government, development of water management infrastructure and adequate economic and financial instruments in the management of water resources.

1.2.5 Water Resource Management in Serbia

In the light of natural conditions and current national setup of the integrated water management approach, there are several significant economic and commercial opportunities for water resources utilization in Serbia, including the navigation in rivers and canal network, spa tourism, agricultural irrigation, fish farming, and hydropower production. Therefore, Chap. 9 starts with legislation, regulatory and institutional framework for water utilization, and continues with the detailed data and information about water resources in Serbia. These key facts include natural conditions, namely climate characteristic, relief, geological composition, soil, and vegetation. Spatial distribution of water resources comprises surface and groundwater resources, while the latest monitoring data on water resources quantity are included to show the annual pattern of runoff and the main elements of water balance. In the third chapter section, the data and information are mapped and tabulated to present locations and numerous indicators crucial for understanding commercial, economic and perspective activities related to water utilization. Among seven considered water utilization types, the most attention is paid to water supply and demand, followed by agricultural irrigation, river navigation, hydropower, fishing and aquaculture, tourism and recreation including spa tourism in Serbia. The fourth section is dedicated to the assessment of water resources quality both related to surface waters and groundwater. Concluding remarks briefly summarize temporal and spatial variability of water resources and discusses significant opportunities for water resources utilization in Serbia.

The authors stressed that the primary water resources utilization sectors in Serbia are water supply and hydro-power production. Irrigation in agriculture holds great, yet insufficiently utilized potential, as well as water transport and fish farming. Tourism, sports, and recreation on rivers and lakes, together with spa tourism play an important role in the overall tourist offer of the country.

Also, the authors emphasise that for further development and progress in the water resources utilization sector it is urgent to launch the Action Plan that will contain the activities necessary for the implementation of the Water Management Strategy in the Republic of Serbia, the deadlines for the implementation of the activities, and stakeholders responsible for the implementation of these activities.

On the other hand, Chap. 10 puts the focus on microbial water quality for irrigation and potential hazards to human health due to the fact the all stakeholders must understand the importance of control of irrigation water quality, given that climate change is expected to influence the supply of water, affecting both quantity and quality. Serbia, the most used water resource for irrigation is groundwater (61%), and the next is surface water (32%). Investigated canals, rivers and several shallow wells showed degraded water quality to some extent. The content of faecal indicator bacteria makes it unacceptable for irrigating fruits and vegetables for raw consumption. Usage of irrigation water of poor microbiological quality may represent a potential risk to human health. The presence of Escherichia coli, E. coli O157:H7, L. monocytogenes, Salmonella spp. on different kind of fresh vegetables has been confirmed, as well as their ability to surface and endophytic colonize root, stem, and leaf of different vegetables.

The authors believe that the outcomes of this research could serve as a guide for setting the general framework for the development of irrigation water quality guidelines of the Republic of Serbia, in order to support the sustainability agenda in the field of water and agriculture.

To complete the picture of the water resources management in Serbia, Chap. 11 deals with the analysis of precipitation due to its important for future water resources management in Serbia.

Precipitation is one of the most important meteorological variables which can impact on the occurrence of drought. Analysis of precipitation and drought data provides useful information for planning water resources, agricultural production and land use in the region.

Monthly precipitation data from 28 synoptic stations in Serbia over the period 1946–2017 were used to analysed precipitation and drought in Serbia. For this purpose, the rainfall variability index was used.

The results showed that 15.84% of years belongs to the dry period, i.e. periods with drought. Extreme dry periods are recognized in 3.76% of analysed years. Most of the years belong to the normal climate regime. The majority of the country had the extreme drought during the 2000 year, while the dry periods are presented throughout 2011.

To sum up, 16% of the years from 2000 to 2017 belong to the dry period out of which 4% belongs to the extreme dry climatic regime. The driest years in Serbia were 2000 and 2011. The majority of Serbia was affected by extreme drought.

Consequently, the national action plans against land desertification must be included. The soil moisture should be increased. To have the most efficient irrigation effects, the appropriate location, quantity and especially quality of water are needed.

1.2.6 Water Resource Management in Bulgaria

Chapter 12 includes information about water resources and management in Bulgaria. It is given information for rivers, ground waters, lakes, and damps. Also, there is information for water management and law in our country.

Water is a renewable natural resource. It plays an extremely important role in nature. As a natural resource, it is one of the indispensable factors of the natural environment and is vital for the human, animal and plant world.

Bulgaria is characterized by its limited water resources, which are extremely unevenly distributed. The water currents and the water areas are 201 040 ha or occupy 1.81% of the total territory of the country. Inland water runoff in a normal, medium dry and very dry year is respectively 20.7 billion m^3, 15.4 billion m^3, 9.3 billion m^3. The surface water flow is 20.5 billion m^3 and only 65% of it is used. Stocks are replenished at the expense of rainfall, i.e. the weather factor is decisive for annual stocks. In our country, we are aware of urban consumption; water resources for ecosystems must be provided because over-consumption is most often at the expense of the needs to be earmarked for ecosystems—wetlands.

The authors proved that Bulgaria's water resources are limited and unevenly distributed within its territory. Rational utilization and conservation of water resources are vital for the sustainable development of Bulgaria. This is in the interest of the people of Bulgaria. Therefore, stringent measures are needed for the rational and full use of water and its conservation—the construction of water treatment plants, the multiple uses of water, the reduction of leakage from watercourses, etc.

On the other hand, the proper understanding of the Bulgarian river systems behaviour, as an integral part of water resources management processes, is connected both to the good knowledge of their natural regime and extremes, such as floods and droughts (see Chap. 13).

Water resources management in Bulgaria is closely connected to the proper understanding of river systems state and behaviour. Rivers are important both to the aquatic and terrestrial ecosystems function and services and to the man related needs and activities, including connected economic branches. For the purpose, careful examination of the river regime and connected issues as climate and physico-geograpical conditions is important—to understand its natural cycle and to detect unusual events caused by the accompanied anthropogenic and climate change impacts. Strengthening the connection to the protective and management procedures various legislative and authoritive measures are also adopted. For better understanding such complex is summarised for the Bulgarian conditions. In the material is provided a basic description of the Bulgarian river systems and connected topological and climate specifics, with attitude to the existing biodivercity, accounting the need of its protection due to adopted policies and practices. Taking into consideration the vulnerable impact of water extreme occurrences in the material are presented some authors case studies for particular Bulgarian rivers. The authors sum up to the fact that the investigations show that in Bulgaria is observed water extremes as floods and droughts, that are irregularly distributed in space and time, showing various grades and emerging significant impacts. They stressed that the only way to mitigate the adverse effects from negative river regime and extreme events occurrences interconnected implementation of legislative, theoretical and practical developments is required.

1.2.7 Water Resource Management in North Macedonia

Chapter 14 is devoted to the drinking water is North Macedonia. Supplying the population with drinking water is an important priority for every country. Besides the geographical location of the state, there are 7.4% of the dwellings without water installation. According to the Census data from the total number of households: 86.7% are connected to public water pipeline, 4.9% is supplied from private air-compressed water tank in the dwelling, 3.5% is supplied from the well, 2.7% other ways, 2.2% are connected to public water pipeline located outside of the dwelling. The situation with the wastewater sewage system is even more urgent, 59.9% of the dwellings are connected to the public sewage systems, and 40.1% have no connection to the public savage system.

The drinking water supply issue is not yet solved even in the XXI century. From the total number of 564 296 households, 13.3% have not solved its water supply with the public pipeline, but in some older way, with wells, air tanks, and pipelines out of the dwellings. The climate change phenomenon has not avoided North Macedonia, due to the geographical location and hilly-mountain geomorphology, various climate factors. The recent study shows complementary climate change in water resources in the country. From 13 naturally regime streams, 4–5 are a statistically significant downward trend in annual maximum, mean and minimum streamflow and 2–5 significant downward trends in seasonal streamflow data in all four seasons. This phenomenon is connected with evapotranspiration rising, made by significant upward trends in the air temperatures. In the Republic of North Macedonia, there are three systems of irrigation (Bregalnica, Strumica, and Tikvesh) and three systems for water drainage (Pelagonija, Struga Plain and Skopje Plain). These territories with other smaller areas cover around 70 000 ha, and after the construction of these ameliorative systems, the agricultural production was multiple increased from 4.5 times for vegetable, triple in tobacco production to 230 time more in sugar beet.

Additionally, Chap. 15 present the challenges facing the waters in the major rivers in the Republic of North Macedonia as they are seriously endangered by various sources of pollution with a focus on the main point sources as household waste, industry, and mining.

The waters in the major rivers in the Republic of North Macedonia are seriously endangered by various sources of pollution, but the main point sources are household waste, industry, and mining. The problematic sources of pollution such as agriculture and wastewater from the dispersed population are also a problem. Regarding the treatment of the wastewaters, the situation is more than concern about the fact that only a small part of the wastewater from the households is being purified using either mechanical (8%), biological (7%) or any other treatment (0.5%). In the Republic of North Macedonia, a big problem appears from the discharging of untreated wastewaters from the industry and mining in certain recipients (soil, sewer, watercourses, accumulations, and lakes). The concentrations of BOD_5 and concentration of ammonium in the main rivers Vardar, Bregalnica and Crna Reka, for the period 2001–2015, show a variable trend. In the analyzed period, a slight drop was recorded in the mean annual concentrations of nutrients in all three rivers. An exception was recorded in the period from 2013 to 2015 when an insignificant increase in orthophosphates and nitrates concentrations were recorded in all three rivers.

The authors sum up to there is a higher concentration of the analyzed parameters causing eutrophication and result in a worse ecological state according to the pressures in the rivers. Therefore, it is necessary to avoid further deterioration of the status of the waters in the analyzed rivers, which would contribute to achieving a good ecological status. Also, it is necessary to define the appropriate measures that would improve their ecological status (to increase the percentage of the population connected to sewer systems and to provide a high percentage of purification of the urban wastewaters).

1.2.8 Water Resources Management in Greece

Chapter 16 is devoted to present the aspects of water resources in Greece where a large network of infrastructures operate in the agricultural water sector; however better organization and support to Land Reclamation Agencies is necessary in order to deal with problems and to increase the efficiency of water management. The dry-warm climate of Greece, with wet winters and dry summers, leads to the need for irrigation in many crops. In order to satisfy this, need many areas are equipped with irrigation systems ($\sim$600 000 ha with collective irrigation networks and $\sim$800 000 ha with private irrigation systems). Collective networks use mainly surface water resources, while private irrigation systems are based on underground water resources (boreholes drilled by the farmers). Agriculture consumes 80–85% of the total water resources used in Greece.

The Land Reclamation Agencies responsible for the management of collective networks lack sufficient and properly trained staff. Concerning the private irrigation systems, illegal boreholes operating in addition to the legal ones and over-pumping create high pressure to the aquifers. Sea intrusion is the biggest threat caused by agriculture to the environment. Furthermore, the evolution of the institutional framework on irrigation towards decentralization has proved to be inefficient.

This chapter presents the operation and management problems of irrigation networks in Greece and makes recommendations to address the issues of design, operation, maintenance, and technical support.

The book ends with the conclusions and recommendations Chap. 17.

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Chapter 2
Danube Delta Biosphere Reserve—Long-Term Assessment of Water Quality

Cristina Despina, Liliana Teodorof, Adrian Burada, Daniela Seceleanu-Odor, Iuliana-Mihaela Tudor, Orhan Ibram, Aurel Năstase, Cristian Trifanov, Cosmin Spiridon and Marian Tudor

Abstract Designated in 1990 as Biosphere Reserve under UNESCO's MAB program and Wetland of International Importance under the RAMSAR Convention in 1991, Danube Delta is the largest best preserved of Europe's deltas. Despite that, its ecosystems are affected by upstream conditions, the Romanian Danube being the end carrier of all wastewater discharges from upstream countries to the Black Sea. Water quality in Romania was reasonably steady prior to the 1950s, but Romanian sudden economic and industrial development between the 1960s and 1980s coupled

C. Despina (✉) · L. Teodorof · A. Burada · D. Seceleanu-Odor · I.-M. Tudor · O. Ibram · A. Năstase · C. Trifanov · C. Spiridon · M. Tudor
Danube Delta National Institute for Research and Development (DDNIRD), Tulcea, Romania
e-mail: cristina.despina@ddni.ro

L. Teodorof
e-mail: liliana.teodorof@ddni.ro

A. Burada
e-mail: adrian.burada@ddni.ro

D. Seceleanu-Odor
e-mail: daniela.seceleanu@ddni.ro

I.-M. Tudor
e-mail: mihaela.tudor@ddni.ro

O. Ibram
e-mail: orhan.ibram@ddni.ro

A. Năstase
e-mail: aurel.nastase@ddni.ro

C. Trifanov
e-mail: cristian.trifanov@ddni.ro

C. Spiridon
e-mail: cosmin.spiridon@ddni.ro

M. Tudor
e-mail: marian.tudor@ddni.ro

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with critical hydrological works made upstream (Iron Gates I and II construction) and inside the delta, resulted in increasing pressure from human activities that exploit natural resources, conducted in a significant worsening of the Danube water quality. Diffuse agricultural sources, especially chemical fertilizer use and the improper working or even the absence of wastewater treatment plants in Central and Eastern Europe can be regarded as the significant input. Some progress in water quality has been made during the last 25 years by the adoption in 1991 of the Urban Waste Water Treatment Directive and Nitrates Directive, but the results were not immediately. A forward step was the implementation in 2000 of EU Water Framework Directive, which encourages all EU countries to achieve good chemical and ecological status. This chapter offers an overview over almost 25 years of the anthropogenic pressures in Danube Delta Biosphere Reserve in the last half-century accompanied by long-term water quality assessment in this area using legislations, physical-chemical (such as salts, nutrients, heavy metals) and biological parameters.

Keywords Danube delta · Water quality · Nutrients · Heavy metals · Biological parameters

2.1 Introduction

Danube River Basin (Fig. 2.1), the most multinational river basin in the world, covering 10 percent of Europe (approximately 801,463 square kilometers), shared by nineteen countries: Albania, Austria, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Germany, Hungary, Italy, North Macedonia, Moldova, Poland, Romania, Serbia, Montenegro, Slovakia, Slovenia, Switzerland and Ukraine extends from west, its source in the German Black Forest and discharges into the Black Sea, to east.

The Danube Basin can be divided into three sectors. The *upper Danube sector* extends from the Black Forest to the Devin Gate below Vienna. In this sector the Danube receives its increasing flow from the major tributaries Iller, Lech, Isar, Inn, Traun, Enns, Cowx et al. (2004), coming from the northern slopes of the Alps Mountains. The *middle sector* from the Devin Gate to the Iron Gates represents the passage of the river from the Vienna Basin to Panonian Depression. Here the river receives its largest tributaries, substantially increasing its flow- Drava, Tisza and Sava. Finally the *lower Danube Sector* through the Romanian and Bulgarian low-lands, Gâştescu (2017). In this sector the rivers are coming from the outer Carpathian Mountains, Jiu, Olt, Arges and the last tributaries the Siret and the Prut rivers, Galatchi and Tudor (2007).

Before reaching his final destination, Black Sea, this great river empties into a spectacular delta via three main branches, a remarkable delta, Europe's largest remaining natural wetland and one of the continent's most valuable habitats for wetland wildlife and biodiversity.

Fig. 2.1 Map of Danube River Basin

The Danube Delta is a world heritage natural reserve, famous worldwide for the numerous pristine fluvial, marine and coastal landscapes, such as gallery-like natural channels, hundreds of lakes, fluvial levees, sand dune-fields, beach-ridge plains, barrier islands and spits, and large lagoons, representing a preserved testimony of complex delta evolution, Vespremeanu-Stroe et al. (2017). The Danube Delta was declared a Biosphere Reserve in 1990 and included one year later on the UNESCO’s World Heritage List and List of the RAMSAR Convention on Wetlands of International Importance especially as Waterfowl Habitat, Gâştescu and Ştiucă (2008).

All the while, the landscape has been shaped and reshaped both by nature and man the Danube Delta is still spreading seaward at a rate of 10–25 m/year for Sulina and Sf. Gheorghe secondary delta and 40–70 m/year along Chilia secondary delta, Tătui et al. (2017). According to Tarrósy and Milford (2011), its ecosystems are affected by changes upstream, such as pollution and the manipulation of water discharge, as well as by ecological changes in the delta itself.

The waters of the Danube River basin (Fig. 2.1) and its tributaries combine to make up an aquatic ecosystem of high economic, social and environmental value. It includes numerous important natural areas as wetlands and floodplain forests. The river is a principal resource for drinking water supply, agriculture, industry, fishing, tourism and recreation, power generation, navigation but also, the end disposal of waste waters for a densely populated region of Europe. This has been generated the building of a large number of dikes, dams and other hydraulic structures that serve to all these human activities. On the Danube River, there are over forty major reservoirs. However, such structures have caused changes in flow pattern and damage to the functions and biodiversity of the river system, such as reduced sediment transport, increased erosion and reduced self-purification capacity, including public health aspects in connection with drinking water supply of the population, recreation and bathing, Galatchi and Tudor (2007).

Furthermore, the intensity of agricultural, industrial and urban uses has created problems of water quality and quantity, like high nutrient loads (nitrogen and phosphorus), contamination with hazardous substances including heavy metals, microbiological contamination, and contamination with substances causing heterotrophic growth and oxygen depletion, leading to reducing biodiversity in the basin, Ronald (2018).

The aquatic habitats of the basin are part of a single system so that harmful activities in one section always affect the other sections, Galatchi and Tudor (2007). According to Giosan et al. (2012) there is a strong coupling between Danube fluxes and the Black Sea's biogeochemistry and ecology, the degradation of the north-west shelf region of the Black Sea water quality, is mostly caused by the cumulative inflow of hazardous substances, micropollutants and nutrients coming from the river. More considerable efforts are compulsory to be done both by EU and Non-EU countries jointly towards this pollution to be diminished and the health of the whole system, including Danube delta and the Black Sea, to be restored. Also, this can be helped by the natural buffering system formed by a labyrinthine network of river channels, shallow bays and lakes and extensive marshes which contribute to filtering out pollutants and can help to the improvement of water quality and also to biological diversity.

This chapter gives an overview of the results of the most important project of the Danube Delta National Institute for Research and Development concerning the water quality assessment. First, the anthropogenic pressure affecting the quality of the Danube water is presented, followed by legislation occurred in the Danube Delta Biosphere Reserve (DDBR) over the time, then water quality assessment, including the results on physical-chemical and biological trends and evolution over almost 25 years is presented. The paper ends with the conclusions.

2.2 Anthropogenic Pressures in the DDBR in the Last Half-Century

During the last half-century, the economic development in the Danube region brought a visible improvement of life quality but also great threats to the environment and to the river itself. The increase of the industrial activities, extensive agriculture, growing municipal communities, all are potential sources of pollution if not properly managed and can have a negative impact on functions of the river, water quality, water uses, aquatic life, as the UNDP/GEF Danube Regional Project (2006) stipulated.

Draining approximately 30% of central and eastern Europe and with an average discharge of 6500 m^3/s, collecting the water from a vast hydrological basin, the Danube River provides over 60% of the entire runoff to the Black Sea, Giosan et al. (2012).

Pollution coming from industrial sources has caused severe and widespread ecosystem dysfunction through their adverse effects. Therefore, industries of numerous large cities in central Europe, including four national capitals Vienna, Bratislava, Budapest and Belgrade that Danube River is passing through, are mostly responsible for most of the discharges of hazardous substances into its basin.

According to Tarrósy and Milford (2011), diffuse agricultural sources, especially chemical fertilizer use in upstream countries and the improper working or the lack of wastewater treatment plants in Central and Eastern Europe also represent a major input. The agricultural practices (agriculture is a large portion of the economy of Hungary and Bulgaria) contribute to the large nutrient load and high levels of nitrates in the water. Pollution by nutrients (nitrogen and phosphorus compounds) generates the over-fertilization or the eutrophication that is affecting not only the Danube River but also the Black Sea, Zavadsky (2006).

Another serious problem is the major discharge of untreated or insufficiently treated wastewaters for over 81 million people living in this basin. The effects that human activities have on the water quality are varied and widespread "in the degree to which they disrupt the ecosystem and/or restrict water use" (Bartram and Ballance 1996). The problem of sewage disposal does not end there. According to European Environment Agency "EEA", (2015) wastewater treatment must continue to play a critical role in the protection of Europe's surface waters, and investment will be required to upgrade wastewater treatment and to maintain infrastructure in many European countries. Despite improvements made in some regions (contributions within projects in some programme periods, 2000–2006 and 2007–2013), diffuse pollution from agriculture in particular remains a major cause of the poor water quality currently observed in parts of Europe. Measures exist to tackle agricultural pollution, and they need to be implemented according to the EU Water Framework Directive (WFD), while the full compliance with the Nitrates Directive is also required, EEA (2015).

Romania, as a European Union member, committed to reaching by 2015 "good ecological status" for all waters, according to WFD, has invested since 2010, within SOP Environment, in improving water treatment plants but some of them are oversized or potentially unsustainable. However, other major investments are still needed to update and upgrade the system for this urban wastewater treatment plants to be efficient, effective and sustainable.

Navigation poses a significant pressure on the Danube, as a major transport route to the sea, Danube have encountered many interventions over the time, often having multi-purpose functions, combining better navigability, hydro-energy exploitation, flood protection and other floodplain uses (agriculture, urban development etc.), all using the same thing: the natural power of the river. The most important structure on the Danube River, according to Stojsavljević (2011) was hydropower dams Iron Gate I and II (1970–1972), the largest hydropower dam and reservoir system, built approximately 1000 km upstream at the Yugoslavia/Romania border. The second largest dam system was Gabcikovo dam built in Czechoslovakia in 1992.

Other important structures were the Rhine-Main-Danube Canal ("Europa-Kanal"), highly important communication between the Black and the North Sea (1992), and the Danube-Tisa-Danube channel network in Serbia's north province of Vojvodina. There are still plans for more dams to be built, which after Panin and Jipa (2002) would diminished the sediment discharge with 30–40% of its previous value, with significant changes in the nature of the river. Also, as Cowx et al. (2004) reported, the most destructive effects caused by the construction of hydropower dams, resulted in a reduction of flood pulses and a blockage of fish migration into the floodplain system. The numerous channels, ports, bridges, hydro and nuclear electric energy plants have triggered ecological deterioration (such as bed erosion, disclosure of side-arms, artificial embankments, changed hydrology etc.) and affected the river ecology (ecological water quality), i.e. habitats, species, ecosystems, river hydrology (water quantity) and morphology along the entire river, Zinke (2011). Apart from the direct deterioration of the river bed and the floodplain, indirect effects on the river's hydromorphology, ecology and landscape occurred, resulting in significant changes in Danube's discharge pattern, Humborg et al. (1997) and an overall degradation or even destruction of the river's natural functions, as Danube Parks project mentioned, Zinke (2011).

The first and very provisional attempt to map the water quality was made in a monograph on the Danube by Liepolt (1967). Also, an overview, on the Danube River and its tributaries, has been offered by Schmid (2000). A degradation of water quality was detected particularly downstream the cities and industrial zones between the 1950s and 1970s. In this context, due to the toxic effects of the industrial wastewaters, the self-purification capacity of the Danube had significantly decreased in that period. Regarding water quality in the Middle and Lower Danube, very little data are available for the period 1950 to 1975, Cowx et al. (2004).

Considering Romania's position in the whole Danube basin (97.8% of the country's surface is included in the Danube River basin), the river is the collector and the emissary to the Black Sea of all discharges from upstream riparian countries, affecting the environmental state of Danube Delta Biosphere Reserve and Black Sea coastal zone by various types of pollution.

Situated in the exit from the entire Danube River Basin, downstream of all sub-basins, Danube Delta is particularly threatened by this pollution.

The Danube Delta region has a complicated history. Previous development (taking place between 1961–1990) was generally characterized by massive anthropogenic interventions within the *Program of total arrangement and exploitation of the natural resources of the Danube Delta*, which transformed a significant part of the Danube Delta and Razim-Sinoe complex into an agricultural/ industrial region. Parts of the floodplain were drained and transformed into cropland, pastures or aquaculture ponds. This works, practiced with no concern for the protection of the environment, have led to the degradation processes in different ways. Ecological changes occurred in the Danube Delta ecosystems due to eutrophication phenomenon were defined by the increase in the quantities of nutrients and organic matter and also disturbance in oxygen condition and according to Gomoiu (1992) had severe consequences on increasing phytoplanktonic production, reduction of specific diversity and simplification of community structure, development of opportunistic species and fluctuations within populations. Also, the administration of chemical fertilizers intensified this anthropogenic eutrophication process.

The beginning of 1970’ had marked the development of industrial areas near Danube Delta Biosphere Reserve by building of large industrial platforms (Metallurgical Plant, Alumina Plant, Shipyard), which entailed to changes either for population and for the environment. This forced industrial development has led to chemical stress factors, the most important being heavy metals. Industrial discharges and inadequate waste treatment and disposal from localities situated in the close vicinity of the aquatic basins generated problems related to water quality and reduction of biodiversity.

Therefore, this strong economic development, which lasted 4–5 decades, had a major impact on the aquatic and terrestrial environment.

It is evident that the return of the Danube Delta to the situation before 1950, even in the conditions of the ecological reconstruction of indigent and abandoned agriculture farms, is not possible in the medium term and probably not even in the long term. The anthropogenic implications in the second half of the 20th century (until the 1990s), without taking into account the laws of the evolution of natural ecosystems, contributed to the disturbance of the deltaic area, even of the ones left in the so-called natural hydrological regime, Gâştescu and Ştiucă (2008).

After 1990, due to the political changes that took place in Romania (the fall of communism, the creation of “Danube Delta” as Biosphere Reserve), a new vision in the conservation and protection of the natural patrimony occurs. New objectives “to ecologically redress the Danube Delta and to conserve the genofund (biodiversity) of the ecofund, to know the productive capacity and to establish the dimensions of the exploitation of the Danube Delta resources, within the admissible ecological limits” were set up, Breţcan et al. (2009).

The transition period after 1990 meant a significant reduction of industrial activities and closing of industrial capacities in the area. Many of these have left behind negative marks for the environment by contamination of large area from the aquatic complexes, water pollution, retention of pollutants in the biotic and abiotic compounds, degradation of natural areas due to storage of processed raw minerals. Also, in the absence of a socio-economic and physical infrastructure capacity to support it, the population from the Danube Delta region has been significantly migrated since 1990 and to this day.

The breathing space provided by the transition period concerning industrial restructuring and agricultural reform created an opportunity to change this situation and to prevent, reduce and control pollution and waste generation substantially to the benefit of the environment and of peoples’ quality of life, Nachtnebe (1997). However, the major changes occur all this time in the aquatic ecosystem of the Danube Delta still need urgent measures to rehabilitate the new remained delicate and fragile ecological equilibrium.

Recently, others new threats that the Danube River is facing with, after the decades of pollution during the communist era, are from microplastics and pharma waste.

2.3 Legislation

Serious environment issues, such as chemical pollution, loss of biodiversity and water quality degradation that Danube River faces with, cannot be treated efficiently at the national level, transboundary cooperation being inevitable and compulsory. Despite the geopolitical and economic diversity of the Danube riparian countries and interests, problems and priorities across the basin, we are all sharing specific values and principles relating to the environment and conservation of natural resources, and we have to face this challenge together.

Due to the Danube's physical and economic geography, the control of the river has played a critical role in European history and continues to be a focal point of the regions vitality.

The first steps of European water legislation date back to the 1970s–1980s, when Bathing Water Directive and Drinking Water Directive, established quality standards for certain types of waters, improving the beaches quality, respectively the quality of drinking water at the tap. Another step in European water legislation focused on key sources of pollution, such as wastewater, agriculture and major industries with the Urban Wastewater Treatment (UWWT) Directive, Nitrates Directive, Integrated Pollution Prevention Control (IPPC) Directive.

The heavy commercial, industrial and agricultural uses of the region in that period have compromised the environmental health and economic potential of the Danube. For these reasons, there is a long history of agreements and treaties created to manage the navigable control and a more recent history of agreements to manage the health and economic growth of the Danube River network.

Thereby, early 1990s, which commence with the cooperation on the Danube over navigational issues gradually extended to joint pro-environment activities. This cooperation process began with "Transnational Monitoring Network", an essential tool with the main objective of providing a well-balanced overall view of pollution and long-term trends in water quality and pollution loads in the major rivers in the Danube River Basin, ICPDR (2015). The efforts culminated in 1994 with the adoption in Sofia/Bulgaria of "the Convention on Co-operation for the Protection and Sustainable Use of the River Danube (Danube River Protection Convention)", Wouters (2013).

To implement the Danube River Protection Convention, the Danube countries established in 1998 the International Commission for the Protection of the Danube River (ICPDR). It is the institutional frame not only for pollution control and the protection of water bodies but it also sets a common platform for sustainable use of ecological resources and consistent and integrated river basin management, Zavadsky (2006). Today, 14 Danube Basin countries and the European Union are "contracting parties" of the ICPDR; they agree to jointly work towards the sustainable management of water resources in the Danube basin.

To the increasing threats of Danube waters pollution, EU response was to develop Water Framework Directive (WFD), unique by the fact that for the first time it was established a framework for the protection of all Europe's waters including rivers and lakes, estuaries, groundwater and coastal waters and their dependent wildlife/habitats under one piece of environmental legislation.

EU WFD has significant linkage with a number of other Directives, including Birds and Habitats directives, Drinking Water, Bathing Waters and Urban Waste Water directives and also Industrial Emissions and Environmental Impact Assessment directives, EPA (2016). As an integral part of the WFD, the Nitrates Directive is one of the key tools in water protection towards agricultural pressures. Other directives, such as Floods and the Marine Strategy Framework are also linked with the WFD which is also supplemented by the Priority Substances Directive and the Groundwater Directive.

Therefore, in 2000, the EU Water Framework Directive (WFD) 2000/60/EC brings major changes in water management practices. It sets a legal framework to protect and improve "the status of aquatic ecosystems, prevent their deterioration, and ensure the long-term, sustainable use of water resources throughout the EU", OECD (2016).

In response, the ICPDR countries, including the non-EU Member States, agreed to implement the WFD throughout the entire basin. The objective of the WFD is to achieve for all inland surface waters, transitional and coastal waters 'good chemical and ecological status (or potential)'—and for all groundwater to achieve 'good chemical' and 'quantitative status' (European Parliament and Council 2000). A set of the most polluting substances, called priority substances, have limit values established on European level and define the 'good ecological status'. The first "Danube River Basin Management Plan" was introduced in 2009 in order to achieve 'good status' by 2015. This deadline could be extended, under some circumstances by two six year periods at maximum (European Parliament and Council 2000). The ecological and chemical status of surface waters and groundwater in the European Union (EU) Member States have to be reported in the River Basin Management Plans (RBMPs) required under the Article 13 of the Water Framework Directive.

In all Danube River Basin countries, there has been a high level of transposition of the EU Directives into the national legislations. They all had the water management planning tools for achieving good status of surface and groundwater by 2015. Since this deadline was not sufficient to attain a good ecological status for many water bodies, the Directive provides for two additional planning cycles running to 2021 and 2027 respectively.

Danube Delta Biosphere Reserve has a management plan, "a document regulating all activities in this natural protected area, as well as from its neighborhood" (http://gov.ro/en/government/cabinet-meeting/management-plan-for-the-danube-delta). The management plan aims to maintain natural physical-geographical framework, protection and conservation of flora, fauna, Danube Delta Biosphere Reserve ecosystems, biodiversity and natural resources. This is a working instrument for the Reserve Administration Danube Delta and all holders/land owners or persons who want to carry out activities in the Reserve and include objectives and measures organized in a program of planned actions updated every five years.

2.4 Physical-Chemical Assessment—Trends and Evolution

The continuous monitoring program of the Danube Delta National Institute for Research and Development over 26 years on Danube River water quality provides long-term and objective information in the state of this waters that meet the needs for sustainable management of water resources. The principal reason for this monitoring was to determine the tendency in the quality of Danube Delta aquatic ecosystems, and how are these affected by the human activities, the release of toxic substances or waste waters discharges. The water quality, described regarding physical-chemical characteristics in correlation with measured biological parameters is presented.

The classification of water quality is established in line with the requirements of EU WFD, transposed into national legislation through the Romanian Order 161/2006, for the approval of the Normative concerning the classification of surface water quality to establish the ecological status of water bodies (Romanian Order MEWM no. 161/2006). Surface water is framed, based on threshold values of quality indicators, into five ecological conditions: very good (first quality class), good (second quality class), moderate (third quality class), poor (fourth quality class) and bad ecological status (fifth quality class).

The study was conducted in the period between 1991 and 2017 in the Danube Delta Biosphere Reserve (DDBR), which preserves the last remaining major wetlands environment in Europe. For this study, four sampling points were selected to cover the area between the river entrance into the Danube Delta and the three Danube mouths into the Black Sea. The locations were: Ceatal Chilia (**S1**), Chilia branch (**S2**)—the northern arm of the Danube, Sulina branch (**S3**)—the middle arm and Sf. Gheorghe branch (**S4**)—the southern arm (Fig. 2.2).

Water quality was monitored, in general, three times per year, in spring, summer, autumn and sometimes in winter.

Water quality analyses were performed both on site, by in situ measurements and in the laboratories of the Danube Delta National Institute for Research and Development Tulcea, Romania (RENAR certified since 2006), according to European Standards. Water samples, for physical-chemical parameters, were collected according to the European standards (SR ISO 5667-6/1997) directly from the river, preserved and properly stored in polypropylene containers to immediately perform the analytical determination.

Different techniques were applied for assessing variations in surface water quality during this period. Inductively coupled plasma mass spectrometry technique (SR EN ISO 17294-2:2017) combine with microwave digestion system is used for

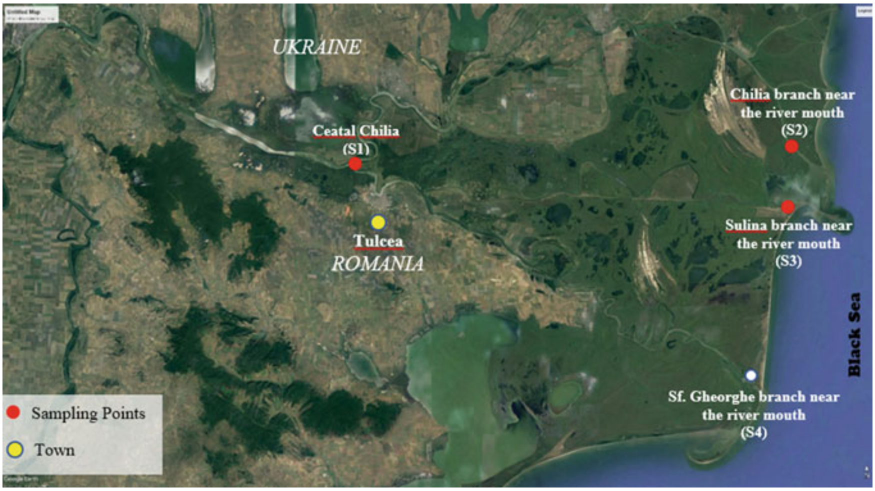

Fig. 2.2 Map of the selected sampling points

the detection of the heavy metals content, molecular spectrometry is used for the nutrients concentrations determination. The results represent annual mean concentration.

Nutrient and heavy metal pollution have been recognized as one of the most critical water management issues in the Danube River basin with impact on Danube Delta and the Black Sea. In this respect, a review of the studies related to the levels of these physical-chemical parameters in the Danube Delta Biosphere Reserve waters from 1991 till now is presented. Water mineralization in this period has been also discussed. Long-term distribution, reflecting the Danube water quality is analyzed using data from the database of the Danube Delta National Institute of Research and Development.

Our investigations started in 1991 after the massive anthropogenic implications occurred before 90s in Danube Delta, in the communism period, and after this area became biosphere reserve. Beginning with that period, numerous conventions and agreements had to comply, the most important in 2010, the Water Framework Directive, with compulsory requirements.

Figure 2.3 presents the variation values of total dissolved salts in Danube surface waters in the period 1991–2017.

Our data indicate that Danube waters both at the entrance into the Danube Delta (S1) and near the river mouths area (S2, S3, S4) tend to have a similar trend, with values varying within a reasonable range between 164 and 256 mg/L, with a variation amplitude which does not exceed 100 mg/L. Generally, variations in the mineralization of Danube water are seasonal, corresponding to the seasonal changes in water flow, in the sense that water mineralization degree decreases at a high level of water, but due to the hydrological regime of the river, these fluctuations are not considerable.

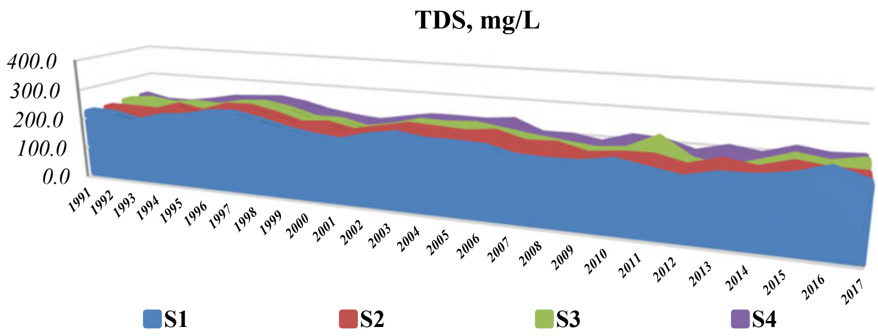

Fig. 2.3 Variations in **Total dissolved salts** concentrations in Danube River—from the entrance into the Danube Delta to the river mouth

In the case of nutrients, ICPDR results (2007) indicate that the highest loads were discharged into the Danube during the 80s; this period coincides with the speed up of the eutrophication process in the Danube Delta, once slowly and naturally. It is the period before the establishment of the Danube Delta Biosphere Reserve, when agriculture and fish farming were intensively practiced in the delta, accompanied by the accentuation of the hydrological deficit of the Danube, which contributed to the acceleration of the eutrophication effects in the area.

Our investigation in the selected case study areas begins in 1991 and the variation of inorganic forms of nitrogen (N-NH_4, N-NO_2, N-NO_3) and total phosphorus content in this period are presented in the Figs. 2.4, 2.5, 2.6, 2.7. The values obtained were reported to good ecological status (second quality class) according to Romanian Order 161/2006 (the EU WFD transposition into national legislation).

As Danube waters are closely linked to Danube Delta lakes, the results of the study showed a dynamic variation of nutrients compounds. A lot of processes are involved in influencing the nutrient compound storage, transport and losses. In the

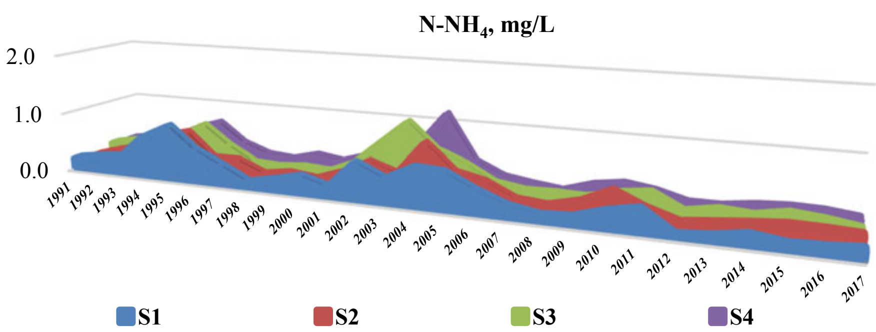

Fig. 2.4 Variations in **N-NH_4** concentrations in Danube River—from the entrance into the Danube Delta to the river mouth

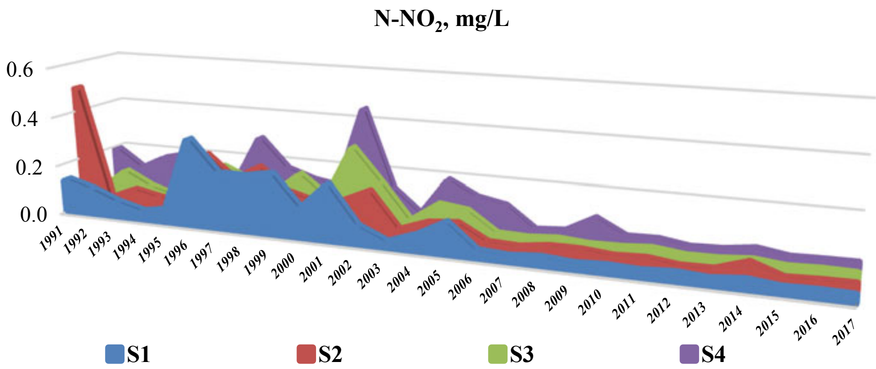

Fig. 2.5 Variations in **N-NO$_2$** concentrations in Danube River—from the entrance into the Danube Delta to the river mouth

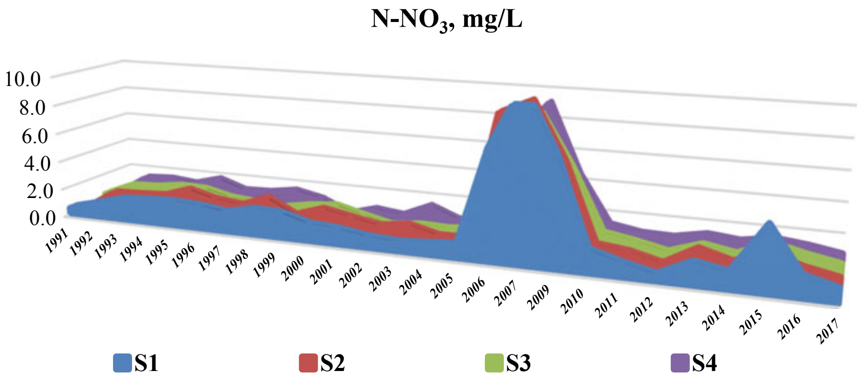

Fig. 2.6 Variations in **N-NO$_3$** concentrations in Danube River—from the entrance into the Danube Delta to the river mouth

Danube River, inorganic forms of nitrogen are all interrelated and generally consist of the most common bioavailable form, nitrates, coming from ammonia transforming into nitrite/nitrate and nitrite slowly transforming also into nitrate in good oxygenated waters.

Ammonium compounds were typically present at relatively low levels, in the studied period, except for 2004, when it was recorded values slightly higher compared to the limit value of 0.8 mg/L N-NH$_4$ for good ecological status. The higher levels of this form of nitrogen, generally observed downstream, in the area of the river mouths, are possibly due to the water intake from the Danube Delta lakes.

The limit value for a second quality class in terms of N-NO$_2$ is 0.03 mg/L. This value was exceeded continuously until 2006, in all sampling points, with extremely high values in 1991 and 1996 when it was recorded values 10 times higher than the reference target, both at the entrance into the Danube Delta, but also in its flowing

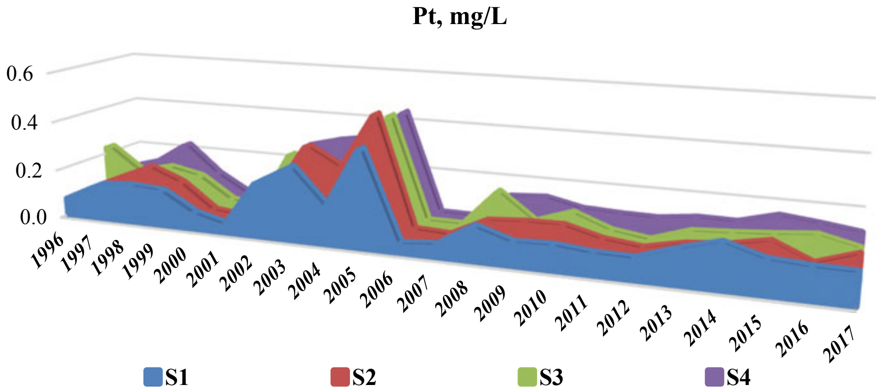

Fig. 2.7 Variations in **P total** concentrations in Danube River—from the entrance into the Danube Delta to the river mouth

area into the Black Sea. This is the effect of the chaotic human intervention, within the Danube Delta, with no concern for the environmental health, which has consequences for many years after.

The range for N-NO_3 according to Romanian Order 161/2006 is <1 mg/L for very good ecological status and >11.2 mg/L for bad ecological status. The results of the study show significant differences among the studied period, with values framing from very good to poor ecological status. The period with highest levels of nitrate, recorded in the middle of 2000s, far beyond the reference value of 3 mg/L in all sampling points, indicate that changes in nutrient management over the time has major consequences and show delay effects in water quality for nitrogen. These results are good evidence of the inputs presence from large-scale agriculture activities practiced within the Danube Delta, substantially modified by human impact over decades, associated with the mismanagement of nutrients in all Danube basin and no adequate ecological policy, in that period. Also, this period with elevated levels of nitrates, correspond to high levels of water in that years, flood pulse. After the year 2010 progress in term of nitrates concentrations have been made, and the concentrations obtained for nitrate meet in general, the requirements for good ecological status.

Total phosphorus is the other essential nutrient for all forms of life and highly correlated with the transport of suspended solids. It occurs an ascendant trend beginning with the year 2002, but the recorded values are in the limit of good ecological status. An exception is the year 2005 when in the area of the Danube River mouths, S1, S2 and S3 the reference value of 0.4 mg/L was slightly exceeded. After that, the concentrations of the total phosphorus in the Danube River have values framed into the first and second quality class.

As a significant water issue in the Danube basin, the pollution with nutrients can lead to nutrient enrichment and cause water eutrophication and excessive algae bloom, influencing not only changes in composition of the species, a decreasing of species biodiversity in the delta but also with influence of water quality in the north-west shelf region of the Black Sea. Poor water quality, detected in some periods during this study, regarding the nutrients load, revealed the lack or insufficient wastewater treatment plants in Central and Eastern Europe.

Monitoring of heavy metals in Danube Delta Biosphere Reserve started in the early 1990s. The efforts were focused to reveal that the heavy metal pollution is a long-standing phenomenon causing considerable concern on human and environmental health.

Figures 2.8, 2.9, 2.10, 2.11 are presenting the situation regarding heavy metals (Cu, Zn, Ni, Fe) between 1991 and 2017.

In Danube Delta, pollution with heavy metals is due to the industry, mining but also agricultural run-off both upstream and downstream countries and it is a problem of the entire Danube basin, threatening its people and environment.

Qualitative data, regarding the evolution of copper concentrations (Fig. 2.8), between 1991 and 2017, indicated variations of this element until 2008. High levels in copper concentrations were observed at the beginning of the '90s, when the recorded values were 4 times higher than the limit value 0.030 mg/L corresponding to good ecological status. However, extreme values were recorded in 1998 and 2006, with two peaks up to 7 times higher than the reference value. As this element, along with zinc, mainly originate in water from agricultural run-off, but not only, these periods with high levels of copper correspond to the agriculture development in the communism period in Central and Eastern Europe countries. Starting with 2008, variations in copper concentrations have been significantly reduced, and the target limit, corresponding to good ecological status for this element has been reached. We estimate that this decreasing trend in the last decade is due to the positive effect of the Water Treatment Plants built along the Danube River since 2006.

Figure 2.9 presents the variations in annual mean concentrations of zinc, recorded in 26 years of the Danube waters monitoring from the entrance in the

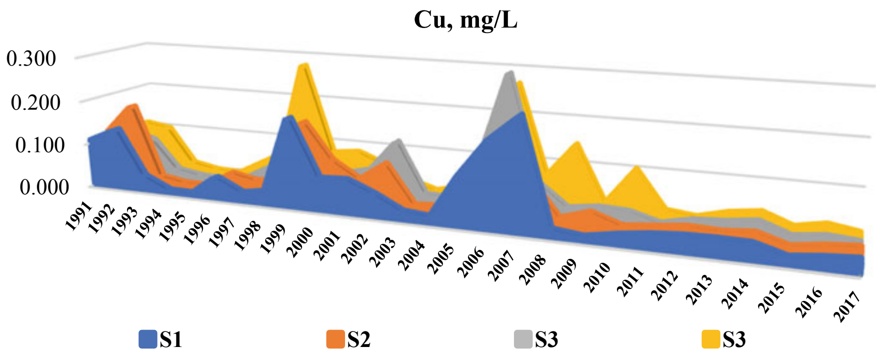

Fig. 2.8 Variations in **Cu** concentrations in Danube River—from the entrance into the Danube Delta to the river mouth

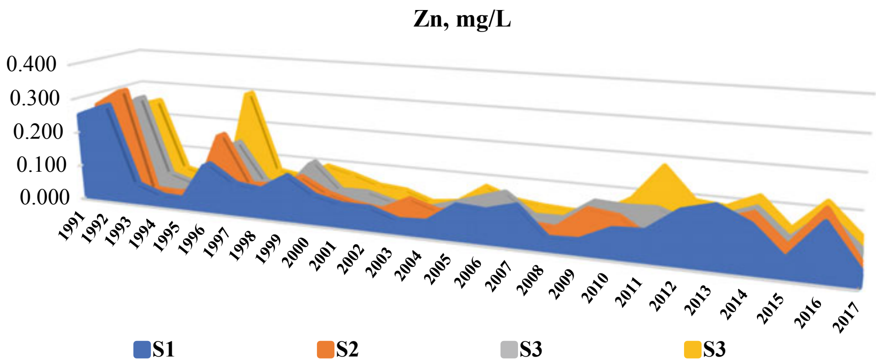

Fig. 2.9 Variations in **Zn** concentrations in Danube River—from the entrance into the Danube Delta to the river mouth

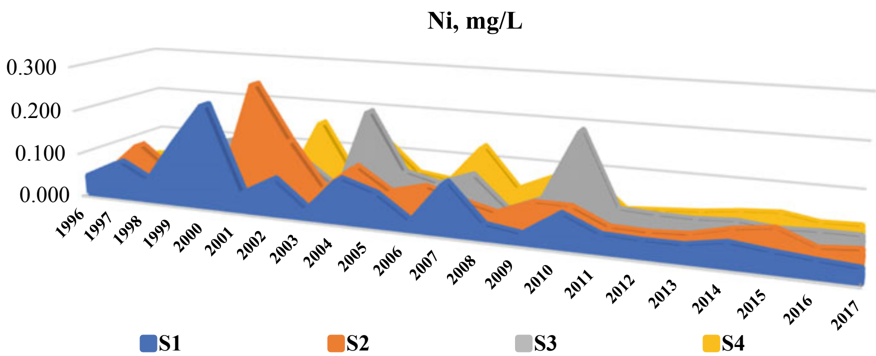

Fig. 2.10 Variations in **Ni** concentrations in Danube River—from the entrance into the Danube Delta to the river mouth

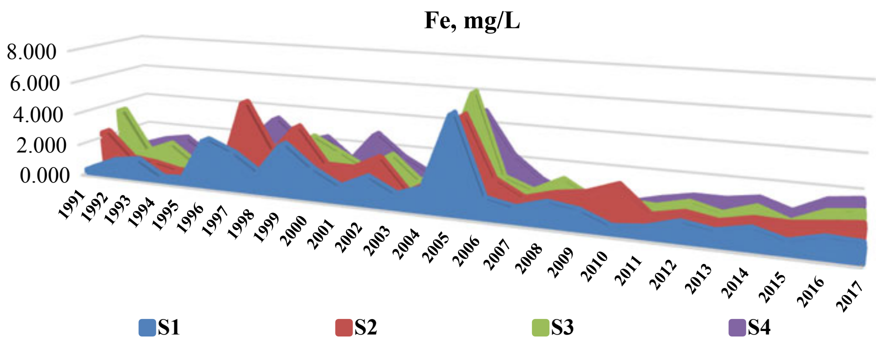

Fig. 2.11 Variations in **Fe** concentrations in Danube River—from the entrance into the Danube Delta to the river mouth

Danube Delta at Ceatal Chilia, to the flowing area into the Black Sea. Our results show significant fluctuations in the first period, 1991 and 1996, when the admissible limit of 0.200 mg/L for second quality class, according to Romanian Order 161/2006, was exceeded with 50%. After that period, a decreasing trend in zinc concentrations was observed with values framing into the good ecological status. Random variation in zinc content found in that period in the selected sampling points could be caused by the fluxes of the heavy metals in Danube waters. Initially, the sedimentation process occurs and then, generally in spring, at high flow rate, a remobilization of these elements from the bottom sediment to the water-sediment interface take place, when previously deposited sediments are removed.

Although at these concentrations, zinc has no risk on environmental health, it should be considered that in the case of a decreasing dissolved oxygen level from 7 to 2 mg/L can lead to an increased toxicity of this element with 50%, Lloyd (1961).

The distribution of nickel concentrations showed high variability in time and space (Fig. 2.10). Significant higher values before 2011, with exceeding up to 7–8 times of the reference value of 0.025 mg/L corresponding to good ecological status, were recorded at entrance into the Danube Delta (S1) and in the three points situated in the area of the river mouths. Nickel has anthropogenic origin, and high levels of this element are mainly related to mining or discharges from urban and industrial activities. In the case of nickel, no systematic trend along the four sampling points in the studied period was found; still, a slight decreasing tendency appeared after 2011, more pronounced in the last years of monitoring.

In the aquatic ecosystems of the Danube, iron is one of the most common elements. According to current legislation, iron concentration in water are framed between <0.3 mg/L (very good ecological status) and >2 mg/L (bad ecological status).

As Fig. 2.11 presents, until 2006, in the sampling points situated near the area of the Danube River flowing into the Black Sea, the annual mean concentrations had a considerable variation, often exceeded the maximum allowed concentrations of 0.5 mg/L for good ecological status, sometimes with values up to 10 times higher.

The poor water quality with high levels of iron detected in that period is due to anthropogenic factors, including industrial wastewaters, urban and agriculture discharges but also the inflow of tributaries coming from countries in the Danube River basin with significant ore resources.

Since 2006, the situation has significantly changed, an improvement in water quality was noticed compared to reference value and the iron values amounting, most of the time, below 1 mg/L.

Elevated levels of these studied elements at the entrance in the Danube Delta and in the sampling points situated near the flowing area into the sea strengthen the fact that the Danube is the receiver and the transmitter to the Black Sea of all the discharges from its entire basin, of all the countries that benefit of its waters.

2.5 Biological Assessment—Trends and Evolution

Ecological status is defined as an expression of the quality of the structure and functioning of aquatic ecosystems based on the assessment of a series of biological quality elements (fish, macroinvertebrates, zooplankton, phytoplankton and macrophytes) and supported by a set of chemical and hydromorphological quality data from Annex V, 2000/60/EC (European Parliament and Council 2000). Significant efforts are demanded in order to restore the aquatic ecosystems to at least good ecological status within a limited time period.

After 1980, the trophic state of the aquatic ecosystems of the Danube Delta has increased, with consequences on the structure of different biotic compartments, Vadineanu and Cristofor (1987). In the case of zooplankton, the species richness has diminished 4–5 times, and the abundance has increased, Zinevici and Parpală (1987).

In the last years, the zooplankton and the Chironomidae community started to recover. For example, the number of chironomid species recorded in 2014, are the same as those identified in 1976, before the adverse effects of eutrophication (Table 2.1).

Table 2.1 Zooplankton and Benthic invertebrates species richness dynamics in some of the Danube Delta lakes (b. = Benthic invertebrates and z. = Zooplankton) (data from: DDNI Technical Reports 1991, 2015, 2017, unpublished data)

Lake		1976	1985	1989	2014	2016	2017
Cuibu cu Lebede	**b**				**28**		
	z.				**39**	**49**	**62**
Furtuna	**b.**				**30**		
	z.				**49**	**52**	**63**
Baclanesti	**b.**		**5**	**7**	**15**		
	z.		**56**		**11**		
Isac	**b.**				**11**		
	z.		**59**	**56**	**61**	**69**	**57**
Uzlina	**b.**				**25**		
	z.				**30**	**60**	**54**
Merhei	**b.**				**24**		
	z.			**46**	**62**	**55**	**36**
Miazazi	**b.**				**27**		
	z.				**68**	**69**	**64**
Matita	**b.**		**7**	**8**	**8**		
	z.		**56**		**20**		
Rosu	**b.**	**12**	**10**	**5**	**12**		
	z.	**161**	**61**	**53**	**42**	**58**	**57**
Rosulet	**b.**				**23**		
	z.				**50**	**57**	**65**

Table 2.2 Zooplankton diversity in Danube Delta lakes

Rotifera	Copepoda	Cladocera
Brachionus	*Thermocyclops*	*Bosmina*
Keratella	*Acanthocyclops*	*Chydorus*
Aspanchna	*Macrocyclops*	*Moina*
Synchaeta	Naupliu stages	*Ceriodaphnia*
Trichocerca		*Simocephalus*
Mytilina		*Daphnia*
Polyarthra		

However, the most important benefits from the cost-efficiency view are in the right targeting of monitoring and in the positive effects on the quality of monitoring and status assessment. These results are furthermore benefited from comprehensive monitoring and reporting of a river basin, which is a requirement of the WFD as well.

Potential impacts of ongoing changes on zooplankton community in Danube Delta aquatic ecosystems depend on the relative magnitudes and interactions between shifts in chemistry and temperature.

The Rotifera dominated the zooplankton population in time 1997–2017. For the most part, it has been observed the dominance of Rotifera>Copepoda>Cladocera groups (Table 2.2). “Rotifers are important components of freshwater ecosystems and sensitive indicators of environmental changes” (https://link.springer.com/article/10.1007/s10750-011-0992-x).

The zooplankton community of the Danube Delta Biosphere Reserve ecosystems is subject to more frequent and greater fluctuations as for the water velocity, oxygen regime and lighting conditions.

In a study of benthic organisms from six aquatic ecosystems conducted between 1981–1985, Botnariuc et al. (1987) have found that the trophic state is rapidly increasing. Chironomid species number is reduced, and only 2–3 species are numerically dominant. The community is dominated by *Chironomus plumosus* a species with adaptation to low oxygen levels.

Channels are dominated by Gastropoda with *Valvata piscinalis* being dominant. In Europe this species is common in flowing water courses, Kerney (1999) and is considered to be an epiphytic algae eater, Fretter and Graham (1962). It is also found on the sediment feeding on detritus. The loamy substrate found in Periteasca is inhabited by individuals of the snail species *Lithogliphus naticoides*.

2.6 Conclusions

The Danube Delta is a complex, open and interactive system that revolves around two major components—water circulation and human intervention.

Our results provide an overview of pollution level evolution in time and space in the Danube Delta Biosphere Reserve, considering the physical-chemical and biological characteristics of the water.

The greatest significance in the pollution with nutrients compounds have agriculture sources, some of them entered into the delta as pollutants in the Danube River.

The data on nutrients load in the Danube Delta are essential, and joint efforts must be made to keep them under the reference limit and to improve the existing nutrient balance.

In respect with heavy metals, some of these elements are persistent, slowly degradable and accumulate in the trophic chain, therefore their reduction, may take a long time, but best available techniques at the industrial level, waste water treatment and good agricultural practices must be applied.

Researches over the period 1991–2017 on heavy metals variations in the Danube waters within the Danube Delta Biosphere Reserve generally have shown a decreasing trend in the last decade, but improvements in all sectors continue to be needed. The highest exceeding were recorded in the early ‘90s, as a consequence of the intensively economic development in the Danube basin region, but these elevated concentrations also show the low capability of the Danube to self-purification in that period.

This situation regarding the pollution occurred in the Danube Delta Biosphere Reserve over the time have various sources like improper management of the discharges coming from industrial, agricultural or domestic inputs, but also accidental water pollution in the Danube River Basin, some of them known, while others not reported.

Regarding biological assessment, we conclude that the zooplankton taxonomic changes were most likely a response to water flow. The species composition in Danube Delta Biosphere Reserve is equitably distributed with gastropods being dominant. In the next period if the actual hydrological condition remains unchanged modification of macroin vertebrate community will be insignificant.

I would like to quote, as a concluding remark, the central statement of the Danube Charter, as it was programmatically worded in the Council of Europe in Strasbourg in 1956: “Water does not know state borders. It demands international co-operation!”

2.7 Recommendations

It is obvious that whatever is happening upstream on the Danube River may become a major source of environmental perturbation for its delta. That’s why the Danube River still need increased and sustained effort between riparian countries in finding cooperation mechanisms for management strategies and implementation plans for prevention of the high diversity of pollutants released in water, from industrial, agricultural or municipal sources.

Also, water level dynamics is an important factor shaping numerous processes in river systems and wetlands. Therefore, more research effort should be concentrated on links between the main pressures like heavy metals pollution or eutrophication under different water levels.

As the main wetland system within the Black Sea catchment and with its status of Biosphere Reserve, Danube Delta is a diverse mosaic of interdependent habitats and ecosystems with complex interactions. In this respect, interdisciplinary researches are needed to bring together stakeholders, politics, ecology, hydrology, social sciences.

Danube's transnational character makes the conservation and the protection of the Danube Delta Biosphere Reserve to be a major environmental concern for all of Central and Eastern Europe.

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Part II
Water Resources Management in Slovenia

Chapter 3
Water Resources in Slovenia

M. Hrvatin, B. Komac and M. Zorn

Abstract Slovenia is characterized by an abundance of water in a great variety of forms. The river network comprises almost 28,000 km of watercourses (1.4 km/km^2). However, these are not equally distributed because about 40% of Slovenia is karst and therefore almost without surface waters. Rivers from four–fifths of Slovenian territory flow several hundred kilometers to the Black Sea and from less than one fifth into the nearer Adriatic Sea. The few small natural lakes are either tectonic, glacial, or karst. The once-extensive swamps and marshes have shrunk significantly due to water regulation, and climate change has also caused the two Slovenian glaciers on Mount Triglav and Mount Skuta to shrink drastically. The population's water supply relies heavily on groundwater. This is divided into aquifers with intergranular porosity, karst fissure porosity, and fissure porosity, all of which are threatened by pollution. Slovenia has a small share of coastal water: part of the Adriatic Sea's Gulf of Trieste. Many parts of the country are threatened by different types of floods. The right to drinkable water is mentioned in the Slovenian constitution as a fundamental right.

Keywords Water resources · Surface water · Groundwater · Hydrological natural hazards · Water management · Slovenia

3.1 Introduction

On a global scale, Slovenia has an above-average volume of water. Across the planet's continents, average annual precipitation is 750 mm; of this amount, 480 mm evaporates, and 270 mm runs off. From 1971 to 2000, Slovenian territory received an average of 1,579 mm of precipitation; of which 717 mm evaporated, and 862 mm ran off (Frantar 2008). In addition to this considerable amount,

M. Hrvatin · B. Komac · M. Zorn (✉)
Research Centre of the Slovenian Academy of Sciences and Arts, Anton Melik Geographical Institute, Ljubljana Novi Trg 2, SI—1000, Slovenia
e-mail: matija.zorn@zrc-sazu.si

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Slovenia is also characterized by its large variety of water forms. Surface water includes rivers, streams, and torrents, natural and artificial lakes, swamps and marshes, and a small but economically very important share of the Adriatic Sea. The groundwater includes various aquifers, thermal, and mineral water (Kolbezen 1998). Because of the considerable precipitation received and the great number of watercourses, it is generally believed that Slovenia has plentiful water. However, the flashy nature of many streams, lack of water-use planning, and irresponsible polluting have seriously threatened the abundant water supply in recent decades (Kolbezen 1998; Natek and Natek 1998).

3.2 Surface Water

Surface land water (Fig. 3.1) includes river network, lakes, wetlands, snowfields, and glaciers. The river network consists of a multitude of major rivers, streams, and torrents with a total combined length of nearly 28,000 km. The average density is 1.4 km of watercourses per km^2 of land, which is among the highest in Europe (Bat et al. 2004).

The surface watercourses are not evenly distributed. The river network branches extensively throughout areas of impermeable rock, and in places, the density of streams exceeds 3 km/km^2 (Kolbezen 1998). More than 40% of Slovenia's land is karst and hardly has any surface streams. The rare surface watercourses in karst areas tend to be sinking streams (Šušteršič 1994). A catchment divide between the Black Sea and the Adriatic Sea crosses Slovenian territory (Fig. 3.1). Rivers on four-fifths of this territory drain into the Black Sea many hundreds of kilometers away, whereas those on barely one-fifth drain into the Adriatic. The Mura, Drava, Sava, and Kolpa drainage basins belong to the Black Sea watershed, whereas the Soča and Reka drainage basins belong to the Adriatic catchment (Kolbezen 1998).

The most significant characteristic of Slovenian rivers and streams is their torrential nature, which is best illustrated by the enormous variance between their highest and lowest discharges. When it rains, torrential streams rise very quickly, carrying large amounts of sediment (Hrvatin 1998; Natek and Natek 1998; Komac et al. 2008).

"Short watercourses are characteristics of Slovenia's river network, and only forty-six rivers are longer than 25 km. The longest river is the Sava, whose Slovenian part is 221 km long. It is followed by the Drava, at 142 km, and the Kolpa, at 118 km. The longest rivers entirely within Slovenian territory are the Savinja (102 km) and the Krka (94 km). Other rivers with more than 50 km inside Slovenia or along its borders are the Mura, Soča, Sotla, Ledava, Dravinja, Pesnica, Idrijca, Ščavnica, Reka, and Sora together with the Poljanska Sora" (Hrvatin 2004: 31).

With regard to water discharge, the Drava is in the first place, with an average annual discharge of 306 m^3/s at Ptuj. The Sava has almost as much, with a discharge of 289 m^3/s at Čatež near the Croatian border, whereas the Mura has only about half as much, with a discharge of 157 m^3/s at Gornja Radgona. Rivers with

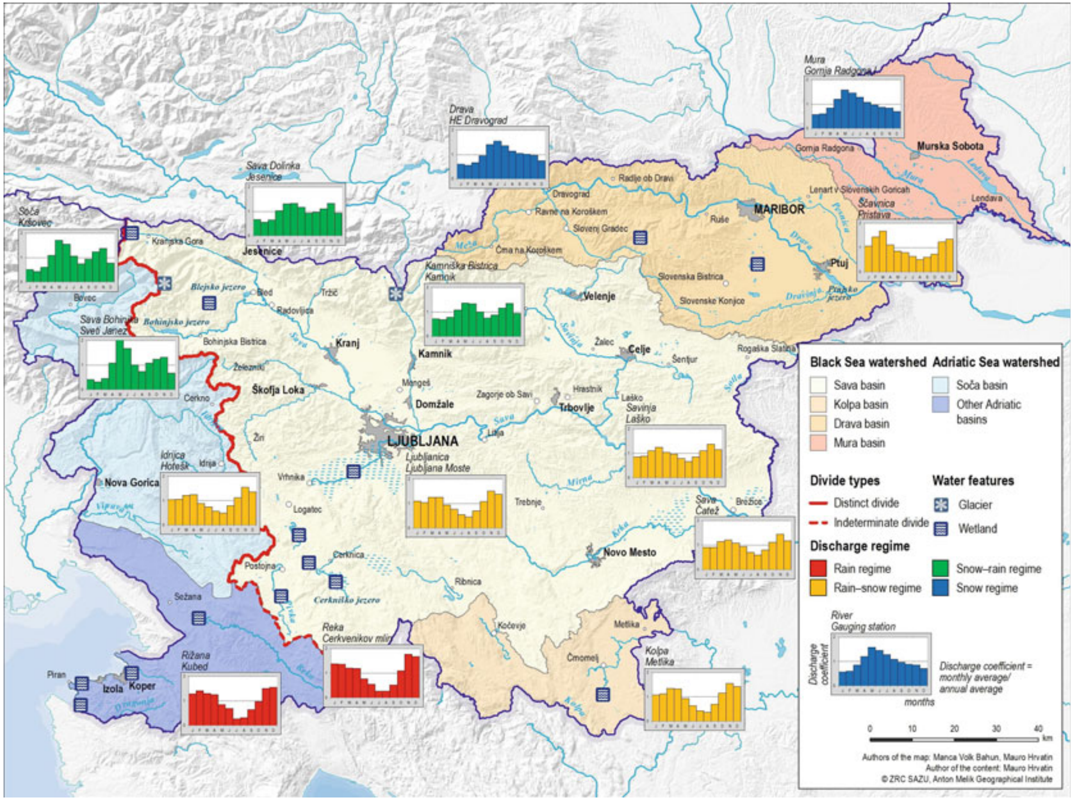

Fig. 3.1 Surface waters in Slovenia with major river basins and discharge regimes

over 50 m^3/s average annual discharges also include the Soča, Kolpa, Ljubljanica, and Krka (Hrvatin 2004).

An average of 1,579 mm of precipitation falls across Slovenia. Of this, 45.4% of the water evaporates, and the remaining 54.6% runs off into streams (Frantar 2008). The runoff coefficients, which show what share of water flows into streams, vary significantly in different regions of Slovenia. These differences are due mostly to evapotranspiration, rainfall regimes and amounts, and the regional relief characteristics. In the mountains, where there is usually abundant rainfall, and the water quickly runs off the surface, the runoff coefficient is higher than in areas with good vegetative cover, gentler hills, and flatlands under agricultural cultivation. The runoff coefficients in the Upper Soča Valley (Julian Alps) exceed 80%, whereas in most of the country the coefficients range between 40 and 60%; they are lowest in Prekmurje Plain, where they only rarely exceed 30% (Kolbezen 1998).

"According to the average oscillation in the discharge during the year, we distinguish four types of discharge regimes. The snow regime is characteristic of the Drava and Mura rivers, whose watersheds extend into the glaciated and snow-covered high mountains of Hohe and Niedere Tauern in Austria. The single discharge maximum occurs at the transition of the spring into the summer and the minimum in the winter. The snow-rain regime is characteristic for the alpine Kamniška Bistrica, Tržiška Bistrica, Kokra, Koritnica, Meža, Radovna, and Tolminka rivers and the upper reaches of the Sava, Savinja, and Soča. The primary discharge maximum occurs with the thawing of snow in late spring, and the secondary maximum occurs during the fall rains. The winter discharge minimum is more distinct than the summer one. The rain-snow regime is characteristic of the Dravinja, Idrijca, Kolpa, Krka, Ledava, Ljubljanica, Mirna, Pesnica, Sora, Sotla, Ščavnica, and Vipava rivers and in the lower stretches of the Sava, Savinja, and Soča. The spring snow discharge maximum always exceeds the fall rain maximum, but the summer discharges are substantially lower than those in winter. The rain regime is characteristic for the Pivka, Reka, and Rižana rivers in southwestern Slovenia. Above-average discharges occur here in the colder half of the year from November to April, while in late spring and summer the discharges are modest due to high temperatures and strong evapotranspiration" (Hrvatin 2004: 31, 33).

Recent decades have seen decreases in discharges and gradually changing discharge regimes in all Slovenian rivers. The reasons for these changes are higher average temperatures, a lower amount of annual rainfall, a lower amount and duration of snow cover, and a rise in the proportion of forested land (Bat and Uhan 2004; Hrvatin and Zorn 2017).

In the past, the rivers' power was harnessed by more than four thousand water-driven watermills (Fig. 3.2) and sawmills, but most of these were abandoned in the twentieth century. They were replaced by hydroelectric power plants (Fig. 3.3) that produce more than one-third of Slovenia's electric energy supply (Bat and Uhan 2004). "River water is also used for cooling in thermoelectric power plants and the nuclear power plant in Krško, as technological water in industry, and for irrigation. Due to the pollution of the river water, it can no longer be used directly for the supply of drinking water" (Hrvatin 2004: 33).

Fig. 3.2 A watermill on the Mura River *Photo* Matija Zorn

Fig. 3.3 Mavčiče hydroelectric power plant on the Sava River in central Slovenia *Photo* Matija Zorn

Standing surface water covers 68.93 km^2, or only 0.3% of Slovenian territory, which is below the European average. Many phenomena such as swamps, various types of ponds and pools, sloughs, side channels, and retention basins are relatively short-lived. Natural lakes with characteristic temperature, biological, and chemical stratification are rare. Most of these are found in Alpine and Dinaric regions (Remec-Rekar and Bat 2004).

Nearly half of the total area of standing water is artificial reservoirs, most of which are in the Pannonian region. These include the reservoirs at hydroelectric power plants (Moste, Mavčiče–Medvode, and Vrhovo–Boštanj), multipurpose reservoirs intended to control and stabilize water flow, often for agricultural purposes and irrigation, fishing, and as stop-over sites for migratory birds (lakes: Ptuj, Ormož, Šmartno, Slivnica, Pernica, Trojica, Ledava, Gajševci, Vogrščček, Klivnik, and Molja), and pit lakes that form in basins caused by abandoned mine excavations, such as the Šalek lakes near Velenje (Šterbenk et al. 2004). Many artificial lakes are ecologically unsound due to inflows of industrial wastewater and accumulations of heavy metals, pesticides, and organic compounds.

Compared to those in neighboring countries, Slovenian lakes are significantly smaller, but they are very attractive to tourists. The best-known natural lakes are Lake Bohinj and Lake Bled, which are of tectonic and glacial origin, and the karst Lake Cerknica. Other lakes popular with tourists are the small alpine karst-glacial lakes in the Julian Alps, such as the Triglav (Fig. 3.4), Križ and Krn lakes (Dobravec and Šiško 2002) and certain lakes in the Dinaric Alps.

Slovenia's largest natural permanent lake is Lake Bohinj, which covers 3.28 km^2 and has a maximum depth of 45 m (Remec-Rekar and Bat 2004). It is a flow-through lake, and so its water is quickly replenished. It is mostly fed by karst springs; among the most important is the inflow of the Savica River, which flows out of the lake as the Sava Bohinjka. Lake sedimentation is slow because of the karst catchment area, but because much of the surface is above the tree line the influx of nutrients is moderate. Moreover, around 100 km^2 of the lake's watershed is part of Triglav National Park and has very few inhabitants, and so the lake is in excellent condition ecologically (Remec-Rekar 2016).

The opposite is true for the smaller Lake Bled (Fig. 3.5), with an area of 1.44 km^2 and a maximum depth of 30.6 m. It does not have a large freshwater intake, and its catchment is significantly more urbanized, burdened by traffic, and exploited for fishing, agriculture and tourism (Remec-Rekar and Bat 2004). This is why eutrophication advanced quickly in the second half of the twentieth century, and the lake had to be saved from dying off by the addition of oxygen-rich water from the Radovna River, the use of siphons, and building a drainage and purification system (Kranjc et al. 2001). Phytoplankton levels used to assess the lake's ecological status show that it was in either moderate or good condition from 2006 to 2015 (Remec-Rekar 2016).

Lake Bohinj and Lake Bled are favorite destinations for tourism, excursions, and recreation. During the swim season the Slovenian Environmental Agency regularly samples and assesses water conditions. Both lakes achieve excellent ratings (Kopalne vode 2017). The average monthly temperature of Lake Bled exceeds

Fig. 3.4 The “Double Lake” in the Julian Alps, which are part of the Triglav National Park *Photo* Matija Zorn

Fig. 3.5 Lake Bled is known for having Slovenia’s only island with a pilgrimage church. Lake is among the most important and most visited tourist destinations in Slovenia *Photo* Bojan Erhartič, Archive of the Anton Melik Geographical Institute

22 °C in July and August, whereas in Lake Bohinj average temperatures are 2 to 3 °C lower (Bat 1997).

Due to its geological, hydrological, geomorphological, botanical, and zoological characteristics, intermittent Lake Cerknica has been considered a wonder of the world and special ecosystem in the Dinaric Karst region since as early as the seventeenth century (Valvasor 1689). In various seasons of the year, the same area allows boating, fishing, cutting hay, pasturing, or ice skating (Fig. 3.6). During usual flooding, it measures 21 km^2, but its total area can exceed 28 km^2, especially during autumn. From 1961 to 1990 it lasted an average of 285 days a year and was dry for eighty days (Kranjc 2002). It is part of the Ljubljanica karst river system, which extends over the Notranjska Lowland. At high water levels, water from the lake flows underground toward Rakov Škocjan, and otherwise toward Planina Cave. Most karst lakes disappear during summer, such as Pivka Lakes and those in the Cerkniško, Radensko, and Planinsko (karst) poljes. The exceptions are Lake Podpeč, which is Slovenia's deepest lake with an underground funnel outlet with a surface area of 1.25 hectares and depth of 47 m, and the Divje Jezero (Wild Lake) near Idrija, which is a more than 150 m deep Vauclusian karst spring (Janež et al. 1997).

Wetlands, an environment at the transition from terrestrial to aquatic ecosystems, can be sea, coastal, continental, or underground and either natural or anthropogenic (Beltram 2004). The Slovenia Wetland Inventory of 2000 contains 3,500 locations, of which only one-third exceed 0.15 hectares. These encompass around 350 km^2, or 1.74% of Slovenian territory (Bat 1997; Beltram 2004;

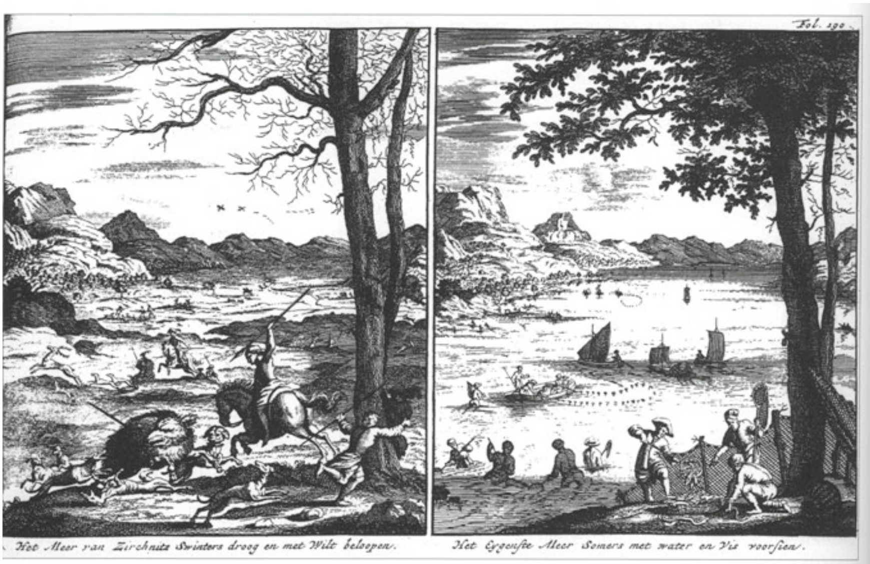

Fig. 3.6 Cerknica Lake, used for fishing for a part of the year and for hunting for another part of the year (Shaw 2008). Many writers were inspired by the karst polje and sought to explain the mechanism of the disappearing lake, as early as the 17th Century

Vreš 2014). The best-known natural wetlands, which differ from one another by flora and fauna, are found in the Ljubljana Marsh (once covering 140 km^2 but now occupying only a few isolated patches due to peat cutting). Others include fens and raised bogs on the Pokljuka Plateau (Šijec, Veliko Blejsko Barje), the Jelovica Plateau, and the Pohorje Hills (the Lovrenc Lakes; Fig. 3.7), fens on the Bloke Plateau and the Jovsi wetland, reedbeds, saline habitats, coastal seawater shoals. Among these wetlands are also smaller lakes including intermittent ones in Cerkniško, Planinsko, and Radensko (karst) poljes. Their area is nearly tripled if the wet meadows and flood meadows along the lower courses of the Mura, Drava, Sava, and Krka rivers are included. Other wetlands include Zelenci Springs, the source of the Sava Dolinka (Fig. 3.8), and the Škocjan Caves cave system (Fig. 3.9), which was added to the Unesco World Heritage list in 1986 as the first underground wetland in the world (Beltram 2004).

Slovenia faced a loss of 40% of wetlands from 1950 to 1992 (Beltram 2004). In 1990 wetlands, including ponds and reedbeds, covered only 2,200 hectares. The importance of wetlands in maintaining water balance and preserving biodiversity, their cleaning ability, positive microclimatic effects, and significance to education and research, are the reasons wetlands were included in the Natura 2000 sites. They have also been included in protected parks such as the nature parks in the Ljubljana Marsh, Radensko (karst) polje, Ljutomer Ponds and Jeruzalem Hills, Rače Ponds and Požeg, the Ormož Lagoons, the Planinsko (karst) polje, and Škocjan Caves Regional Park.

Fig. 3.7 The Lovrenc Lakes—raised bogs on the Pohorje Hills *Photo* Matija Zorn

Fig. 3.8 Zelenci Spring—the spring of the Sava Dolinka River *Photo* Matija Zorn

Snowfields and glaciers are important but also very unstable elements in high-mountain regions. Their current status compared to various historical sources shows that the number and extent of formerly widespread, large mountain snowfields are declining. The glacier on Mount Triglav (Gabrovec et al. 2013) (Fig. 3.10) and the one below Mount Skuta (Pavšek 2007) have shrunk rapidly in recent decades.

3.3 Groundwater

There is significantly more groundwater than surface water in Slovenia. Its spatial distribution depends on hydrological conditions determined by the rock structure and its porosity and permeability. Unconsolidated deposits and porous rock beds that contain economically significant amounts of water are called aquifers.

Geological units of Slovenia that contain groundwater include aquifers with intergranular porosity (19.8%), karst fissure porosity (33.2%), and fissure porosity (14.2%) (Fig. 3.11). The rest of the land consists of layers with intergranular or fissure porosity with lower conductivity (25.2%) called aquitards, and of almost impermeable rocks (7.6%) called aquicludes (Prestor et al. 2002; Uhan and Kranjc 2004).

Fig. 3.9 Škocjan Caves cave system is listed in the Unesco Word Heritage *Photo* Matija Zorn

Aquifers with intergranular porosity include tectonic basins and river valleys that are thickly covered with Quaternary and some Neogene gravel and sand deposits. The most important deposits are the Kranj–Sora, Ljubljana, and Krško–Brežice basins, the Kamniška Bistrica plain, and the Lower Savinja Valley in the Sava drainage basin, the Drava–Ptuj basin in the Drava drainage basin, the Apače, Mura, and Ljutomer basins in the Mura drainage basin, and the Vipava Valley and Soča basin in the Soča drainage basin (Kolbezen 1998). Even though the aquifers

Fig. 3.10 The Triglav Glacier is located in the Julian Alps, on the northeastern face of the highest peak in Slovenia, Mount Triglav (2,864 m). In the second half of the nineteenth century, it still covered nearly 46 hectares and ranged across the rugged high-mountain terrain to the edge of Mount Triglav's north face (upper figure; *Photo* Alois Beer, Archive of the Anton Melik Geographical Institute). In 1946, when regular monitoring was started, the ice area was measured as 14.4 hectares, but by 2012 the glacier had shrunk to half a hectare (lower figure; *Photo* Jaka Ortar, Archive of the Anton Melik Geographical Institute)

with intergranular porosity cover barely one-fifth of the country, they contribute 18.9 m^3/s, or over a third, of Slovenia's dynamic groundwater reserves. More than half of all reserves are in the Sava drainage basin, a good quarter in the Drava

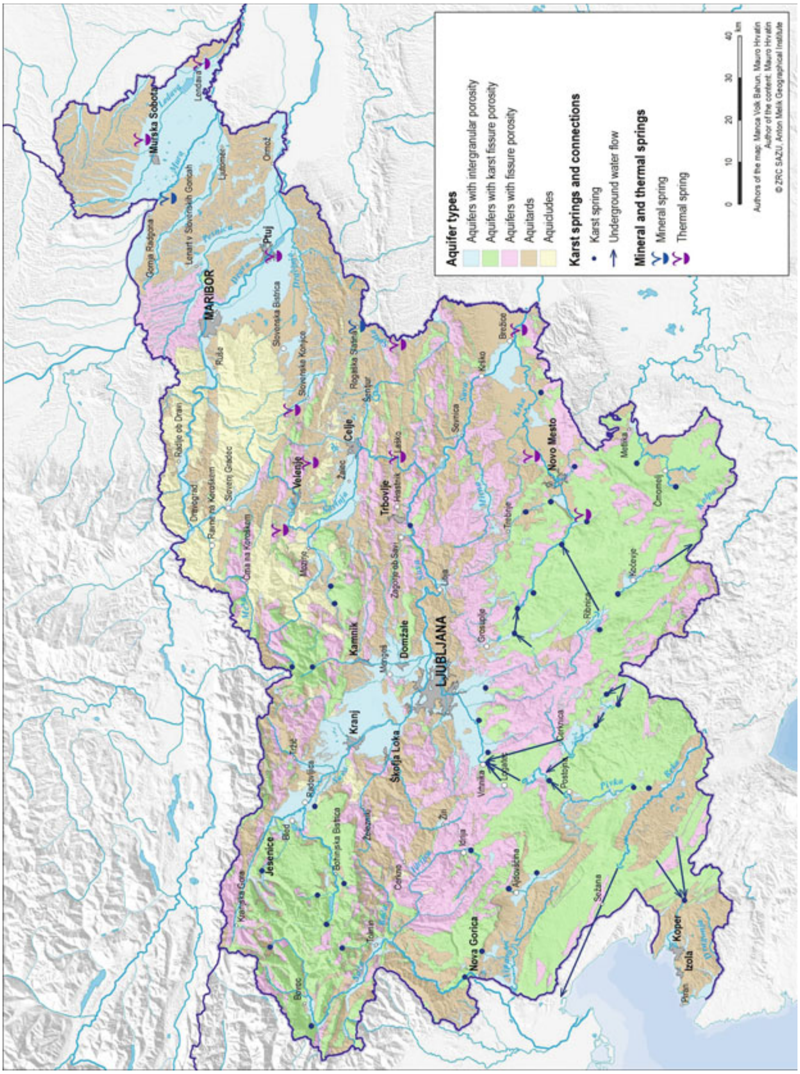

Fig. 3.11 Different aquifers, major karst springs, most important underground karst water flows and more important mineral and thermal springs

drainage basin, and less than one-tenth in the Mura drainage basin. The Savinja, Sotla, and Soča drainage basins together contribute less than one-tenth of the reserves (Brenčič 2009).

At the moment, aquifers with intergranular porosity supply more than half of Slovenia's drinking water. Because the basins are very densely populated, intersected by roads, and intensively cultivated, and at the same time polluted rivers are directly linked to groundwater, "there is a great and constant threat of pollution hanging over of this important natural resource, either directly from the surface or indirectly from the rivers. The pollution of the groundwater could prohibit its use in the public water supply for years or even decades. The greatest threat of groundwater pollution occurs during droughts because the dropping level of the water table allows the penetration of polluted river water into the gravel and sand" (Hrvatin 2004: 34).

Aquifers with karst fissure porosity are even more frequent and important than aquifers with intergranular porosity in Slovenia. They are characteristic for limestone areas, while aquifers with fissure porosity occur in dolomite areas. The intermittent occurrence of impermeable rocks significantly reduces their permeability (Uhan and Kranjc 2004).

In karst areas, rainwater drains into the ground through fissured and chemically soluble rocks. Here it joins various underground rivulets, streams, and rivers, is captured in underground lakes and flows through deep cavities. It returns to the surface in karst springs at the periphery of the karst areas (Fig. 3.12) (Brenčič 2009).

Karst terrain works like a sieve, and the interlaced water cavities allow harmful substances to flow through the underground, endangering cave habitats and drinking water. In many places sinking streams carry urban and industrial wastewater; these collect in cave watercourses and return to the surface at karst springs. Karst water requires special protection because the waste material does not decay as quickly and effectively underground as on the surface. Industrial pollution with polychlorinated biphenyls (PCB), for example, has made the karst Krupa Spring in Bela krajina unusable as drinking water for many human generations (Habič 1991).

Aquifers with karst fissure porosity are frequent in Dinaric and Alpine regions. They feed the springs of Soča, Sava, Idrijca, Vipava, Ljubljanica, Kamniška Bistrica, Krka, and Kolpa rivers and many of their tributaries. Some karst springs, such as the Rižana, Hubelj, Malni, Podroteja, Mrzlek, Rakitnica, and Dobličica spring, are vital for the water supply of entire regions. During droughts, they represent three-quarters of all the available water supplies (Kranjc 1998).

Numerous **thermal and mineral springs** represent a special treasure in eastern and northeastern Slovenia. Their distribution depends on geothermal heat flows, which increase from the west to the east of the country. The temperature at a depth of 1,000 m is around 20 °C in western Slovenia, but it exceeds 70 °C in the northeast. The highest measured temperature at the mouth of the borehole was recorded in Ljutomer (148 °C), while the highest measured temperature in a borehole was recorded near Lendava (202 °C) at a depth of 3.7 km (Lapanje and Rman 2009). Around thirty natural thermal and mineral-thermal springs with

Fig. 3.12 The karst spring of the Unica River, the penultimate segment of the karst Ljubljanica, originates in Planina Cave at the edge of the Planinsko (karst) polje *Photo* Matija Zorn

temperatures from 18 to 38 °C and a joint output of around 180 l/s have been identified so far. Many thermal and mineral-thermal springs with temperatures from 20 to 72 °C come from deep boreholes; their joint output is 840 l/s (Ravnik 1999).

The sources of thermal water are deep-lying dolomite rock beds, whereas mineral water collects in porous tertiary sand and gravel, such as in Radenci, and in tectonic fissured igneous and metamorphic rocks, such as in Rogaška Slatina (Fig. 3.13) and Jezersko. Mineral and thermal water with dissolved CO_2 was found in northeastern Slovenia when looking for oil and natural gas at depths of 700 to 1,300 m at Moravske Toplice, Lendava, and Banovci (Natek and Natek 1998).

Thermal water from boreholes is used at spas to heat swimming pools and as balneotherapy in Čatež, Dolenjske Toplice, Šmarješke Toplice, Podčetrtek, Ptuj, Laško, Rimske Toplice, Topolšica, and Zreče (Lenarčič and Plut 1995). One-third of geothermal energy is used to heat buildings and hot water in Murska Sobota and Lendava, and to heat greenhouses (Lapanje and Rman 2009). Mineral water is bottled for sale as table water in Rogaška Slatina and Radenci, both of which also offer mineral water for therapeutic purposes in their local spas (Žlebnik 1993).

Considering the rich natural potential of mineral and thermal water in Slovenia, it is relatively underutilized. There is still great potential for sustainably designed spa tourism and exploitation of environmentally-friendly geothermal energy (Lenarčič and Plut 1995; Lapanje and Rman 2009).

Fig. 3.13 The mineral springs spa at Rogaška Slatina has served tourists for over two centuries *Photo* Matija Zorn

3.4 The Adriatic Sea

Slovenia has a share of the Adriatic Sea: not quite one-third of the 551 km^2 Gulf of Trieste, which is the northernmost part of the Mediterranean Sea that extends into continental central Europe (Radinja 1990). Although the Slovenian share of sea area is small, its economic and geopolitical significance is disproportionately large. The Slovenian coast is 46.6 km long (Orožen Adamič and Rejec Brancelj 1998) and is fairly sharply differentiated by geological structure. Its catchment area is only 450 km^2 and is made up partly of flysch and partly limestone. Four types of coastline appear in alternation. The first, accumulative type was formed by the outflows of rivers and streams. Koper Bay, Škocjanski zatok Lagoon, and the Strunjan, Portorož, and Piran bays are submerged river mouths that form ria-type coastlines. The second coastline type, which is connected with flysch in Istria, is abrasive and was formed through the action of sea waves. Steep walls or cliffs that are up to 70 m high and an abrasion terrace are characteristic of this type. The best example is the Strunjan cliff between Izola and Piran (Fig. 3.14). The third coastline type is calcareous and occurs only on one-tenth of the Slovenian coastline, around Izola. Considerable share (app. 80%) of the coastline has been urbanized and constitutes the fourth type (Ogrin and Plut 2012; Kladnik et al. 2014).

The Slovenian sea is shallow and rarely exceeds a depth of 20 m. The underwater relief is characterized by an indistinct coastal "Roman" terrace 2 m beneath the surface, and the edge of a steep slope some 10 to 100 m away, which begins 9 m beneath the surface. Then there is a sediment floor composed mostly of sludge and fine sand. The deepest point in the Slovenian sea lies in the depression by Piran (−37.25 m), which is dubbed the "submarine Triglav" (Orožen Adamič 1990), Mount Triglav being the highest pick in the country with 2,864 m. Because it is so shallow, the sea is characterized by considerable temperature fluctuation and ecological fragility. Despite this, the water in twenty-one Slovenian coastal swimming areas received excellent ratings from 2012 to 2015 (Turk 2016). The average annual temperature of the sea's surface layer is 15.8 °C, the lowest average monthly

Fig. 3.14 Up to 70 m high vertical flysch cliffs along the Slovenian coastline *Photo* Matija Zorn

temperature (in February) is 8.1 °C, and the highest (in August) is 24.0 °C (Rejec Brancelj 2004). Due to the abundant influx of fresh water, the salinity is lower than the Adriatic average and fluctuates between 33‰ and 38‰. Tidal motion is weak because the tidal range averages only 66 cm. The bora north wind reduces the sea level, whereas the highest sea level occurs with low air pressure and a south wind. At these times the lowest parts of the coastline are threatened by flooding (Bernot 1990; Bat 1997; Kolega 2006). The general rise in sea level is a consequence of tectonic coastline sinkage and global climate change (Kolega 2006; Trobec et al. 2017).

Due to its small size and enclosed nature, the Gulf of Trieste is one of the more polluted parts of the Adriatic Sea. Around 400,000 inhabitants live along the gulf coast in Italy and Slovenia, and their waste is joined by industrial wastewater, coastal traffic, tourism, and to small degree agriculture. A large influx of organic and inorganic matter comes from the Po River in Italy (Natek and Natek 1998). Human inhabitants have strongly shaped the coastal landscape in the past with water drainage, terracing, construction, arrangement of salt pans, and building ports, but in recent years there have been many attempts to reduce the negative environmental impacts. The coastal stretches in which preserving biodiversity is most important are protected in the Strunjan Landscape Park, the Sečovlje Salina Nature Park, and the Škocjanski zatok Nature Reserve.

3.5 Hydrological Natural Hazards

The flooding of major rivers in Slovenia threatens an area of about 500 km^2, which is roughly 2.5% of the country's territory (Fig. 3.15). Torrential flooding and lowland flooding occur as well as flooding of karst poljes, and Slovenia also experiences coastal, urban, and artificial floods (Zorn and Komac 2011).

About 7.3% of the population of Slovenia live in flood-prone areas, with the greatest proportions living in the Savinja River drainage basin (12.9% of the population of that area), in Koroška region (11.6%), in Zasavje region (10.3%), and in central Slovenia (9.3%) (Komac et al. 2008). On average, about €14 million in damage per year was caused by floods from 1991 to 2008, or 16% of the total damage caused by natural disasters in this period (Zorn and Komac 2011). The greatest damage was caused in the drainage basin of the Savinja in 1990 (more than €500 million in direct damage), and in the last decade direct economic damage exceeded €200 million on three occasions (2010, 2012, and 2014).

Overbank floods occur during high river discharges resulting from heavy precipitation in autumn or melting of snow in spring (Hrvatin 1998). At present, they only rarely extend over large areas of flood plains because they were artificially reduced by extensive regulation and melioration of the majority of rivers in the twentieth century (Komac et al. 2008). In the past, flood plains were uninhabited rich ecosystems of wetlands, but they later became farming and urbanized areas that

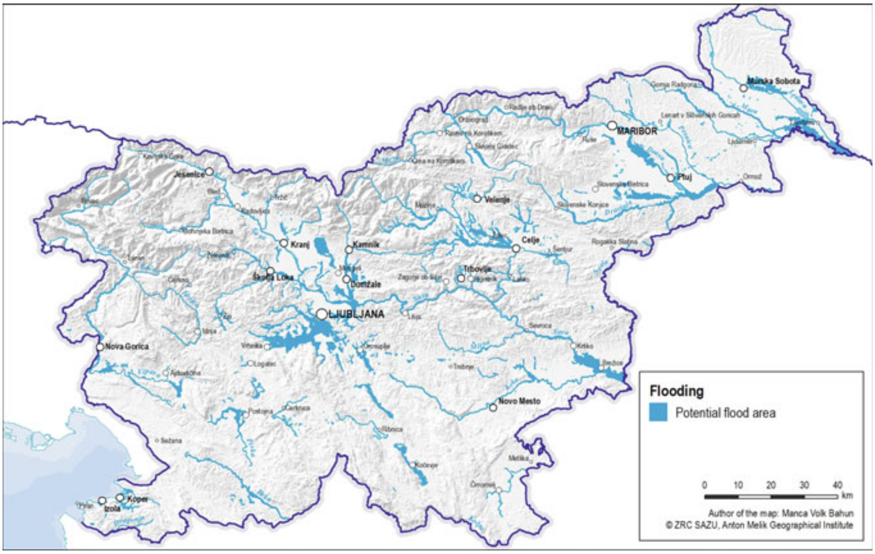

Fig. 3.15 Flood-prone areas in Slovenia

need suitable flood protection measures (Natek 1992). In order to mitigate overbank floods, levees were often artificially raised.

Overbank floods affect a large part of the country and typically occur in plains in the lower reaches of major rivers such as the Ljubljanica, Savinja, Krka, Drava, Mura, and Sava, as well as along smaller rivers such as the Gradaščica, Pšata, and Kamniška Bistrica near Ljubljana, the Pesnica and Ledava in eastern Slovenia, and the Vipava in the west (Komac et al. 2008).

The largest flood-prone areas are the Ljubljana Marsh (80 km^2; Fig. 3.16), along the Dravinja (66.5 km^2) and the Krka (62 km^2), and along the lower reaches of the Savinja, Sava, Sotla, and Kolpa rivers and in the Cerknica (karst) polje. Since the beginning of the twentieth century, there have been major lowland floods in 1901 (all of Slovenia), 1910 (Drava), 1923 (Soča, Sava, and Savinja), 1925 (Mura), 1926 (Ljubljanica, Savinja), 1933 (Sava, Savinja), 1954 (Savinja), 1972 (Mura), 1990 (Savinja), 1998 (Sava), 2000 (Savinja), 2004 (Bača), 2005 (Sava), 2007 (Sora), 2010 (Ljubljanica), 2012 (Drava), and 2014 (Ljubljanica, Mura).

Torrential floods are characteristic of mountainous and hilly areas (Fig. 3.17) with a preponderance of narrow valleys. Of all watercourses in Slovenia, a third are torrential ones that appear occasionally. They are important because they threaten 237,000 hectares of land or about 12% of the country's territory. Along the Dragonja and Drnica in the Mediterranean hills in the southwest, the valley floors are sparsely settled, and torrential floods do not cause a lot of damage (Zorn 2008). In the Julian Alps, torrential floods are limited to the steepest mountain slopes (Kolbezen 1998). In the Karavanke Mountains, torrential floods are typically frequent along torrential streams such as the Belca, causing damage in the newer parts

Fig. 3.16 Flooding in September 2010 affected new construction in the Ljubljana Marsh *Photo* Matija Zorn

of settlements and to infrastructure (Komac et al. 2008). In hilly central Slovenia, with the Sora and Savinja rivers, traditional settlement retreated to higher fluvial terraces and inactive alluvial fans in order to avoid torrential floods, but today these valley floors are densely settled (Komac et al. 2008). In the northeast, flash floods are common in the Slovenske Gorice Hills and Haloze Hills, and in the north, they are limited to the Pohorje and Kozjak Hills, where the greatest torrential river is the Mislinja (Gams 1991).

Coastal floods are fairly common in the autumn months, when storm waves develop due to the combined influence of winds, low air pressure, and tidal bores, and bring flooding to the lower-lying parts of coastal towns. Annual floods affect about one percent of the territory of coastal municipalities, and extreme events about four percent. Extreme floods in the Municipality of Piran affect about a sixth of the territory. Between 1963 and 2003, the sea caused limited flooding on 256 occasions, and in 1967, 1970, 1980, 1981, 1983, 1987, and 1994 floods were quite extensive (Robič and Vrhovec 2002; Kolega 2006).

Karst floods are a distinctive phenomenon on karst poljes in the Dinaric karst region in southern Slovenia. They occur where the karst groundwater level rises above the elevation of the polje floor and percolates slowly through hundreds of cracks and voids in the floor and rim of the poljes. A unique trait of karst floods is the clarity of water due to the low sediment load, creating transparent intermittent

Fig. 3.17 Impact of a torrential flood in the Davča Valley in 2007 *Photo* Matija Zorn

lakes that last for several weeks or even months (Komac et al. 2008; Ferk 2016). In their normal extent karst floods are not categorized as natural disasters because they do not threat settled areas, but during the highest water levels they may reach to the edges of some settlements. The most typical periodically flooded karst poljes are the Planina polje (Fig. 3.18), Cerknica polje, Lož polje, Radensko polje, Ribnica polje, and Kočevje polje (Komac et al. 2008). Since 2000 there have been major flood events in 2000/2001, 2008/2009, and 2014 (Frantar and Ulaga 2015).

3.6 Water Management

Water management in Slovenia is governed by the Waters Act (from 2002; updates 2008 and 2012) (Zakon o vodah 2002, 2008, 2012) and its implementing regulations, and partially also by the Environmental Protection Act (from 2004) (Zakon o varstvu 2004). Both acts contain a certain amount of material from the EU Water Framework Directive (from 2000) (Directive 2000), which dedicates special attention to ensuring the good quality of all water and defines the legal framework for protecting and maintaining clean water as well as ensuring its long-term sustainable use.

Fig. 3.18 Normal flooding in karst poljes does not threaten settlements. A normal flood in the Planina polje *Photo* Miha Pavšek, Archive of the Anton Melik Geographical Institute

The Waters Act has three segments: water protection, water regulation, and decision-making on water use. According to the Waters Act, water and freshwater areas are a "public good" (Steinman and Banovec 2000; Globevnik 2017) anyone can use in a manner that does not harm the water, the hydrological regime, or the natural balance of aquatic and riparian ecosystems and that does not thereby encroach upon the rights of others, whereby all are given the right in full to "general water use" (Rozman 2017). The Environmental Protection Act regulates supplying the population with drinking water and wastewater management (Globevnik 2017). It is legally based on water management following the principles of environmental protection, and it is a comprehensive activity (i.e., it takes into account the natural processes and dynamics of water, as well as the mutual connection and interdependence of aquatic and riparian ecosystems), a democratic activity (with public participation), and a sustainable activity (Globevnik 2017).

According to the Waters Act (Article 4) (Zakon o vodah 2002), the management of water and of freshwater and riparian areas is primarily the jurisdiction of the state. It is organized through branch offices of the Slovenian Water Directorate as part of the Ministry of the Environment and Spatial Planning (Globevnik 2017). Nonetheless, the act provided (Article 162) for the establishment of water panels in order to allow local communities, holders of water rights, and NGOs to have a voice in water management. This part of the act was not implemented (Mikoš 2011) and it was later struck out (Waters Act update from 2012) (Zakon o vodah 2012).

Comprehensive water management takes place in Slovenia as a six-year planning process defined by the Water Management Plan, with one plan for the Danube watershed, which encompasses approximately 80% of Slovenia's territory, and one for the remainder of Slovenia in the Adriatic watershed. The current management plan for both regions was prepared for the period from 2016 to 2021 (Načrt 2016a, b). The Water Management Plan is a national document that defines the mechanisms for managing water policy in order to achieve good-water quality and for managing the policy in line with the EU Water Framework Directive. Pollution of Slovenian water by dangerous contaminants is minimal because 95% of Slovenia's bodies of water have a good chemical status. On the other hand, nearly 40% of the surface water does not have a good environmental status (Rejec Brancelj et al. 2011).

Water management has a long tradition in Slovenia. For example, even the Romans regulated part of the Ljubljanica River in the Ljubljana Marsh in order to increase its navigability (Zorn and Šmid Hribar 2012). Two hundred years ago, extensive drainage work was carried out in the same area in order to reduce the risk of floods and to obtain farmland. As early as 1872 (while Slovenia was still part of the Austro-Hungarian Empire) a "quite modern" water act was adopted that put in place several "modern" principles, such as the polluter pays principle, stakeholder participation, and water user associations (Steinman and Banovec 2000). The passage of the 1884 Act on Provisions for the Safe Discharge of Mountain Water (Gesetz 1884) was followed by the regulation of headwaters and flashy streams, and toward the end of the nineteenth century and at the beginning of the twentieth century by the construction of water mains and sewer networks in large towns (Rismal 2016). The beginning of the twentieth century also saw the introduction of hydropower to generate electricity, and the construction of hydroelectric plants continues to this day.

In 2016 the right to (safe) drinking water was enshrined in the Slovenian Constitution (Article 70a) (Ustavni 2016), which used the resolution "The Human Right to Water and Sanitation," approved by the United Nations General Assembly in 2010, as a basis. The purpose is for drinking water sources and their maintenance to take precedence over commercial use (Mikoš 2017). According to the Waters Act, the use of water for supplying drinking water takes precedence over all other uses of water. The majority of Slovenia's population (99.5%) obtains drinking water from public water mains, which in the majority of cases are supplied by public utilities owned by the municipalities (Rozman 2017). In 2012, 82 m^3 of water per person was provided (extracted for the public water supply), of which 58 m^3 of water per person was consumed for various needs (for households 41 m^3 per person and for various commercial and non-commercial activities 17 m^3 per person). Households consumed about 114 L of water per person per day (Žitnik et al. 2014).

3.7 Further Insights and Some Views on the Future

Slovenia's natural abundance of drinking water reserves is a priceless natural treasure and advantage for the country (Rismal 2016) that people are all too often unaware of, especially in the light of climate change and the resulting changes to hydrological regimes. In recent decades, hydrological changes have been observed in Slovenia (Hrvatin and Zorn 2017), which are manifested in a downward trend in minimum discharges and average medium discharges as less water is available because precipitation and snow cover also have downward trends. In the last fifty years, the amount of precipitation on an annual scale has decreased by 15% in western Slovenia and slightly less (10%) in the eastern part of the country. During the same period, snow depth has decreased by 55%, and evaporation has increased by 20% in the last forty years (Vertačnik et al. 2018). Conversely, an upward trend in maximum discharges has been observed, which increases flood risk. Changes are also noticeable in discharge regimes. In the Slovenian Alps, the autumn and winter discharges are gradually increasing, the spring and summer discharges are gradually declining, and the autumn discharge maximum already exceeds the usual spring maximum (Hrvatin and Zorn 2017).

To better understand these changes, in addition to analyzing discharge data, an analysis of changes in the volume of groundwater, climate parameters, water consumption (Tošić et al. 2016; Vertačnik et al. 2018), and land-use changes should be carried out. Nonetheless, concerns that Slovenia does not have as much water available as was ascertained not very long ago are becoming increasingly justified (Bat and Uhan 2004). No special measures and recommendations have been adopted yet to address the rapid and significant changes in discharges that have been occurring over the past few decades, but this will soon be imperative if the trend continues.

Due to the uneven distribution of precipitation over the year, great differences in its annual volume, and various other climate, lithological, and geomorphic factors, periods of drought are becoming increasingly common (Natek 1983; Sušnik and Gregorič 2017). The strategy for fighting drought has not been particularly successful, which was also confirmed by a 2007 report by the Slovenian Court of Auditors, according to which the national budget expenditure on remedying the consequences of drought in agriculture was 26.2 times the costs of implementing drought-prevention measures (Revizijsko 2017). The Slovenian Ministry of Agriculture, Forestry, and Food prepared recommendations for the needs of agriculture concerning adaptation to more arid weather conditions, such as the Technological Recommendations for Reducing the Sensitivity of Agricultural Production to Drought (Tehnološka 2008), the Technological Measures for Reducing the Effects of Drought on Growing Corn (Tehnološki 2014), and the Strategy for Adapting Slovenian Agriculture and Forestry to Climate Change (Strategija 2008).

Aridity is accompanied by low water discharges, which leads to a lower groundwater level and quantity, which in turn affects the water supply. Low discharges also affect power production at hydroelectric plants, and they also significantly increase the risk of water pollution (Plut 2000).

Irrigation is a known drought-prevention measure. Just over 2% of farmland is irrigated in Slovenia. The quantity of water required to irrigate various types of crops varies between 500 and 2,500 m^3/ha in an average year and from 2,180 to 5,600 m^3/ha in a dry year, which does not take into account the loss of water on the way from the pumping site to the crop, which can amount to up to 50% (Pintar 2007; Načrt 2017). The greatest irrigation needs in Slovenia are in the Vipava Valley in southwest Slovenia and in the northeastern part of the country, where the majority of watercourses have modest discharges in the summer and therefore a biological minimum must be ensured for them. To expand the irrigation land, irrigation systems with reservoirs should be built, which requires a major change to the river basins and the water balance, and raises many environmental concerns. In addition, the existing reservoirs are not performing their function, either due to the ecological status of the water (Dobnikar Tehovnik 2008) or because they are not used (Fig. 3.19).

In addition to the upward trend in maximum discharges, the scale and frequency of floods have been affected by deforestation, farming, and urbanization. Various human-induced changes have altered the appearance and economic use of flood-prone areas (Šifrer 1983; Komac et al. 2008). Extensive regulation work has been taking place for over a century now to protect such areas against floods, but it also affects the ecological status of waters. Therefore, the legitimacy and ecological suitability of amelioration and regulation measures is a relevant issue in many places.

Fig. 3.19 The Vonarje Reservoir on the Sotla River on the Slovenian–Croatian border, which has been empty for over twenty years. The reservoir was built as a multipurpose structure: for flood prevention, drinking water, farmland irrigation, fishing, and tourism-recreational activities. Due to poor water quality, the flood prevention was the only use permitted (Zupančič and Kovač 2009) *Photo* Matija Zorn

The Slovenian Administration for Civil Protection and Disaster Relief, which operates under the auspices of the Ministry of Defense, has prepared a series of recommendations (Preventivni 2018) on measures to take before, during, and after a flood. People are advised to inform themselves in a timely manner of the flood risk in the area they live in. In forests and especially near torrents, fallen and broken vegetation should be regularly removed, and water-borne debris that accumulates in narrow sections of rivers or at structures such as bridges and culverts should be regularly removed. Effective hydrological forecasts are an important preventive measure. In this regard, an extensive upgrade to the system for monitoring and analyzing the status of waters took place at the Slovenian Environment Agency, which is in charge of monitoring waters in Slovenia, from 2009 to 2015 (Vogrinčič et al. 2015).

Problems that occur during drought or floods can be prevented or at least partly mitigated through various measures connected with the functioning of the relevant water infrastructure. This includes dams, flash flood barriers, high-water dikes, channels, various types of protection for river banks and bottoms of riverbeds, chutes, and weirs. The Slovenian Environment Agency is responsible for the maintenance of water infrastructure and to this end awards concessions to public utility services (Globevnik 2012).

Water infrastructure structures control the dominant directions and volumes of the surface runoff and debris in watercourses. This protects the transport, power, communication, and municipal infrastructure and other built structures along the watercourses against damage. Less than half of the minimally required funds for maintaining the river network and nearly ten thousand water infrastructure structures are available from the national budget each year. Therefore, a reduction in the discharge capacity and increased flood risk and damage during meteorological disasters can be expected to continue in the following years. In 2009 and 2010 alone, the total damage to watercourses and water infrastructure exceeded €250 million, and less than 5% of this value was earmarked for maintaining watercourses and the water infrastructure from the national budget (Globevnik 2012).

In the second half of the twentieth century, increased population density, industrialization, new farming methods, and the development of transport rapidly impacted the quality of Slovenian waters. This deterioration was most rapidly observed in watercourses that were directly exposed to pollution. Despite the significant self-purification capacity of most rivers, the pressure was too great. The number and length of overly polluted sections increased rapidly and reached a peak at the end of the 1980s. During the 1990s, the situation stabilized due to various cleanup measures and general economic conditions, and at least in some places, the situation improved after that (Bat and Uhan 2004).

In terms of quality, watercourses already differ because of the natural, especially lithological, conditions typical of individual river basins. These primarily cause differences in the hardness, basicity, electrical conductivity, and overall quantity of dissolved solid matter in the water. However, the bulk of differences in the quality of watercourses results from industrial wastewater and sewage, and diffuse pollution caused by agriculture and transport. It is manifested in a high biochemical and chemical oxygen demand and pollution through detergents, phosphates, nitrogen compounds, and so on. The highest level of this type of pollution is typical of watercourses along densely populated, industrialized, and agriculturally intensive areas (Bat and Uhan 2004).

Groundwater, which supplies more than half of Slovenia's demand for drinking water, is under threat primarily because of the increasing volume of wastewater and inappropriate activities in ecologically sensitive areas. The greatest problem related to the quality of groundwater is the diffuse source pollution caused by agriculture. Due to the use of mineral fertilizers, manure, and pesticides, the remains of nitrates, ammonia, sulfates, potassium, phosphorus, and pesticides are often present in the groundwater (Plut 2000).

The shrinking and degradation of wetlands is one of the most alarming human-induced changes to freshwater ecosystems. From 1950 to 1992, 40% of wetlands were destroyed in Slovenia, taking into account swamps, reedbeds, and ponds alone. From 1973 to 1991 alone, over 70,000 hectares of wetlands were drained, depleting their biodiversity, and intensive single-crop farming in these areas causes groundwater pollution (Beltram 1999).

In the past, wetlands were considered potential farmland of lower value and cesspools of disease. Because of unfamiliarity with their landscape ecological functions, they are still often used for dumping waste or extending settlements and roads. The 1971 Ramsar Convention on Wetlands places special emphasis on the need for their conservation as important ecosystems. Therefore, it is recommended to both establish protected wetlands and control any activities affecting their wider surroundings (Beltram 1999; Bolješič 1999). So far, the following sites in Slovenia have been included on the list of Ramsar Sites: the Sečovlje Saltpans (1993), Škocjan Caves (1999), and Lake Cerknica (2006).

3.8 Conclusion

As mentioned in the introduction to this chapter, Slovenia has an above-average quantity of water. However, because of droughts, pollution, and problems with the drinking water supply, over the past decades issues concerning the available quantity of water first attracted the attention of the professional community and soon after that also the attention of the Slovenian public. To date, other aspects have primarily been at the forefront of studying waters, such as their use for generating power, regulation, and flood protection, because it has been unimaginable that the problem of insufficient water supply, which is common in many places around the world, could also exist in Slovenia. Today the fact that climate change is a reality suggests that one of the effects of this change is also a change in the quantity of water.

3.9 Recommendations

As can be deduced from the previous text, there are many fields related to water management that require constant monitoring and improvements. These include the following:

- Due to the long history of water management, there are many water-management structures. An inventory of these structures was made only recently, but it only presents their location. Updating the inventory with data about the age, present status, and function(s) of the structures is highly recommended. This will allow proper assessment of their present function, their value, and funding needed to reconstruct them.
- The water infrastructure was mostly built from the 1950s until the 1970s, and it has not been reconstructed since. Several structures are no longer functioning; sediment dams, for example, have not been emptied. Because Alpine settlements in particular are often below and close to these structures, the population in these regions faces increasing danger of high sediment transport by flashfloods.
- As new types of water-related hazards appear, new studies of these phenomena should be prepared. For example, in the Pannonian plains of northeastern Slovenia, floods related to sudden rises in groundwater lasting for weeks have caused considerable damage to agriculture in recent years. On the other hand, Alpine regions are facing considerable damage from torrential floods.
- Drought constantly causes considerable damage to farming, also because the use of crops is not adapted to natural conditions but to financial supports. Assessment and use of proper financial and other measures is recommended in order to support the use of drought-resistant crops. In this regard, new options for financing and managing the existing irrigation system as well as expanding this system should also be evaluated.
- Although many cleanup measures have been implemented to reduce water pollution, additional improvements are recommended in this regard.
- To increase awareness about water-related issues, it is recommended that topics related to water management be included at all levels of education.

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Chapter 4
Induced Riverbank Filtration (IRBF) for Managed Artificial Groundwater Recharge (MAR) in Slovenia

Irena Kopač and Matevž Vremec

Abstract The increase in the water supply demand, intense farming, and climate changes led to overexploitation and contaminated aquifers in some regions of Slovenia. A solution to this problem was an introduction of artificial groundwater recharge systems. Within the Project FREEWAT, we established two groundwater flow models to analyze the efficiency and optimize the working functions of the established groundwater recharge systems. One of the sites of the groundwater model is the deep aquifer of Vrbanski Plato (the main source of drinking water for the most extensive water supply system in Slovenia), where managed artificial recharged was introduced thirty years ago. Additionally, an analysis of a newly constructed MAR system with IRBF on the shallow aquifer of Apače field was carried out. Water resource management tools like FREEWAT have become a significant contributor to an establishment of an efficient MAR system and consequently a water quality healthy aquifer. Among the two studied sites, the hydrogeological tool FREEWAT was used to analyze the efficiency of the MAR system against possible contamination, the effect of the MAR system on the groundwater body and the increase of the capacity of the pumping station with additional groundwater recharge.

Keywords Managed artificial groundwater recharge (MAR) · Induced riverbank filtration (IRBF) · Water resource management · Vrbanski plato aquifer · Apače field aquifer · FREEWAT

I. Kopač (✉)
Aneri Eco Engineering (AEI), Radenci, Slovenia
e-mail: irena.kopac.ik@gmail.com

M. Vremec
Faculty of Engineering Maribor, University of Maribor, Maribor, Slovenia
e-mail: matevz.vremec@gmail.com

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4.1 Introduction

Induced riverbank filtration was first introduced in Slovenia nearly 50 years ago in the Maribor water supply system at the Vrbanski Plato aquifer. Since then, several managed artificial recharge (MAR) systems with induced riverbank filtration (IRBF) have been established across the country to provide a consistent supply of drinking water and protection against possible contamination of the pumped groundwater (Fig. 4.1).

This article covers two major MAR systems with IRBF in the north-eastern part of Slovenia, one constructed in the area of the deep aquifer Vrbanski Plato and the other constructed in the area of the shallow aquifer Apače field. The oldest among the two is located in the vicinity of the second largest city of Slovenia, Maribor, with approx. 110.000 inhabitants. The system main function is to provide protection for the pumping station Vrbanski Plato, which is the main source of drinking water for the municipality of Maribor, against possible contamination from the city center and increase the capacity of the pumping station.

The MAR system at Apače field was constructed under the project Supply of drinking water to the Pomurje region—system C, which aimed to provide drinking water to more than 26.000 inhabitants among eight municipalities of the Pomurje region. The MAR system with IRBF was constructed at the two-major pumping station of Podgrad and Segovci. The system is designed to increase the capacity of the pumping stations in the summer months and provide protection against possible contamination of nitrates from the eastern side of the aquifer. For optimum

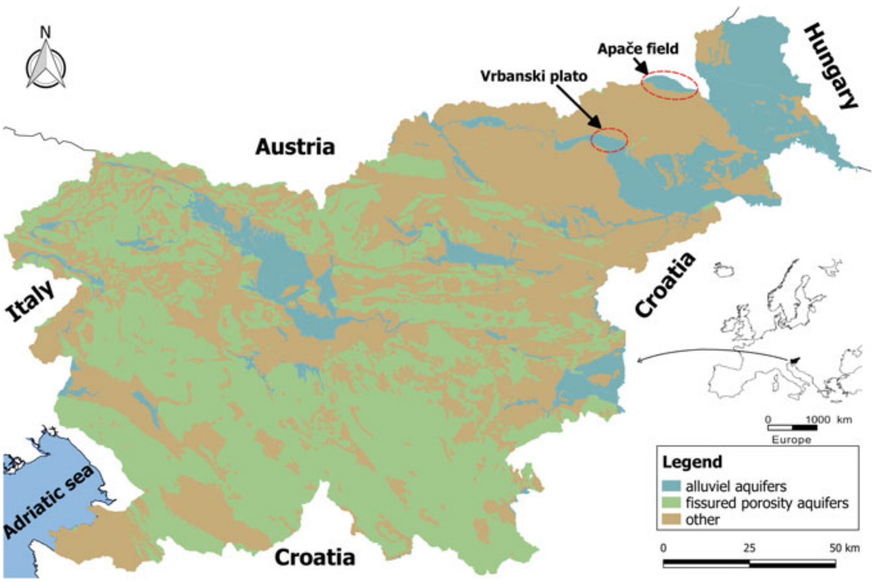

Fig. 4.1 Hydrogeological map and aquifers of Slovenia (*Source base* ARSO Slovenia)

efficiency of the MAR and IRBF system, a groundwater flow model was established to test the efficiency of the system in different model scenarios and to optimize the quantity of recharged water to provide 100% protection against possible contamination.

4.2 Vrbanski Plato—Deep Aquifer

4.2.1 General Information of the Vrbanski Plato Aquifer

The aquifer of Vrbanski Plato represents the most significant source of drinking water for the Maribor water supply system. The first major pumping station on the aquifer of *Vrbanski Plato* was constructed in the year 1960 when the lack of drinking water supply forced the municipality to build an experimental pumping station. The predicted usage capacity of drinking water was before the construction of the dam in *Melje* and the hydroelectric power plant in *Zlatoličje* predicted to be around 100 l/s. After the construction of the dam in *Melje,* the level of the river Drava rose and increased the yield of the aquifer, where it is now possible to pump up to 460 L/s without specific measures and up to 760 l/s with artificial groundwater recharge (Kopač 2008).

Due to the increasing awareness of the importance of this pumping station, the first studies for groundwater recharge began with building four experimental wells on *Maribor Island* in the year 1978. After repeated water shortages in the year 1985, it has finally decided to build the first phase of the artificial groundwater recharge with pumping wells on *Maribor island*, water treatment plant in *Vinarje valley* and two infiltration wells. These were done in years 1986–1990. The system already showed its benefits in the year of 1993 and in 1997 with providing additional needed quantities of water and easier to deal with remediation of pollution by pesticides and by trihalomethanes (Fig. 4.2).

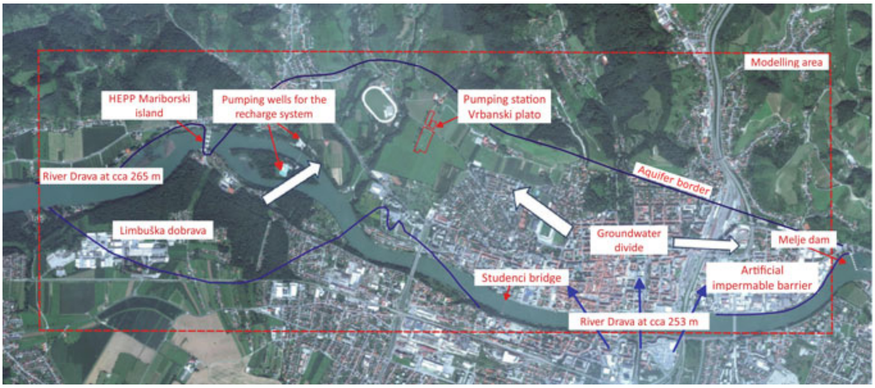

Fig. 4.2 Conceptual model of Vrbanski Plato aquifer (Kopač and Vremec 2017a, b)

Since the end of 1986, with the first phase of the artificial groundwater recharge fully carried out, until 1992, detailed control measurements were conducted, which ensured the integrity of Maribor Island and protected the groundwater quality. Later, the monitoring focused primarily on the quality and the level of the groundwater. On the basis of these observations, the data of several groundwater models of the Vrbanski Plato were made. These models have been following trends in their field, but they never got enough attention from stakeholders or water management (Kopač et al. 2017).

The Vrbanski Plato aquifer is independent of rainfall as the aquifer is mainly recharged by the river Drava, which flow remains mostly stable throughout the year (due to the dam in Melje, the operator of the hydroelectric power plant can fluctuate the water level in river Drava maximum approximately 2 m). Unlike most of the aquifers in Slovenia, which are dependent on precipitation, the Vrbanski Plato aquifers capacity is constant which means constant/smooth pumping and supply of the drinking water throughout the year (Fig. 4.3).

The responsible company for the supply of drinking water the Maribor and surrounded municipalities is the company *Mariborski vodovod* (Maribor Water Supply company), which uses the pumping station Vrbanski Plato on the left bank of river Drava as their main drinking water supply. The *Vrbanski Plato* aquifer represents the most critical source of public water supply in the management of the *Maribor water supply* company, which is with 1615 km water supply pipes, 49 wells, 129 water reservoirs the most extensive system of water supply in Slovenia. With the total capacity of 760 l/s, the pumping station of Vrbanski Plato can meet whole current water needs in this region, but for now, it covers up to 70%, depending of working of the other pumping stations. Some of them are more climate depended, and in drought periods, we need more water from Vrbanski Plato. In the year 2015 for example, the pumping station Vrbanski Plato comprised 67% of the Maribor drinking water supply (Kopač 2008).

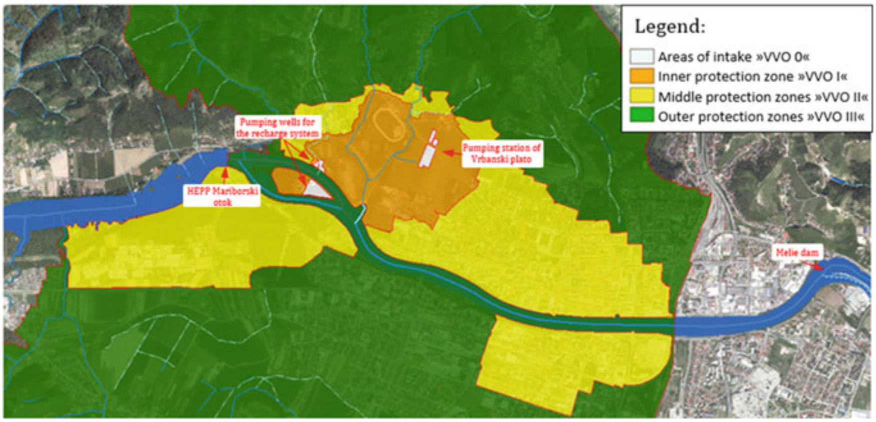

Fig. 4.3 Water protection zones on the aquifer Vrbanski plato (*Source base* ARSO Slovenia)

4.2.2 Active Protection System (MAR) with Induced Riverbank Filtration

The phase I of the active protection system was in the area of Vrbanski Plato constructed in the period from 1986–1990. The system itself ensures the minimal safety of the pumping station against possible pollution. The I. phase of the artificial groundwater enrichment system has a capacity of 150 l/s and includes four wells on the natural river island of Maribor Island, a water treatment plant and four injection wells in the valley of *Vinarje*. The I. phase of active protections represents the basis for the implementation of planned the II. and III. phase of active protection, which will include the construction of the complete active protection system and the increase of the capacity of the Vrbanski Plato pumping station (Kopač 2008).

The II. phase of active protection of the Vrbanski Plato pumping station foresees an increase of the pumping station capacity by 100 l/s. With this measure, the Maribor Water supply company could replace two wells near Bohova, which are under constant threat of contamination with dangerous substances from the traffic of a nearby highway. Partial prevention of catastrophic contamination of the pumped drinking water with contaminated groundwater, which could come from the city and the regional road Maribor—Dravograd, is also planned for the II. phase of the active protection. In the view of the occurrence of pollution with pesticides from the right bank of Drava river and partially from the area of the city, prevention of inflow from these directions is included in active protection. Finally, it is necessary to provide a technological design for preventing the decline in the capacity of the riverbank filtrate pumping wells on the Maribor island and the left bank of river Drava (Fig. 4.4).

The III. phase of the active protection of the Vrbanski Plato pumping station is intended to increase the capacity of the pumping station for long-term needs. At this stage, a capacity of 1000 l/s is foreseen for the active protection system, with the usage of the riverbank filtrate and direct river water. This phase includes the same security elements as the previous phase with the addition of the use of the Drava water itself. The capacity of the Vrbanski Plato pumping station and the protective pumping/injection/drainage wells will be increased so that the risk of catastrophic contamination of pumped water with contaminated groundwater, which is located below the city and from the regional road Maribor—Dravograd, will be avoided entirely.

On a natural island between two sleeves of the river, the bank filtrate for the artificial recharge is pumped with four wells with altogether capacity of 300 l/s. The quality of the pumped riverbank filtrate already corresponds to the EU drinking standards. On the other hand, the influence of pesticide pollution is noticeable from the city and the right bank of river Drava. The total concentration of pesticides (0,2 μg/l) and Atrazine (reaching 0,1 μg/l) are still below the EU standards (0,5 μg/l), but measures should be taken to prevent this negative influence (Kopač 2008).

The pumped riverbank filtrate goes through the water treatment plant, consisting of lamella settlers, cascade aeration, and rapid filtration, which could eliminate the

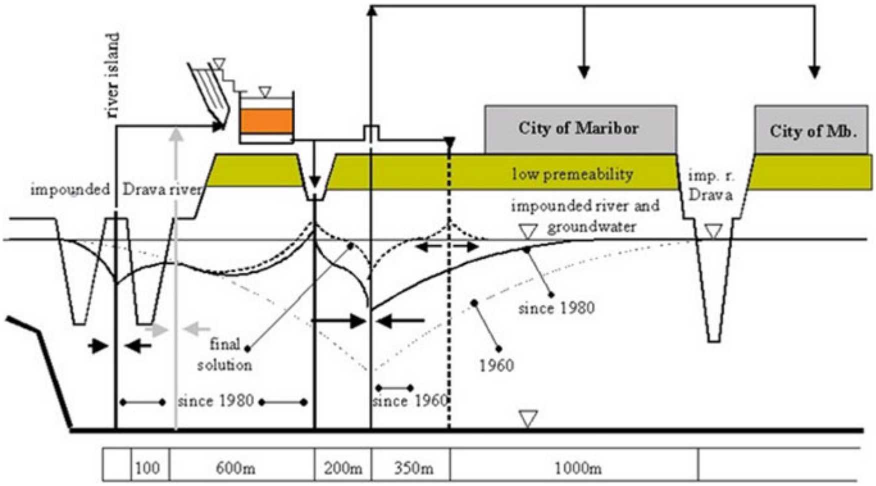

Fig. 4.4 General scheme of the planed system—cross section (Rismal and Kopač 2000)

manganese and iron created by the bank filtration before it is recharged into the aquifer via the negative injection wells. In case of possible detection of larger groundwater contamination, the water treatment plant also includes the upgrade option of ozonation, coagulation and powdered activated carbon treatment (Kopač 2008).

In recent 45 years, the need for an operational recharge system gained vital importance as three severe pollutions of drinking water occurred in that time. The first accident with Cr^{+6} was caused by inadvertent operation in the lacquering company that lays at that time above the groundwater streamline of two wells. The considered solution to get the drinking groundwater rid of the Cr^{+6} was to pump both wells empty for several years. To prevent the possibility of another pollution from the city, the artificial recharge was renamed to "the active protection of the drinking groundwater". It was conceived with two aims: to prevent polluted groundwater flow from bellow of the city to flow into pumping wells and to increase the "natural "capacity of groundwater without the influence of the city at the same time.

The total plan of the active protection of the aquifer has not been fully accomplished yet, as the negative wells, for the reasons not mentioned here, were constructed only on one side and not on both sides of the pumping wells. The result of the rough plan is that the possible pollution of drinking water from the city's side had not been entirely prevented yet.

The insufficient recharge system was the reason for the second pollution with Trihalomethanes. As the waterworks stopped a specific amount of the artificial recharge to save the pumping costs, the consequence was that the polluted groundwater from bellow of the city and the right side of river Drava reached the pumping wells in full extent. With restarting the artificial recharge again with full capacity, the concentration of Trihalomethanes quickly dropped below the acceptable concentration. This experience finally convinced the responsible, that the planned system must be completed so that no intrusion of pollution from the city nor the opposite right bank of the river could reach the underground drinking water reservoir (Kopač 2008).

4.2.3 Implementation of a Groundwater Flow and Transport Model

In the area of the Vrbanski Plato aquifer we have a lot of monitoring data. Most of it is provided from the water supply company Mariborski vodovod (within his water safety plan, build on HACCP system) and MUVOON—Inter-municipalities Agency for environmental protection and nature conservation Maribor. MUVOON already for 15 years carries out yearly immission monitoring on groundwater, soil and surface water, which influences groundwater. Within several projects and research, including the last one HORIZON 2020 project FREEWAT (Grant Agreement No. 642224) we managed to establish a calibrated groundwater flow model (MODFLOW 2005) and also an additional transport model (MTD3-USGS), which are meant for sustainable water resource management and research scenarios for the next steps of artificial groundwater recharge.

For the groundwater model we decided for one model layer with unconsolidated gravel and sand and with silt on the riverbank and the next models of water management scenarios (Kopač and Vremec 2017a, b):

1. steady-state model with 50 × 50 m grid cell size and with average monitoring data for the year 2015; here, we made a base model and studied three additional scenarios:
    a. average pumping in the wells (396 l/s) and active artificial groundwater recharge (165 l/s) (base model simulation with calibration and validation);
    b. average pumping in the wells (396 l/s) without artificial groundwater recharge;
    c. maximum pumping (636 l/s in the year 2015) in the wells and active artificial groundwater recharge (191 l/s in the year 2015);
    d. maximum pumping (636 l/s in the year 2015) in the wells without artificial groundwater recharge;
2. steady-state model with 5 × 5 m grid cell size and with average monitoring data for the year 2015;
3. transient model with 5 × 5 m grid cell size (see Fig. 4.5) for a period between July 2014 to June 2017, including a large quantity of heating oil, that has been spilled in March 2016 in the inner city of Maribor and two newly constructed pumping well for reducing the contamination of the heating oil in October 2016.

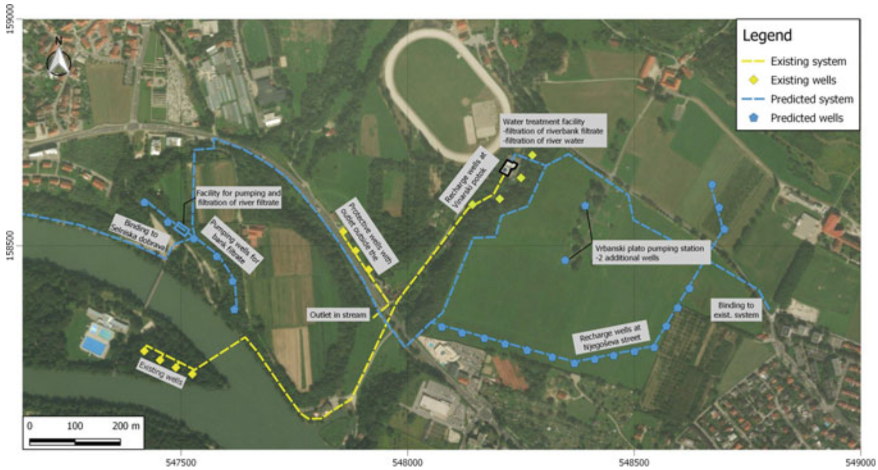

Fig. 4.5 Scheme of planned II. phase of active protection (Kopač 2008)

The established model area is located between the following extreme points in the modulated Gauss-Krüger, coordinates:

Xmin: 545325 m	Xmax: 551725 m
Ymin: 157000 m	Ymax: 159225 m

The investigated domain of the model is 2250 m large and 6400 m long. The bottom surface (Fig. 4.6) of the model layer was determined based on a raster file that is representing the impermeable layer. The raster file of the impermeable layer was created with the interpolation of drill holes data of the impermeable layer gathered across the area of the aquifer (Figs. 4.7, 4.8, 4.9 and 4.10).

The top surface of the active domain was determined with values of a digital elevation model. Based on the input data the aquifer thickness stretches from 0,1 m on the borders to 25 m.

The results of the groundwater model indicated that the thickness of the unsaturated zone stretches from 0,1 to 40 m on the north border under the hills.

The hydrogeological and geometrical characteristics of the groundwater model were determined based on pre-made reports (Kopač 2008) and research in this area. Based on the research we determined lower hydraulic conductivity in the area of the riverbed, due to soil settling, which is sealing areas of the riverbed and contributing to a lower hydraulic conductivity comparing to the rest of the aquifer. Regarding the previous research, we divided the grid into different hydraulic coefficient zones (polygon and line shapefiles), which were later calibrated using the UCODE module.

The groundwater hydrology of the examined model area is hugely diverse. Consequently, the following boundary conditions were taken into account:

Fig. 4.6 Existing wells of the I. phase of active protection (Kopač 2008)

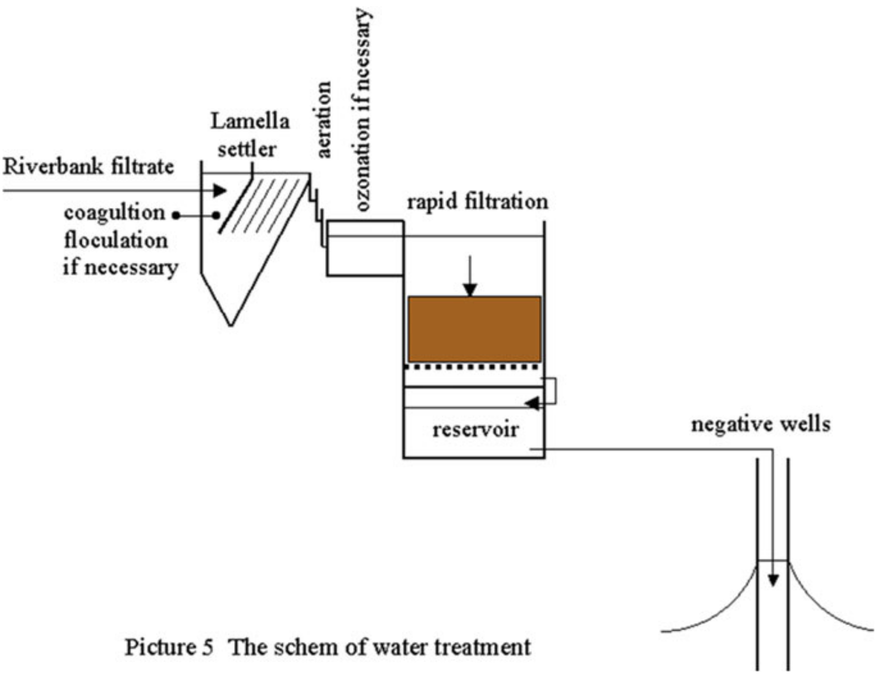

Fig. 4.7 Scheme of water treatment (Rismal and Kopač 2000)

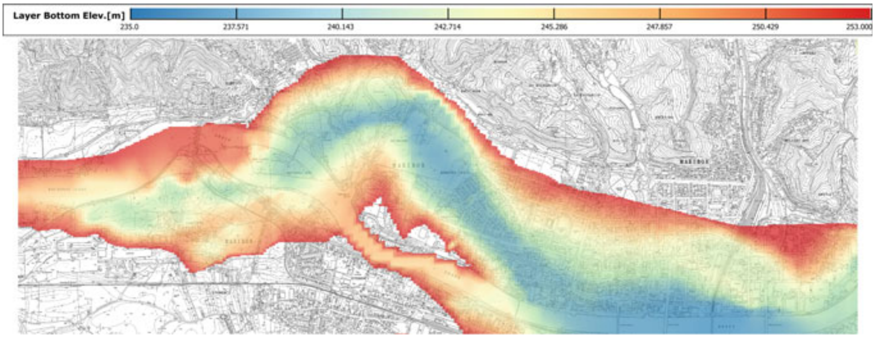

Fig. 4.8 Contour table of the height of the impermeable layer (Kopač and Vremec 2017a, b)

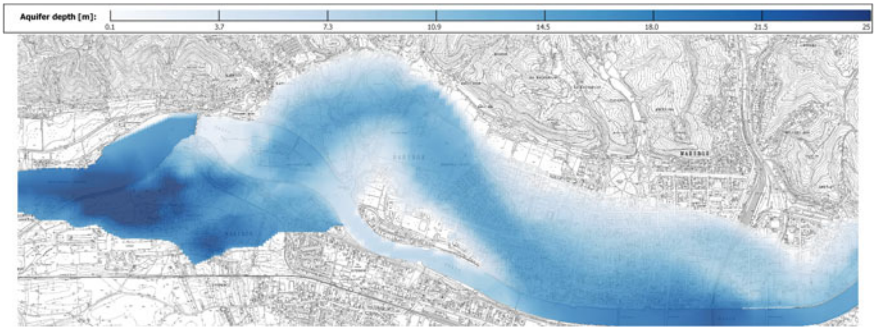

Fig. 4.9 Contour table of the model layer thickness (Kopač and Vremec 2017a, b)

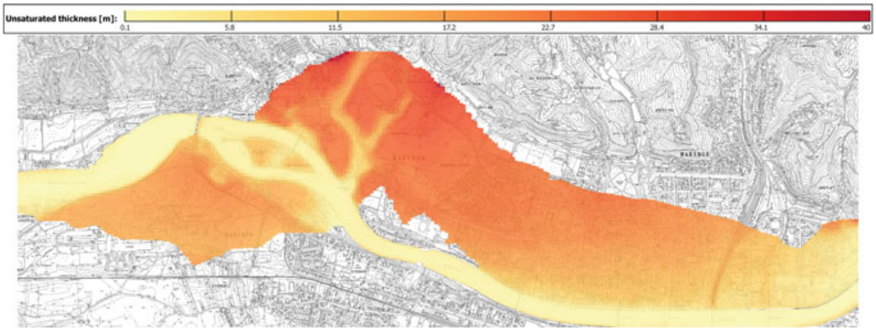

Fig. 4.10 Contour table of the unsaturated layer thickness (Kopač and Vremec 2017a, b)

- the RIVER package—infiltration of the Drava (around 400 l/s as average) infiltration of groundwater from the right side in Drava River (around 5 l/s): the geometry of the river bottom was determined based on measurements of the cross-sections of the river regular made by Drava Power Plants Company;

- the RECHARGE package—surface precipitation (around 35 l/s as average) of two zones (city area and green area),
- the CHD package—hinterland groundwater flow from the Pohorje mountains (around 25 l/s as average);
- the WELL package: pumping from 4 pumping wells on Maribor Island and 14 pumping wells (around 400 l/s as average) in the area of the Vrbanski Plato pumping station, 2 pumping wells in area of heating oil pollution (as 20 l/s as average), and 2 artificial groundwater recharge wells in the area of the Vinarje valley (around 165 l/s as average);
- the DRN—the draining of groundwater in Melje (35 l/s as average).

4.2.4 Results of the Water Management Scenarios

In March 2016 a large quantity of heating oil was spilled in the inner city of Maribor. For the localization of the oil plume and recovery measures, nine new boreholes were drilled. Groundwater sampling showed that the contamination did not spread to a larger area. Based on an extended analysis, a measure with the implementation of two remediation wells for a floating oil layer recovery system by dual pump-and-skim technology (Delin and Herkelrath 2014) was applied for the prevention of the spreading and long-term attenuation of the contamination. The dual pump and-skim technology was composed of two pumps inside each remediation well with a large groundwater pump for the formation of a cone of depression and a small skimmer pump for the temporary pumping of the floating oil layer. The water is pumped into an oil separator and a storage tank that is regularly cleaned (Kopač et al. 2017).

On the 19th October 2016, two remediation pumping wells started to operate in the area of the municipality, for reducing the contamination from the heating oil spillage that happened in this area. The simulations performed with the transient model are meant to indicate the effects of the newly constructed wells on the aquifer water table and the location of the watershed divide. The stress periods were therefore divided into several groups. The first indicating the time, before the construction of the wells, and the others indicate different times of equal pumping quantities at the newly constructed wells. This time discretization goes from July 2014 to June 2017 in the HORIZON 2020 FREEWAT project (Kopač et al. 2017).

The results of the use of FREEWAT platform in QGIS environment consist of a database entry groundwater monitoring, key hydrogeological maps, and land use maps of the area, producing models of groundwater flow and pollution transport and display of key results and data model. Because of heating oil spillage, the most important result for our local authorities and stakeholders involved in water resource management was to present proper water management with a model to ensure that the polluted area will not spread to the catchment area of the Vrbanski Plato pumping station. Of course, we also got a clear picture of the flow of the groundwater in this area and the operation of induced riverbank filtration (IRBF) as part of our managed aquifer recharge schemes (MAR).

The location of the watershed divide in the center of the city is crucial for the quality of the groundwater pumped at Vrbanski Plato. Therefore we observed the location of the watershed divide while conducting the different scenarios (a,b,c,d). The location also signifies the flow direction of the oil spillage show in the lower figure with the orange–gray oval sign (Fig. 4.11).

The model simulation with an average pumping station and with active water recharge systems indicated that the spill extended towards the drain in Melje and was not threatening the quality of the drinking water pumped at Vrbanski Plato. All of the other scenarios (maximum pumping at the Vrbanski Plato or no artificial groundwater recharge) simulated the shift of the watershed divide towards Melje, consequently redirecting the oil spillage and more polluted water towards the pumping station of Vrbanski Plato instead of directing the contaminated water towards the drainage in Melje (Kopač et al. 2017). One year after the spill approximately one half of the spilled oil has been recovered. With the setup of the recovery system and the remediation wells, the contaminant was stabilized in a depression created in the water-table (Figs. 4.12 and 4.13). The full remediation and attenuation of the spillage will be a slow process, which will take years to recover from.

To support next steps of remediation we constructed a detailed transient and transport model with 5 × 5 m grid cell size. These all were helpful for testing the usefulness of tool QGIS/FREEWAT and for confirming successful engineering measures in the area of fuel oil spillage.

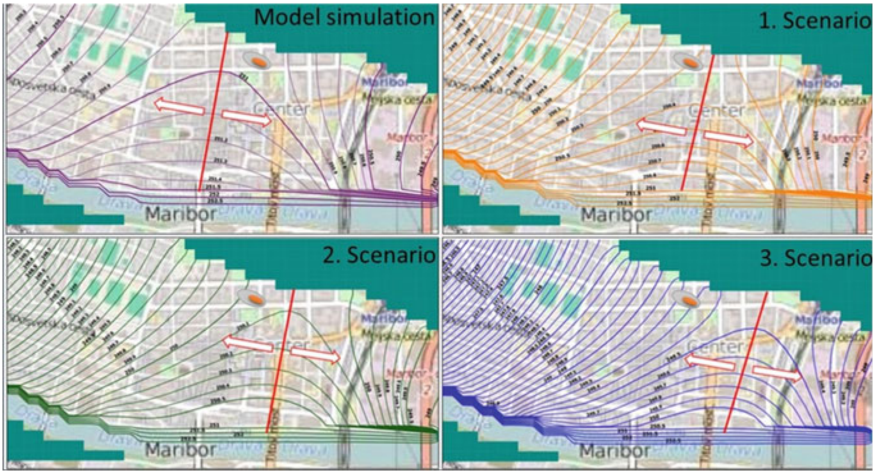

Fig. 4.11 Simulated groundwater head in different scenarios (Kopač and Vremec 2017a, b)

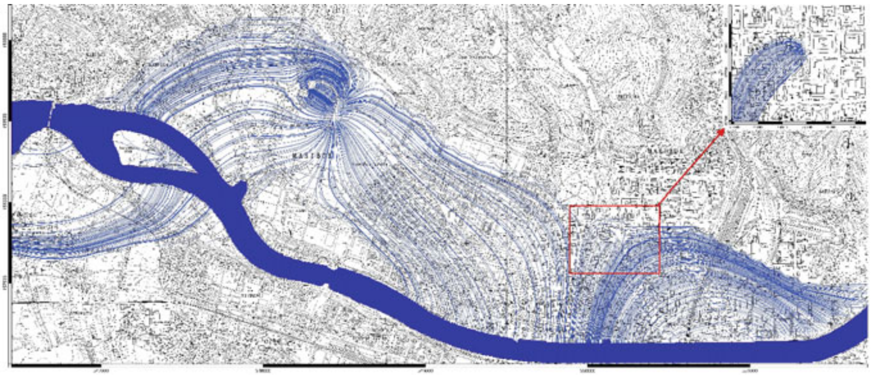

Fig. 4.12 MODPATH particle tracking after the construction of the remediation wells (Kopač and Vremec 2017a, b)

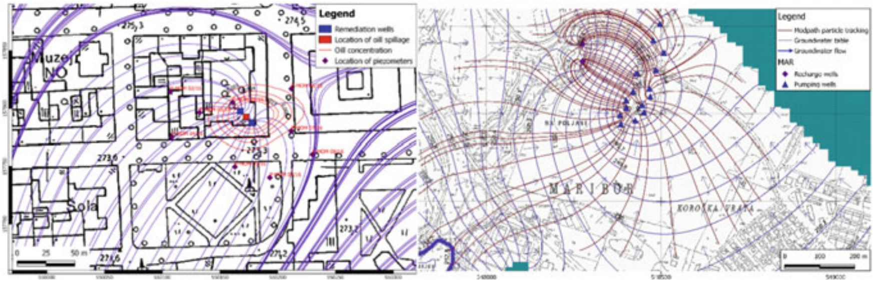

Fig. 4.13 Location of heating oil spillage with two remediation wells with groundwater flow and oil concentration (maximum pumping) (left picture); Modpath particle tracking in the area of the Vrbanski Plato pumping station (right picture) (Kopač and Vremec 2017a, b)

4.3 Apače Field—Shallow Aquifer

The aquifer of Apače field represents one of the main sources of drinking water in the Mura valley. Therefore its protection is a critical task for the water supply company. Before the construction of the managed artificial groundwater recharge, the responsible water supply company encountered the next problems, regarding the quality of the pumped groundwater:

1. Exceeding values of pesticides and nitrates, due to intensive farming
2. The decrease of groundwater level, due to the deepening of the river Mura riverbed

To preserve the quantity and quality of the groundwater resources, a major project on safe water supply, financed by the EU Cohesion Fund, was designed and

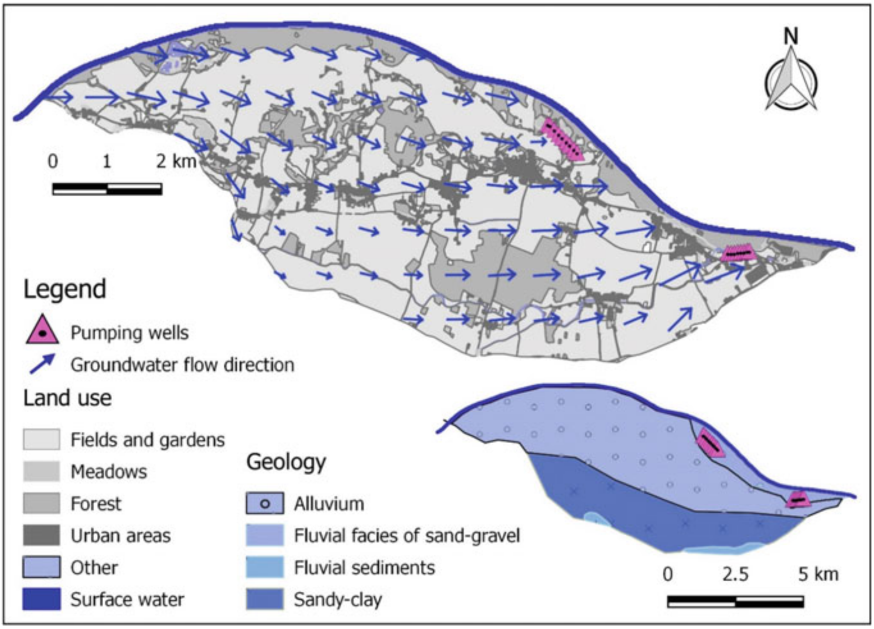

Fig. 4.14 Land use map of Apače field with the groundwater flow direction (*Base source* http://RKG.gov.si/GERK, groundwater flow Kopač and Vremec 2017a, b, the geological map: base source ARSO)

included induced riverbank filtrate for groundwater recharge system, which connected the two most important pumping stations of Segovci and Podgrad (Fig. 4.14).

4.3.1 General Information of the Apače Field Aquifer

Apače field is a plane in the statistical region of Pomurje with an area of 44,78 km^2. The plain extends between Konjišče in the northwest and Gornja Radgona in the east. The plain is bordered with river Mura in the north, which also represents the state border with Austria, and with the hills of Slovenske gorice in the south.

The stone structure of the Apače field mainly consists of Quarter, Pleistocene and Holocene sandy/gravel natural levees. Above Zgornje Konjišče the area comprises of a low sandy/gravel levee at an altitude of 230 m above sea level. The quaternary deposits between Konjišče and Podgrad mainly comprise of poorly granulated sandy gravel, ranging in thickness between 4,2 and 11,3 m. The thickness of the sandy gravel between Segovci and Podgrad is about 6,7 m. A 1,5 m layer of clay is deposited on top of the sandy gravel levee between the channel of river Mura and the regional road between Vratja vas—Podgrad.

On the south and south-western part of the Apače field, the sand silty clay cover can range to 6 m in thickness. The basis of the quaternary levee consists of plio-Miocene sediments: clay, molten clay, silt, sandy silt, silty marl, marl, clayey marl and dense muddy sand. The surface of the tertiary layers is constantly dropping with the riverbed of the Mura river.

The groundwater is in shallow depths. The groundwater regime depends heavily on the amount of water in river Mura and precipitation. The aquifer of Apače field is mainly recharged from river Mura, precipitation on the field, infiltration of the smaller streams: Mlinski potok, Bizjak and Plitvice that inflow from the nearby hills of Slovenske gorice and backwater from hills in the south. The aquifer reserves range around 190 l/s. The water resource is very sensitive to climate change, even a slight decline in the groundwater level can have a significant impact on the aquifer and its yield. The climate change affects the river stage, the annual rainfall and the daily temperature, which all contribute to lower water tables.

The aquifer is open with free surface water almost in the entire area, except on the southern periphery (at the foothills of Slovenske gorice) there are some places covered with a less permeable layer. The aquifer is 4–12 m thick. In the central part of the aquifer, the depth can vary between 6 and 7 m. The groundwater level is at a depth between 2.5 and 3.5 m and is directly in contact with the river network. In the Apache field, drinking water is currently pumped from two pumping stations:

- Segovci
- Podgrad

Both pumping stations apply the system of horizontal drainage. The water sources are also additionally recharged with the induced riverbank filtrate. The pumped groundwater in the pumping station Segovci is used for the public water supply of Apače municipality, the pumping station of Podgrad covers the rest of the municipalities. The average amount of daily pumped groundwater is 10,4 l/s in Segovci and 52.1 l/s in Podgrad.

The following regulation applies to the management and use of the water in Apače field:

- Decree on the water protection area for the aquatic body of the aquifer of the Apače field (Official Gazette of the Republic of Slovenia, No. 59/07, 32/11, 22/13 and 79/15).

According to the above regulation, Apače field is divided into three areas (as shown in Fig. 4.15):

- The most important water protection area (I)
- Closer water protection area (II)
- Wider water protection area (III)

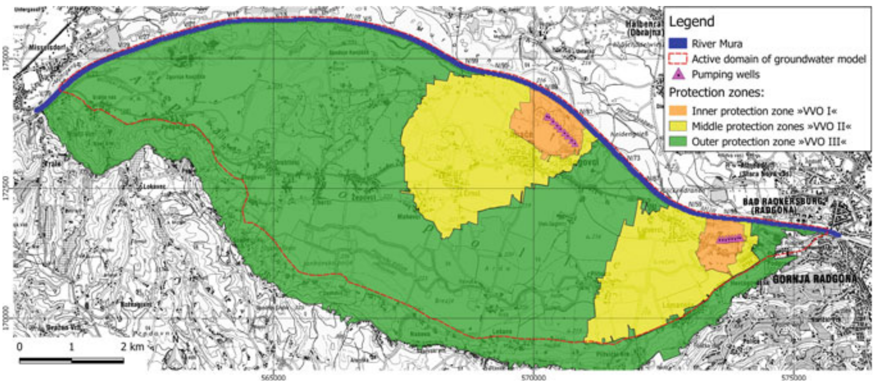

Fig. 4.15 Water protection zones in the area of the aquifer Apače field (*Base source* ARSO)

4.3.2 Public Water Supply System for Pomurje—Sistem C

The public water supply system for Pomurje with main cities Murska Sobota, Gornja Radgona and Radenci were established between 1964 and 1986. The system included a 400 m inbuilt drainage that was a part of planned artificial groundwater recharge system which should induce riverbank filtrate from river Mura and a flood embankment, with the aim of simultaneously protecting the draining water and the backyard agricultural land. However, since the planned device for the treatment of the induced bank filtrate, which was at that time poor quality (approx. 200 mg/l $KMnO_4$ or 50 mgO_2/l), wasn't constructed, the artificial recharge was carried out only in droughts as a solution to the construction of a 700 m long drainage in the area of the pumping station Segovci. Since the construction of this pumping station in the 1960s, the quality of river Mura improved significantly due to the construction of wastewater treatment plants in Austria. Even at low flow rates of river Mura, the chemical consumption of $K_2Cr_2O_7$ dropped to 15 mgO_2/l and the TOC to 2,9 mg/l. The NTU of the river filtrate also dropped under 0,5 (Rismal 2013). Therefore, instead of the previously planned physical-chemical purification of the riverbank filtrate, a bioremediate biochemical purification with the aquifer adsorption capacity is introduced. The system also includes disinfection with ozone and filtration through activated carbon (Figs. 4.16, 4.17 and 4.18).

Iron and manganese are present in the riverbank filtrate. Between the filtration, they are reduced to the soluble form of Fe-2 and Mn-2, with Nh4 and ammonium S-2. With the recirculation of the riverbank filtrate, we achieve oxidation of the soluble matter so that the two soluble are removed already from the groundwater in the aquifer. The oxidized groundwater is then induced in the already constructed drainage (Rismal 2013).

To further improves the organoleptic properties and to remove residues of remaining pollutants, such as pharmaceutical metabolites, etc., the extracted groundwater also undergo ozonation, filtration through activated charcoal and

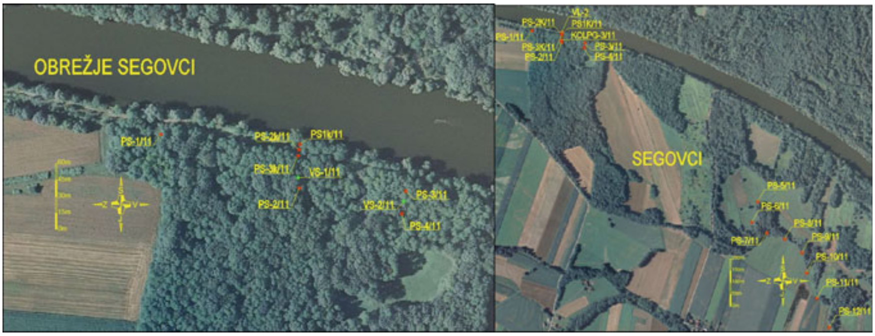

Fig. 4.16 Location of the MAR system in the area of the pumping station Segovci (*Source* IEI Ltd.)

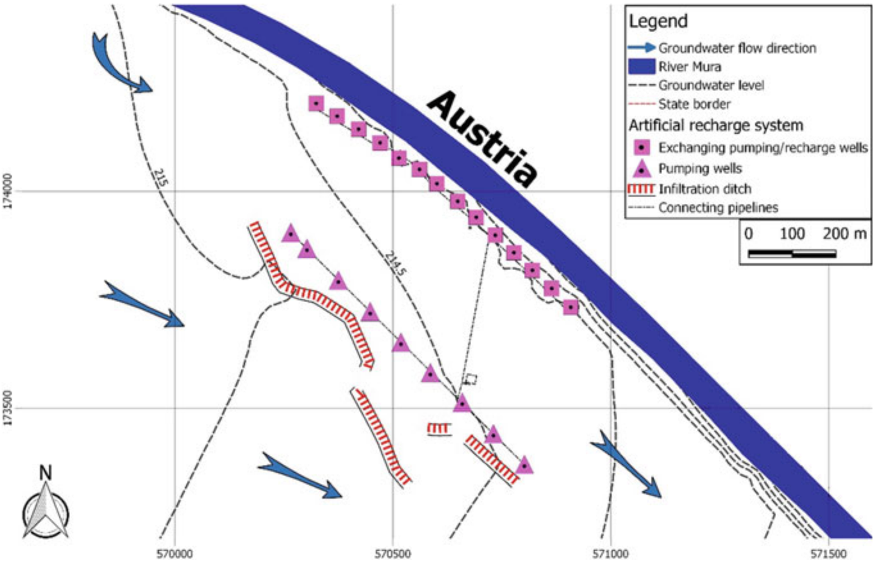

Fig. 4.17 Groundwater flow direction and location of the MAR system in the area of the pumping station Segovci (Vremec et al. 2017)

addition of residual chlorine for the prevention of later microbiological growth in the network (Table 4.1).

4.3.3 Pumping Station Segovci

The Segovci pumping station lies on a low gravel/sandy plain under the town of Segovci. The pumping station includes drainage with a pumping well. The drainage is

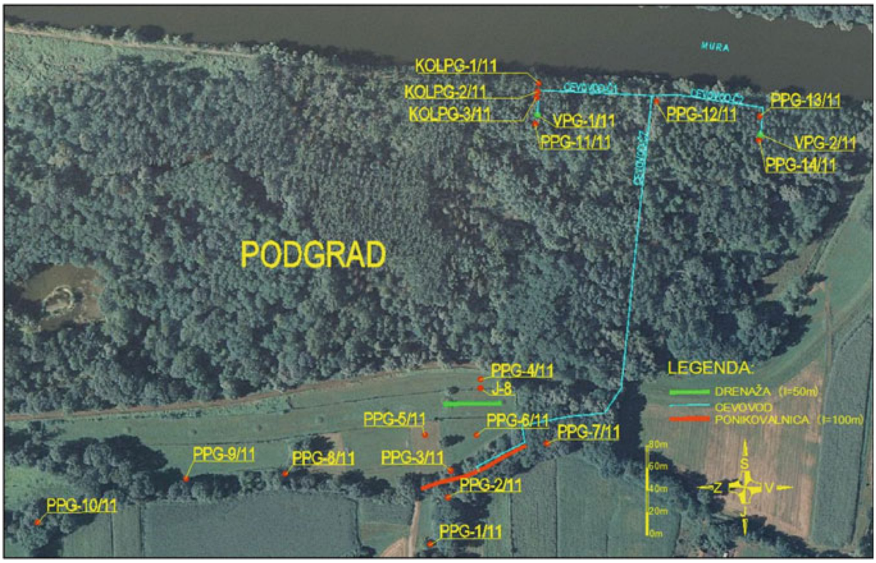

Fig. 4.18 Location of the MAR system in the area of the pumping station Podgrad (*Source* IEI Ltd.)

Table 4.1 Aquifer characteristics at the pumping station Podgrad and Segovci (Rismal 2013)

PUMPING STATION	SEGOVCI	PODGRAD
The thickness of upper silty-sand layer (m)	till 1,2	till 1,2
The thickness of sandy-gravel layer (m)	4	4,6
Depth till groundwater (m)	2,76	2,8
The thickness of wetted area of the aquifer (m)	2,5	3
Hydraulic conductivity (m/s)	between $1{,}50 * 10^{-3}$ – $2{,}64 * 10^{-2}$	between $1{,}89 * 10^{-3}$ – $2{,}09 * 10^{-2}$
Gradient i	0,003	0,003

800 m long, located in a low gravel/sandy levee on the right bank of river Mura. Concrete pipes with a diameter of 60 cm are placed on the impermeable base at a depth of 5–6 m. The walls of the tubes are perforated on the upper side with a machine drill with a diameter of 10 mm. The drainage pipeline is every 60 m equipped with an input shaft of concrete pipes with a diameter of 80 cm. Cleaning gravel material is located directly above the drainage hose. On the surface, the gravel material is covered with clay and then a humus layer. The drainage runs into a well with a diameter of 5 m and is deepened under the bottom of the drainage pipes by 1.5 m (Figs. 4.19 and 4.20).

The capacity of the drainage system in Segovci is designed to be around 70 l/s.

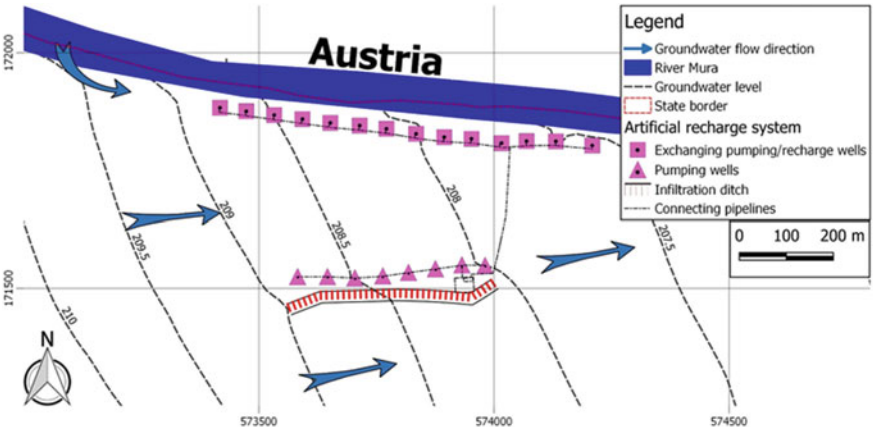

Fig. 4.19 Groundwater flow direction and location of the MAR system in the area of the pumping station Podgrad (Vremec et al. 2017)

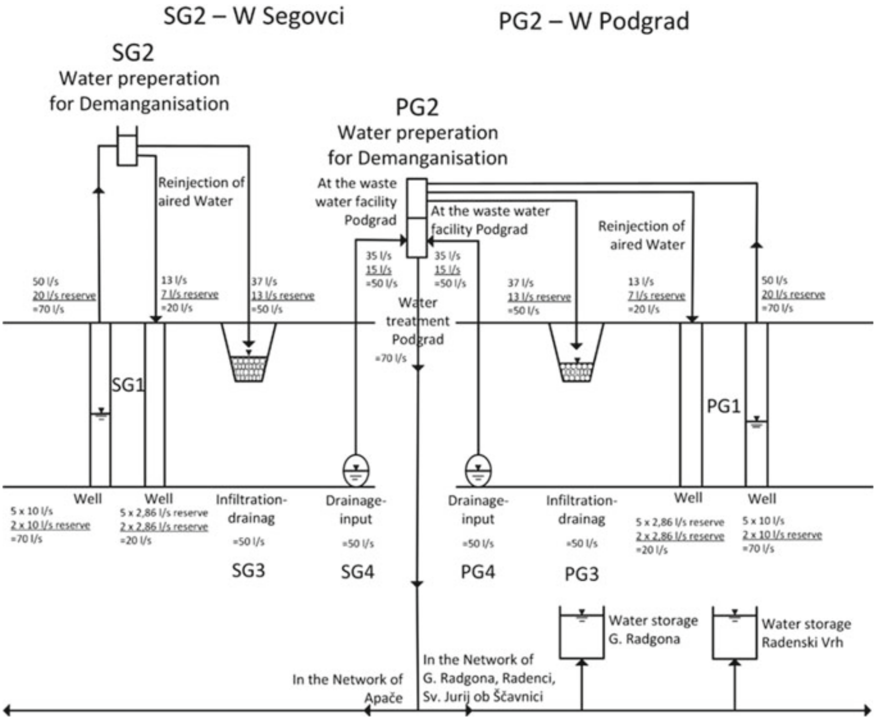

Fig. 4.20 Scheme of managed artificial recharge system at the pumping stations Podgrad and Segovci (*Source* IEI Ltd.)

The extraction rate at the pumping station without groundwater recharge usually doesn't exceed 14 l/s, as with higher extraction rates, the nitrate content in the pumped water can increase (significantly) over the permissible limit.

When pumping up to 14 l/s of groundwater at the pumping station Segovci, the quality of the water meets the Rules on Drinking water (Official decree of the Republic Slovenia No. 19/04, 35/04, 26/06 and 92/06).

The basic parameters of the sandy gravel levee in the area of the pumping station Segovci:

– thickness of sand gravel: 4 m,
– thickness of clayey mud and clay sandstone: up to 1.2 m,
– the thickness of saturated layer: 2,5 m (low level)
– coefficient of permeability, k: $6,1 \cdot 10^{-3}$ m/s
– the gradient of groundwater flow, i: $3 \cdot 10^{-3}$.

4.3.4 Pumping Station Podgrad

The pumping station of Podgrad is a drainage pumping station with horizontally positioned pipes with a total length of 400 m. The drainage is dug into a low gravel sandy levee on the right bank of river Mura. The concrete pipes with a diameter of 60 cm are placed at a depth of 4–6 m on the impermeable base. The walls of the pipes are perforated on the upper side with a machine drill with a diameter of 10 mm. The drainage pipeline is every 60 m equipped with an input shaft of concrete pipes with a diameter of 80 cm. Cleaning gravel material is located directly above the drainage hose. On the surface, the gravel material is covered with clay and then a humus layer.

In the area of the pumping station, the saturated thickness of the aquifer is usually around 3 m but can be reduced by a third at low water levels. The captured water is collected in a central well, in which a pump operates in cycles, depending on the amount of water in the water storage above Gornja Radgona. The drainage pipe is at the extreme western part connected with the pipeline for water supply from the pumping station Segovci. The existing well, in which the drainage runs to, was deepened and now located 1.5 m under the bottom of the drainage pipes. The diameter of the well is 5 m. The capacity of the drainage system in Podgrad is designed to be around 55 l/s.

The source for the enrichment system are 14 wells located in the Mura riparian zone near the pumping station Segovci and 13 wells located near the Podgrad pumping station. The extracted groundwater from the wells is then infiltrated into injection drainage, which is situated 50 m south of the pumping drainage.

The field is divided into two chambers, 40 m in length, divided by a 2 m wide area of clay material. The recharge system operates in a way that every second well extracts groundwater with a flow rate of 10 l/s and every second well recharges the water with a flow rate of 2.68 l/s. The water is pumped and returned to the aquifer to saturate it with gaseous oxygen to separate manganese and iron from the drinking water. The rest of the extracted water is pumped into an infiltration trench. Under the trench are 8 installed pumps that, if necessary drain the water to pumping station Segovci. Another feature of this enrichment system is the rise of the groundwater level in the area of the recharge above the level of the surrounding groundwater; this prevents the surrounding water from the fields, which are usually rich in nitrates and pesticides to flow into the pumping drainage (Vremec et al. 2017).

4.3.5 Implementation of Groundwater Flow Model

In the project GEOHIDRO (Vremec et al. 2017) a steady-state groundwater flow model was established to analyze the efficiency of the artificial groundwater recharge system in the area of the Apače field aquifer. For the groundwater flow model, we decided on one model layer with unconsolidated gravel, sand, and silt and the next water management scenarios:

- activated groundwater recharge system with average pumping quantities and average yearly data for precipitation and evaporation.
- deactivated groundwater recharge system with activated pumping wells with yearly average pumping quantities, and average yearly data from precipitation and evaporation.
- activated groundwater recharge system with "summer" pumping quantities and "summer" data for precipitation and evaporation.

The established model area is located between the following extreme points in the modulated Gauss-Krüger, coordinates:

Xmin: 560 390 m	Xmax: 575 910 m
Ymin: 169 470 m	Ymax: 175 790 m

The investigated domain is 15,52 km long and 6,32 km large. The bottom surface of the model layer was determined based on a raster file that is representing the impermeable layer, which was created with the interpolation of drill holes data of the impermeable layer gathered across the area of the aquifer (Fig. 4.21).

Based on the input data the aquifer thickness stretches from 24 m on the borders to 0,1 m in the inside (Fig. 4.22).

In the groundwater flow model, the next boundary conditions were taken into account:

- the RIVER package—infiltration of river Mura; the geometry of the river bottom was determined based on measurements of the cross-sections of the river bed.;
- the recharge package—water balance of the city Gornja Radgona;
- the WELL package:

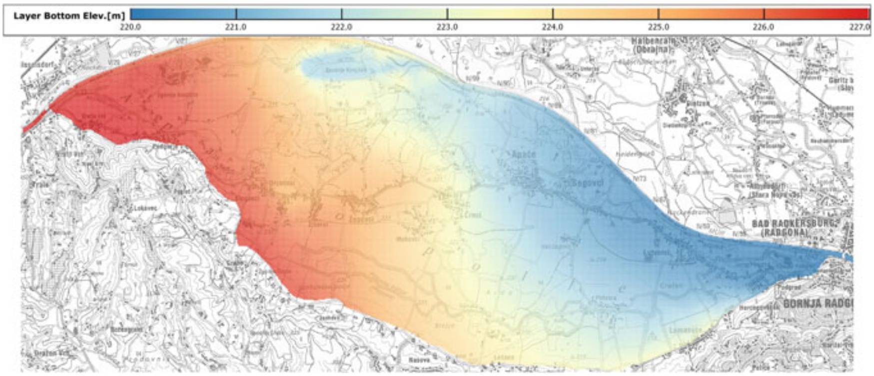

Fig. 4.21 Contour table of the height of the impermeable layer

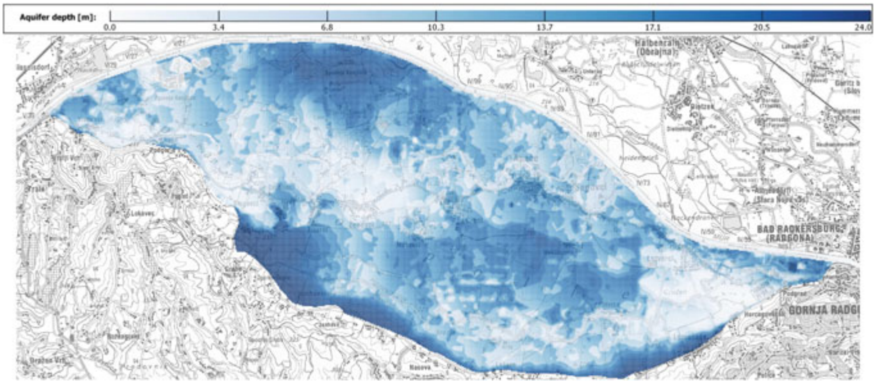

Fig. 4.22 Contour table of aquifer model thickness

- the flow of hinterland water from Slovenske gorice;
- artificial groundwater recharge system in the pumping station of Podgrad and Segovci.

4.3.6 Results of the Groundwater Flow Model

The results of the groundwater model indicated that the established MAR increased the groundwater level up to 0,7 m in the area of the infiltration ditch. The simulations indicated that the performed induced riverbank filtration with managed artificial recharge almost eliminates the influence of the groundwater extraction for the needs of the supply of drinking water and eliminates its impact on the entire groundwater system in the area of aquifer Apače field (Figs. 4.23 and 4.24).

In the master thesis (Kolar 2018), an additional analysis was done using a group of small lakes in the north-western part of the aquifer (used for fishing) as a source of possible contamination of groundwater. A flow direction analyze was done to inspect if the contaminated groundwater from the lakes will flow towards the artificial groundwater recharge system in Segovci or towards the river Mura. The flow of contaminated groundwater was observed with the MODPATH particle tracking method in 2 different scenarios:

1. Scenario (high water level): increased precipitation values, increased level of river Mura by 2 m, increased the flow of hinterland water from Slovenske gorice.

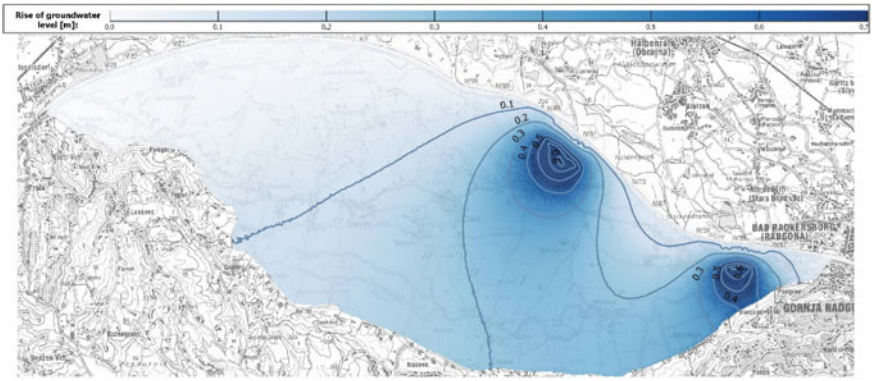

Fig. 4.23 Simulated results of the rise of groundwater after the construction of MAR (Vremec et al. 2017)

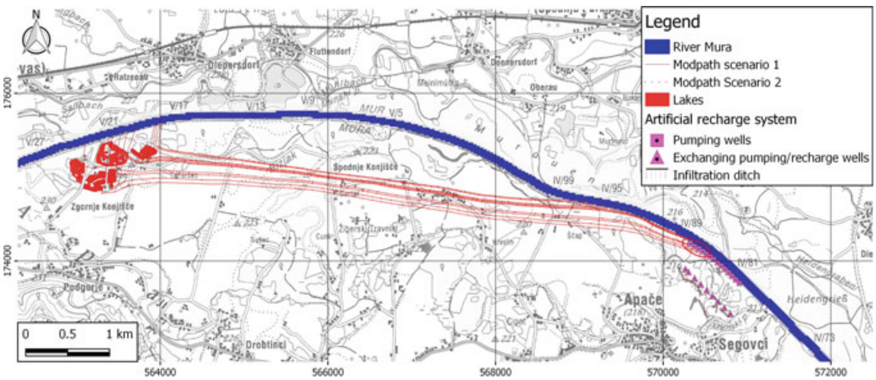

Fig. 4.24 Results of Modpath particle tracking for the simulation of Scenario 1 and 2 (Kolar 2018)

2. Scenario (low water level): decreased precipitation values, decreased level of river Mura by 2 m, decreased flow hinterland water from Slovenske gorice.

The simulations showed that in the second scenario, which simulates low groundwater levels in the summer months, the contaminated groundwater could reach the 4 most northern positioned riverbank filtrate pumping wells. In case of future contamination of the lake water, regular monitoring analyses should be included on the riverbank filtrate pumping wells.

4.4 Conclusion

Managed artificial groundwater recharge systems (MAR) coupled with induced riverbank filtration (IRBF) have proven itself as an irreplaceable contributor in the protection of the pumping station Vrbanski Plato and pumping stations Podgrad and Segovci on Apače field. Pumping station Vrbanski Plato is used as the main source for the drinking water supply in the municipality of Maribor and some and some nearby municipalities (water supply to more than 120.000). The pumping stations Segovci and Podgrad supply drinking water for the municipalities of Apače, Ljutomer, Sveti Jurij ob Ščavnici, Križevci, Gornja Radgona, Radenci, Veržej and Razkrižje (supply to more than 26.000 inhabitants). While the MAR in Segovci and Podgrad is constructed to prevent possible contamination of nitrates and recharge the aquifer in the summer months, the MAR in Vrbanski Plato is used to protect the pumping station from possible contamination from the city center and increase the overall capacity of the pumping station to maintain a constant water withdrawal throughout the year. The use of water resource management tools like FREEWAT have in both cases shown a significant role in the establishment, maintenance and optimization of an efficient MAR system with IRBF. The numerical models produced inside the FREEWAT hydrogeological environment can be used to analyze the MAR systems impact on the groundwater level, the change in the groundwater flow direction, the efficiency of the system against possible contamination and also for optimization of the MAR system to reduce the operating costs related to water pumps.

4.5 Recommendation

It was a lot of the work done as research within EU projects and give us good results. In practice, we still face a more unmanaged option, with improvisation. To get all the benefits of managed IRBF and MAR versus recent current practice this should now be upgraded to the appropriate Decision Support System (DSS) based on remote data acquisition and transmission, including GIS physically based fully distributed numerical modeling to continuously monitor and manage well fields, reducing costs and human operated activities. The DSS combining and integrating all needed measurements and the modelling environment can give operators of these systems an alert system about the scheme performance and reaching limits of infiltration rates against cost effectiveness or water quality indices.

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Part III
Water Resource Management in Croatia

Chapter 5
Groundwater Resources in Croatia

Danijel Orešić and Ivan Čanjevac

Abstract The quantity and distribution of groundwater resources in Croatia are determined primarily by hydrogeology and climate. The most important aquifers in inland Pannonia region are formed as alluvial deposits of intergranular porosity and of high hydraulic conductivity in the Sava and Drava river valleys. In Croatian karst region, the main groundwater reserves are tied to prevailing highly permeable carbonate rocks. Renewable groundwater reserves in Croatia are estimated to be 22,430 milions m^3/year, most of it (85.5% of groundwater on round 48% of the territory) in Dinaric karstic part. This points out to the importance of karstic area when considering groundwater resources in Croatia. The total water withdrawal in Croatia amounts to about 1 billion m^3 of water annually, some 40% of it being groundwater withdrawal, mostly for the public water supply. The groundwater reserves are in general not overused. However, most important aquifers are vulnerable, and locally under environmental pressure. Nevertheless, groundwater reserves are still mostly in good condition regarding their quantity and quality.

Keywords Croatia · Groundwater · Renewable reserves · Water withdrawal · Hydrogeology · Karst

5.1 Introduction

The Republic of Croatia is a middle-sized country at the south of Central Europe (Fig. 5.1), a member state of the European Union (since 2013), with a land area of 56594 km^2, and a further 31479 km^2 of interior sea waters (from coast to basic line) and territorial sea (12 nautical miles from the basic line in the open sea direction) (Croatian Bureau of Statistics 2017). According to The Census of Population, Households and Dwellings of 2011, its population was 4284889 and the official

D. Orešić (✉) · I. Čanjevac
Faculty of Science, Department of Geography, University of Zagreb,
Zagreb Marulićev trg 19, HR-10000, Croatia
e-mail: doresic@geog.pmf.hr

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Fig. 5.1 Croatia in relation to the Danube River drainage area and the Adriatic Sea drainage area (cartography by I. Rendulić)

mid-year population estimate for the year 2016 is 4174000 (Croatian Bureau of Statistics 2017).

Croatia is a crescent-shaped country, bordering with Italy, Slovenia, Hungary, Serbia, Bosnia and Herzegovina and Montenegro. Its interior or upper arm is extended along the south-southwestern rim of the Pannonian basin, mostly on the hills and plains between Drava and Sava rivers, reaching southeast to the Danube River. The Pannonian arm is mostly lowlands, but true low plains are set on its east. There are also hills in the region, as well as Pannonian island mountains, so called because they existed as islands in the ancient (Miocene and Pliocene) Pannonian Sea.

Croatia's southern half, or its lower arm, is stretching along the eastern coast of the Adriatic Sea, from the Slovenian border at Bay of Piran in the northwest, to the Montenegro border at Bay of Kotor in the southeast, excluding the 24 km long coastline section near Neum which belongs to the Republic of Bosnia and Herzegovina. This part of the country belongs to the Dinaric Alps, limestone and dolomite mountains, predominantly stretching in northwest-southwest direction (so-called Dinaric direction). The most of them are separated by karstic valleys and karstic fields elongated in the same direction. As some of the mountains are aligned in proximity to the coast, they are effectively preventing the Mediterranean climatic influences reaching further inland. Their more barren and rocky coastal mountain sides are adding to the coast's ruggedness. The coast and islands also belong to the Dinaric mountain system, formed as the outlying parts of it were partially submerged by the postglacial sea level rise. Mainland coast is round 1880 km long, for the most part highly indented. The Croatian archipelago encompasses 79 islands (> 1 km^2 in area), 525 islets, and 642 rocks and rocks awash, or a total of 1246, with additional 4398 km of coastline (Duplančić Leder et al. 2000).

5.2 Hydrogeologic Characteristics

The quantity and distribution of subsurface water in Croatia is determined primarily by geologic, and especially lithologic characteristics, as well as by climate. By its hydrogeologic characteristics Croatia is clearly divided into two completely different hydrogeologic regions: inland one, of predominantly clastic sedimentary rocks, usually referred as Pannonian (or Pannonian and peri-Pannonian) and the other being predominantly karstic, usually referred as Dinaric region (Hrvatske vode 2009). The border between those regions runs through the narrow middle section of Croatia, dividing it into two almost equal areas (Fig. 5.2). It is interesting to notice that these regions almost correspond to the two main drainage areas in Croatia, the Danube (Black Sea) drainage area and the Adriatic Sea drainage area. However, a part of the Danube drainage area is in the karstic Dinaric region, namely

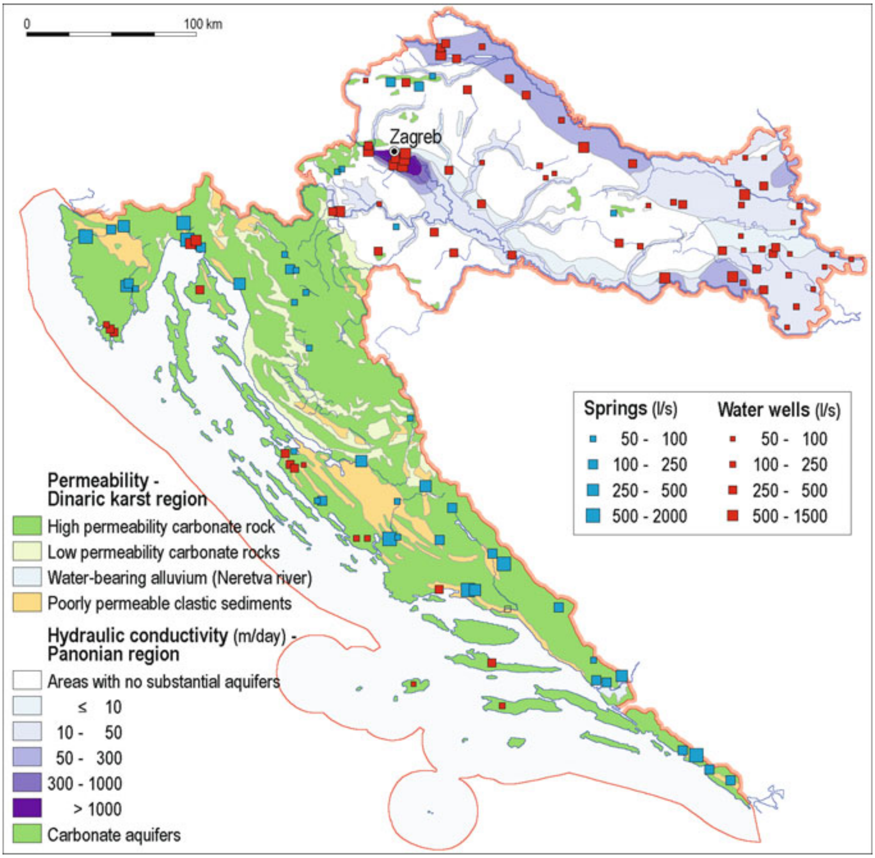

Fig. 5.2 Rock permeability, springs and wells used in public water supply in Croatia *Source of data* Hrvatske vode 2009; cartography by I. Rendulić)

the upper Kupa River basin and upper Una River basin, bringing their waters from the karst area into the Pannonian region, and into the Sava River (consult the chapter on Surface water resources and their management in Croatia).

In the Pannonian region, in continental Croatia, there are rocks of various porosity and permeability, and clastic sediments prevail. The most important aquifers here are formed as thick Quaternary deposits of intergranular porosity in the Sava and Drava river valleys. These alluvial aquifers do have some considerate differences in details, but more importantly they share a set of similar characteristics (Hrvatske vode 2016): Their alluviums are of high hydraulic conductivity, especially in the upper parts of the Sava and Drava rivers, where they are largely represented in superficial gravels. However, their conductivity and yield drop downstream as the grain size is generally reduced, and the share of fine-sized grains gets higher. Also, the aquifers further downstream are no longer unconfined, but semi-confined and confined, which also influences the way aquifers are water-fed. The aquifers are more or less continuously buried deeper downstream along the Drava River and more intermittent with some locally uplifted structures along Sava valley. The infiltration of unconfined Sava and Drava River alluvial aquifers (upstream, in the west of the region) is estimated at about 30% of average annual precipitation, whereas eastward (downstream) the semipermeable covering deposits are getting thicker, and they also widen laterally, diminishing infiltration to 10–20% of annual average precipitation. In eastern Slavonia and Baranja aquifers are also confined under the loess plateaus, and sometimes anoxic.

Beside the Sava and Drava alluvial aquifers, larger tributaries of Sava and Drava rivers have some Quaternary aquifers of secondary importance and low yields. However, in most of the area in between Sava and Drava rivers there are no productive aquifers as more fine Neogene sediments (marl, clay, mudstone, loess, sandstone) are prevailing in the lowlands and hills, and also covering the lover slopes of the Pannonian mountains. On higher parts of the Pannonian island mountains, some of pre-Neogene rocks are exposed. Those are mainly metamorphic and granitic rocks in the mountain's cores, generally considered to be of Precambrian or Lower Palaeozoic age that are raised from the crystalline basement of the Pannonian basin along the faults. To far lesser extent, there are also younger, Mesozoic formations represented by carbonate rocks. All those pre-Neogene rocks, when sufficiently fractured, act as aquifers of secondary porosity, but they generally do not yield much and may be only locally important in water supply.

The Dinaric hydrological region has an area of around 29,400 km^2 or 52% of Croatia's land area (Matas 2006). It is an area where, geomorphologically, karst relief type prevails. Karst (22,130 km^2 or 39.1% of Croatia's land area) and fluviokarst (1,772 km^2 or 3.1%) together cover 43.7% of Croatian territory (Bognar et al. 2012). The hydrology of the Dinaric karst is one of its most distinctive and recognizable elements. The Dinaric karst, in general, is an area where hydro-geomorphic phenomena were studied for the first time in the world in details and where some hydrogeological ideas were born (Prelovšek 2010). It is where rivers sink at swallow holes (known as *"ponor", singular*), dissipate into karst groundwater system, or even continue to flow as subsurface streams only to reappear at some other place. It is an area where waters can move through underground cannel systems appearing at strong karst springs (usually called *"vrilo"* or *"vrelo", sing*ular) or even as springs under the sea level (known as *"vrulja", singular*). All the classical elements of karst relief are found here (Bognar et al. 2012; Bonacci 1987, 2015), including large cave systems underground and largest surface karst features such as karst fields (flat-floored enclosed depression, known as *"polje", singular*) and karst plains (or plateaus, levelled karst surfaces formed by corrosion planation in the level of the karst water, usually called *"zaravan", singular*). Other typical features are dolinas, uvalas, dry valleys, collapsed dolinas. Because of the pure limestone that prevails, only thin non-continuous soil cover is present. Although in most of the area there is abundant precipitation, the skeletal soil and karst cannot keep it on the surface, so in general, aridity is a problem, especially on the coastal mountain sides and on the islands. With abandonment of traditional land use, especially pasture, and depopulation of certain areas during the 20th century, a natural succession occurs, and Mediterranean shrub and degraded woodlands are spreading. More inland, on higher mountain belt (Gorski kotar region) there is more precipitation, and there are more dolomites supporting a soil cover and resulting in a lush forest mountain cover.

In Croatian karst region, the main hydrologic difference occurs between the prevailing highly permeable carbonate rocks,[1] and the confined zones of impermeable or poorly permeable sediments, typically flysch sediments or Quaternary sediments of various origin covering most karst fields. Prevailing carbonate rocks are limestones and dolomites, commonly very thick (in places over 8000 m; Velić et al. 2002) and intensively karstified. The main characteristic of all karst terrain is that there are no surface watercourses, or they are rarely found. Sinking, losing and underground streamflows are typical and relatively frequent karst phenomena (Bonacci 2010). Any surface water easily drains downward through joints, cracks and fractures. While draining, water enlarges these cracks by dissolving the limestone and forming channels, caverns and cave systems. Only rarely do rivers traverse karst areas carving deep canyons, carrying enough sediments to clog the cracks and/or reaching a deeper, less karstified and less permeable or a saturated zone.

Carbonate area can itself be grouped into two hydrogeological units: high yielding very permeable carbonates, mostly limestones. Natural karst springs here regularly yield over 10 l/s, even to several tens of thousands of litres per second, if they have a large topographic and underground water-feeding area. Often there is a large difference in karst spring discharge between rainy and dry periods, as the

[1]Even pure and fractured limestone can support superficial flow if regional factors (e.g., hydrological barriers, hydraulic gradients that are too low) do not favour underground flow. Nevertheless, fully developed underground drainage is characteristic for areas with very pure limestone (those with less than 1% of impurities are abundant in Dinaric karst), with springs at relatively low elevation. At such places, subvertical drainage turns subhorizontal at water level and drains toward springs nearby, even if there is no contact with impermeable rocks (Prelovšek 2010).

underground waters are moving fast, and the karst underground can be filled and drained fast. Some springs are under the sea level and cannot be used. Pumping of water from the carbonate aquifers on coastal zone and especially smaller islands might result in sea water intrusion.

The secondary unit is comprised of carbonates of generally lesser permeability, like dolomites. The Dolomites may act as underground barriers to subsurface runoff in the karstic underground. Under weathering, unlike more soluble limestones, dolomites disintegrate on the surface into sand and gravel. This is sometimes so intensive that whole surface is covered with dolomite gravel (Mihevc 2010). Precipitations infiltrate trough this material into the karstic rock beneath, but still this sediment on the surface, as well as generally lesser permeability of the dolomites, can slow down the infiltration, and enable surface runoff. Soil and forest cover can develop. Fluviokarst, a mixture of fluvial and karst features, is typical on dolomite. On steeper relief and higher mountains fluvial features like gullies and even river valleys are to be seen, and on more levelled surfaces shallow dry valleys, uvalas and dolinas are typical, but usually, no rocks are exposed as soil covers the bedrock dolomites. In the past, fluviokarst was important as it could be more readily settled, used for agriculture, with pastures, meadows and even fields in the landscape.

Based on lithological differences, major geomorphological features and hydrological characteristics, Croatian karst can be divided into three parallel zones (Herak et al. 1969; Šarin 1984): low coastal and insular Adriatic karst, mountainous hinterland karst and low inland karst.

The low coastal and insular zone is formed mainly in Cretaceous limestones, where karst is dominant relief type, but in many cases, the homogeneity of karst is interrupted with belts of Eocene flysch rocks trending in a typical Dinaric northwest-south-easterly direction, and stimulating superficial drainage, even sometimes containing small ponds, often low lying and brackish. Largest such area is undulated Ravni kotari region (hinterland of Zadar), where low lying valuable arable flysch valleys are separated by elongated carbonate hills. A larger flysch zone is also present in the hills of inner Istria, allowing surface flow. Also common in the low coastal zone are levelled carbonate surfaces, corrosion plains (called "zaravan"), altogether very distinct relief features of the Dinaric karst, absent only in the central highest parts of the Dinaric karst (Roglić 1957). It is widely accepted that their development requires a long period of karst denudation—corrosion planation limited by water table level (Ford and Williams 2007; Bočić et al. 2015). Largest such surfaces are Zapadnoistarska (or Istarska) zaravan (West Istrian or Istrian plain) and Sjevernodalmatinska zaravan (North Dalmatian plain). As the corrosion planes where later uplifted by regional tectonics, the water table dropped and the allogeneic trough-rivers carved up canyons in them. Such are up to 150 m deep canyons of Krka, Čikola and Zrmanja rivers dissecting the North Dalmatian plain, and shallower canyons of Mirna and Raša rivers (as well as the large dry valley of Limska draga) in Istria. All of them are partly submerged at their downstream end by the Adriatic Sea, after the Holocene sea-level rise. One of the main characteristics of the low coastal and insular zone is the contact of fresh water with seawater.

Most islands are small, built of fractured carbonate rocks, mostly with only skeletal soil. Most of them are low and thus have much less precipitation than the coastal mountains. They regularly lack local fresh water resources. In the past, rain water gathering was the most important way of water supply. Only some larger islands have flysch zones and thus locally important contact springs. The largest Croatian island Cres (405.7 km^2) is an exception in providing fresh water for itself and neighbouring island of Lošinj, having a large natural freshwater lake[2] with a volume of up to 220 mil m^3. The lake is not only a significant water phenomenon for the islands of the Adriatic Sea, but for all the Mediterranean islands (Katalinić et al. 2008).

The interface between fresh and water and salt water along the coast is complex. Exemplary submarine springs or "vruljas" are found below the mountains Učka, Velebit (Fig. 5.3), Biokovo and in Stonski zaljev (Ston bay), and lots of water are lost that way. In some coastal springs, water is mixed (brackish) due to a system of crevasses, which presents a problem for water supply, especially in summer when discharges are the lowest. However, there are some strong coastal springs very important in water supply, most abundant among them being Ombla spring near Dubrovnik, with an average discharge of about 23.7 m^3/s (natural discharge was higher but reduced due to human interventions in the catchment area; Milanović 1996; Bonacci et al. 2014).

Mountainous hinterland karst zone in Croatia is predominantly deep karst on thick carbonate rocks. Some tectonic windows of Palaeozoic impervious or less permeable rocks support superficial runoff that drains into swallow holes (ponors), for example, NE of Velebit, but only in very rare cases rivers flow across this zone, like Kupa and Neretva rivers. It generally lies above 500 m amsl, and it often rises quite steeply from the coast itself: mountains Učka, Velebit or Biokovo for example. Behind karst plains (Zapadnoistarska zaravan and Sjevernodalmatinska zaravan) the rise is more gradual. The most characteristic geomorphological and hydrological phenomena in this zone are karst fields, large flat-bottomed depressions in karst.

Fully enclosed karst fields (closed poljes) are naturally inundated during the rainy winters and spring seasons (Mediterranean precipitation regime) as the high waters from saturated karstic underground flow into the field trough one or more springs, usually at the margins, at the somewhat higher end of the field bottom. One or more swallow holes (ponors) on the lower end of the field are overwhelmed and

[2]The most probable theory on the origin of the lake is that it is a karst field depression, where the Holocen sea-level rise influenced the underground flows out of the depression, and changed the former hydraulic relationships. The contemporary lake is a cryptodepression with the lowest point recorded in a funnel-like depression (likely a swallow hole zone during land phase) 61,3 m below sea level. The average lake water level is about 13 m above sea level and it functions as a freshwater lens thick enough to prevent possible seawater intrusions (Ožanić and Rubinić 1995). The present hydrologic regime is allowing yearly pumping that amounts up to 2.3 mil m^3 of excellent quality water (average of 72 l/s, but in dry months up to 160 l/s) but eventual water pumping increments must be conducted with great caution and strict control (Ožanić and Rubinić 2001).

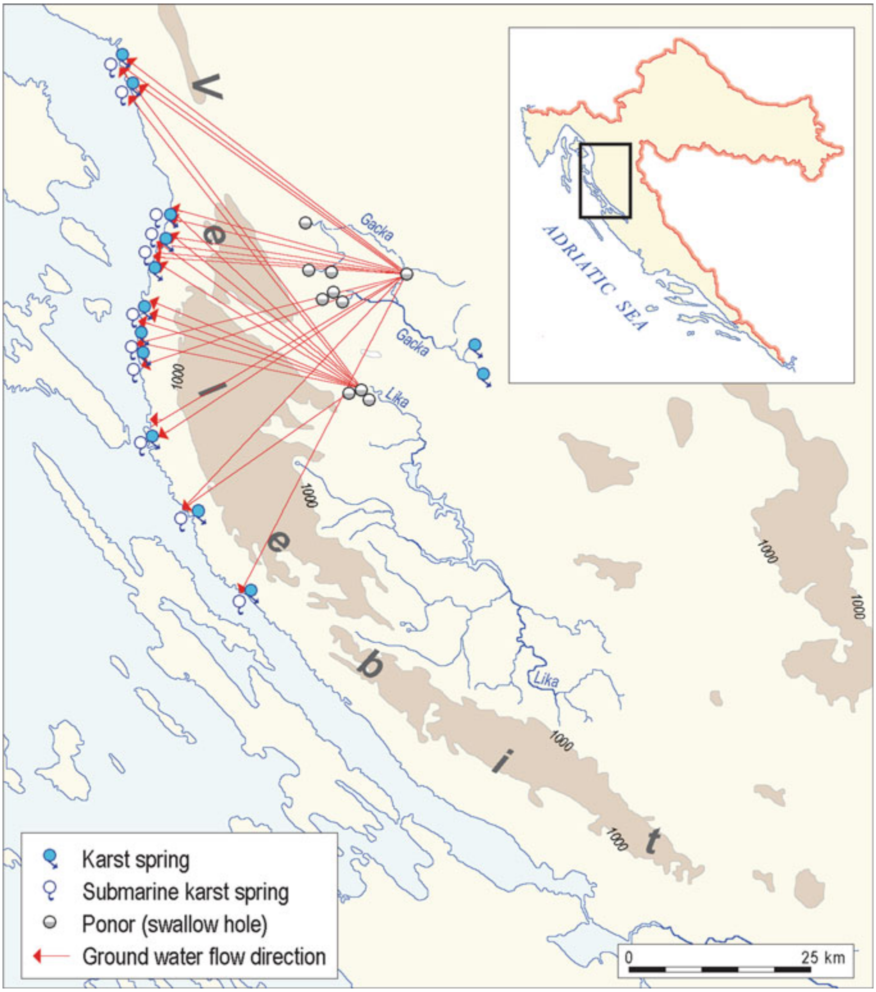

Fig. 5.3 The Lika and Gacka rivers (Dinaric karst of Croatia), typical sinking streamflows *Source* Bonacci 2010; cartography I. Rendulić

cannot drain all the waters as fast as they flow in, so a seasonal lake form. Sometimes even a swallow hole is turned into a spring during the wet season (thus acting as what is known as estavelle). Even karst fields drained by surface watercourses (open poljes) naturally flooded. However, most large karst fields where drained by surface stream regulation and underground tunnels and pipes after the WWII, some as part of the newly built HPP systems.

Among typical hydrologic phenomena like polje flooding, complex underground water flow between poljes, ponors and estavellas, there are also vauclusian karst springs. Karst springs are usually highly abundant, funnel shaped and among deepest in the world. Most prominent are Una (248 m deep), Sinjac (203 m deep), Kupa (154 m deep), Kamačnik (118 m deep) Glavaš or Veliko vrilo (115 m deep) and Krnjeza (106 m deep); depths are of latest date (DDISKF 2018), but subject to change.

The low inland karst is characterised by low elevation hills and karst plains, which can be all considered as part of a single large levelled surface between Kupa and Una rivers (Bočić 2009), thus occupying most of the inland karst area and being the largest karst plain in Croatia. This Kupa—Una karst plain lies mostly between 200 and 300 m amsl and its dissected by up to some 100 m deep canyons of Kupa, Dobra, Mrežnica, Korana and Una rivers and some smaller tributaries. Its surface is dotted with dolines and it is an example of shallow karst where saturated zone rarely exceeds 50 m, and horizontal and sub horizontal cave systems are developed (Bočić et al. 2016).

5.3 Renewable Groundwater Reserves

The renewable groundwater resources in Croatia have been estimated in the past, mostly partially by particular river basins, rarely for the whole country (Gereš 1998; Brkić and Mayer 2005). The differences where quite high, and especially between minimal and maximal estimated values. The reasons are many, mostly in relatively inadequate piezometric network and monitoring in the past. Lack of piezometric observation data is a problem continuing even to the date in most of the karstic region. However, with Croatia preparing to become EU member state (which it did in 2013), groundwater quantity estimation and quality monitoring had to be improved in Croatia in order to pursue the goals of the EU Water Framework Directive (2000). In the preparation period, the major step was to delineate and characterise groundwater bodies in Croatia, which was done separately in Danube drainage area (Brkić et al. 2005) and in Adriatic Sea drainage area (Brkić et al. 2006). A total of 461 basic groundwater bodies were determined, covering almost all of the Croatian territory,[3] out of which 363 in the Danube River drainage area and 98 in the Adriatic Sea drainage area. Since 49 basic groundwater bodies from the Danube basin are in the karstic area, this means there are 314 of them in Pannonian part and 147 in Dinaric (karstic) part of the country. After initial analyses, during the second phase, in accordance with the Groundwater Directive (2006), CIS Guidance and other relevant documents, the numerous basic groundwater bodies were grouped into groundwater bodies for monitoring, and in 2009 first reliable quality and quantity data where obtained (Biondić et al. 2009; Brkić et al. 2009) according to the internationally compatible methodology. Data where

[3]Groundwater bodies cover 55.867 km^2 out of a total of 56.594 km^2 of Croatian land area, including 11 larger islands with their own groundwater resources used in public water-supply system, or could be potentially used, in excess of 10 m^3/day).

included in the first Croatian River Basin Management Plan 2013–2015 provided by the Croatian Waters[4] (Hrvatske vode 2013). In total there are 32 (grouped) groundwater bodies assessed in Croatia, 20 in the Danube River drainage area and 13 in the Adriatic Sea drainage area. Out of 20 in the Danube basin, 5 are in karstic area, so there are 15 in Pannonian part and 18 in Dinaric (karstic) part of the country. Latest data about the state of groundwaters are found in studies from 2016 (Biondić et al. 2016; Nakić et al. 2016) and in the Croatian River Basin Districts Management Plan 2016–2021 (Hrvatske vode 2016).

In the Danube River drainage area (Fig. 5.4, Table 5.1) most of the groundwater bodies (8) are in aquifers of intergranular porosity or predominantly intergranular porosity with a considerably less share of fracture porosity (6). One groundwater body assigned to Pannonian part is in the aquifer of fracture to fracture-cavernous porosity, namely the Žumberak-Samoborsko gorje, on the edge of Dinaric Alps and largely composed from carbonate rocks, though usually considered peri-Pannonian. Other 5 groundwater bodies are undoubtedly in Dinaric part of the Danube basin, and so they are in karstic aquifers of predominantly fracture-cavernous porosity. Of all the groundwater bodies in Danube River drainage area, 66% are transboundary, meaning they are continuing in neighbouring Slovenia, Hungary, Serbia and Bosnia and Herzegovina. Many of the aquifers are bound to border rivers, like Kupa and Sutla (Slovenian border), Mura and Drava (Hungarian border), Danube (Serbian border), Sava and Una (Bosnia and Herzegovina border).

In the Adriatic Sea drainage area, the main criterion for the determination of the groundwater bodies was natural bondage between surface waters and underground waters in the karstic terrain. Exceptionally, although not connected, for practical reasons all the 11 island (basic) groundwater bodies (initially chosen for their groundwater reserves are used or could be potentially used in public water supply) are grouped in one groundwater body (Fig. 5.4, Table 5.2).

All the Adriatic area groundwater bodies are in karstic aquifers, and so all have fracture-cavernous porosity. Situated in Dinaric karst, almost half (45%) of them are transboundary bodies, leading to considerable dependency in reference to their good state. In northern Istria and in Rijeka area, those bodies are continuing into Slovenia, and in the case of groundwater bodies Krka, Cetina and Neretva in Dalmatia they are largely in neighbouring Bosnia and Herzegovina.

Renewable groundwater reserves in Croatia[5] (Tables 5.1 and 5.2) are estimated to be 22,430 millions m^3/year, out of which 9,223 millions m^3/year (41% of groundwaters on round 62% of territory) are in the Danube River drainage area and 13,207 millions m^3/year (59% of groundwaters on round 38% of territory) are in the Adriatic Sea drainage area. Referring to the partition of Croatian territory to

[4]Croatian waters (in Croatian: Hrvatske vode) is a legal entity for water management in Republic of Croatia, established by the Water Act. The institution is public, responsible for managing water and public water estate, protective and hydro-ameliorative water structures.

[5]Technically not for all of Croatia, as the groundwater quantity is estimated for all the determined groundwater bodies, and they cover 98.7% of Croatia, but the 1.3% of the left-out area consists of small islands with negligible groundwater reserves.

Fig. 5.4 Grouped groundwater bodies in Croatia *Source of data* Hrvatske vode 2016; cartography by I. Rendulić

Pannonian and Dinaric region, 3,257 millions m^3/year (14.5% of groundwaters on round 52% of territory[6]) is in Pannonian part and 19,173 millions m^3/year (85.5% of groundwaters on round 48% of the territory) in Dinaric karstic part. This points out to the importance of karstic area when considering groundwater resources in Croatia. It is worth noticing that the fresh groundwater resources on karstic islands are of great natural value, not as rich in water, but they have an invaluably significant role for the vulnerable karst underground ecosystem (Bonacci 2015).

[6]The shares of the Pannonian and Dinaric parts are in relation to the total area covered by determined groundwater bodies; it is the main reason why the given shares differ from the usually defined shares of Pannonian (48%) and Dinaric karst area (52%) in the total land area Croatia.

Table 5.1 Grouped groundwater bodies in Danube River drainage area

Groundwater body code	Groundwater body name	Porosity type	Area (km^2)	Renewable groundwater reserves (*10^6 m^3 annually)	Participating countries
CDGI-18	Međimurje	Integranular	747	113	HR/SL,HU
CDGI-19	Varaždin area	Integranular	402	88	HR/SI
CDGI-20	Bednja drainage area	Mainly integranular	724	52	HR/SI
CDGI-21	Legrad-Slatina	Integranular	2,370	362	HR/HU
CDGI-22	Novo Virje	Integranular	97	18	HR/HU
CDGI-23	Eastern Slavonia–Drava and Danube drainage area	Integranular	5,009	421	HR/HU, RS
CSGI-24	Sutla and Krapina drainage area	Mainly integranular	1,405	82	HR/SI
CSGN-25	Lonja–Ilova–Pakra drainage area	Mainly integranular	5,186	219	HR
CSGN-26	Orljava drainage area	Mainly integranular	1,575	134	HR
CSGI-27	Zagreb	Integranular	988	273	HR/SI
CSGI-28	Lekenik–Lužani	Integranular	3,444	366	HR/BA
CSGI-29	Eastern Slavonia–Sava drainage area	Integranular	3,328	379	HR/BA,RS
CSGI-30	Žumberak–Samoborsko gorje	Fracture to fracture-cavernous	443	139	HR/SI
CSGI-31	Kupa	Mainly integranular	2,870	287	HR
CSGI-32	Una	Mainly integranular	541	54	HR/BA
CSGI-14	Kupa	Fracture-cavernous	1,027	1,429	HR/SI
CSGN-15	Dobra	Fracture to fracture-cavernous	755	758	HR
CSGN-16	Mrežnica	Fracture-cavernous	1,372	1,324	HR
CSGI-17	Korana	Fracture-cavernous	1,227	870	HR/BA
CSGI-18	Una	Fracture-cavernous	1,561	1,585	HR/BA
Total Danube River drainage area		–	35,071	9,223	–
Pannonian part		–	29,129	3,257	–
Dinaric (karstic) part		–	5,942	6,966	–

Source of data Hrvatske vode 2016

Table 5.2 Grouped groundwater bodies in the Adriatic Sea drainage area

Groundwater body code	Groundwater body name	Porosity type	Area (km^2)	Renewable groundwater reserves (*10^6 m^3 annually)	Participating countries
JKGI-01	Northern Istra	Fracture-cavernous	907	441	HR/SI
JKGN-02	Middle Istra	Fracture-cavernous	1,717	771	HR
JKGN-03	Southern Istra	Fracture-cavernous	144	32	HR
JKGI-04	Rijeka bay	Fracture-cavernous	436	581	HR/SI
JKGI-05	Rijeka–Bakar	Fracture-cavernous	621	973	HR/SI
JKGI-06	Lika–Gacka	Fracture-cavernous	3,756	3,871	HR
JKGN-07	Zrmanja	Fracture-cavernous	1,537	1,683	HR
JKGN-08	Ravni kotari	Fracture-cavernous, intergranular	979	299	HR
JKGN-09	Bokanjac-Poličnik	Fracture-cavernous	302	72	HR
JKGI-10	Krka	Fracture-cavernous, intergranular	2,704	1,236	HR/BA
JKGI-11	Cetina	Fracture-cavernous	3,088	1,825	HR/BA
JKGI-12	Neretva	Fracture-cavernous, intergranular	2,035	1,301	HR/BA
JOGN-13	Islands	Fracture-cavernous	2,493	122	HR
Total Adriatic Sea drainage area		–	20,719	13,207	–

Source of data Hrvatske vode 2016

5.4 Groundwater Withdrawal

The recent overall data on water withdrawal in Croatia are presented in the 2nd River Basin Management Plan (Hrvatske vode 2016). The quantities of registered withdrawal were calculated from mandatory reports, provided by communal water supply organizations, various private concessioners and licenced individual users, containing data on water extracted at each water supply source. In the year 2012, the total registered water withdrawal (not including the hydropower withdrawal) in Croatia was calculated to be some 953 million m^3, which is equal to 222,5 m^3 of extracted water per inhabitant. Out of this, about 41% was groundwater withdrawn from water wells, further 17% was withdrawn spring-water and the rest 42% refers to water withdrawal from surface water sources, mostly rivers, much fewer reservoirs and least of all lakes.

Direct groundwater extraction (from water wells) is the most important water source in the Danube basin area, where most important aquifers are alluvial deposits, while in the Adriatic basin area, where karst prevails, the spring-water is the most important source of water (Table 5.3). It is worth noticing that in Croatia it is also in the karstic Dinaric region where surface waters are more intensely used (rivers, lakes), although they are sparse. This is to be expected considering the difficulties of direct exploitation of groundwaters (other than spring-water) and the

Table 5.3 Fresh-water registered withdrawal[1] in Croatia according to the purpose, source and area of water extraction (the year 2012)

Purpose	Source	Amount of water extracted in 1000 m^3/year		
		Danube basin area	Adriatic basin area	Croatia (total)
Public water supply (communal water supply)	Rivers	13,582	32,672	46,254
	Springs	21,553	139,734	161,287
	Reservoirs	1,465	25,398	26,863
	Natural lakes	0	2,320	2,320
	Water wells	209,474	14,552	224,026
	All sources (total)	246,075	214,675	460,749
Industrial water supply[2]	Rivers	300,644	1,605	302,249
	Springs	126	4,013	41,39
	Reservoirs	9,507	8,780	18,287
	Natural lakes	419	0	419
	Water wells	141,897	11,919	153,816
	All sources (total)	452,593	26,317	478,910
Irrigation	Rivers	10	0	10
	Springs	0	0	0
	Reservoirs	550	0	550
	Natural lakes	0	0	0
	Water wells	769	0	769
	All sources (total)	1,329	0	1,329
Other[3]	Rivers	2,280	13	2293
	Springs	2,231	254	2,485
	Reservoirs	0	0	0
	Natural lakes	0	0	0
	Water wells	7,414	227	7,641
	All sources (total)	11,925	494	12,419
TOTAL	Rivers	316,516	34,290	350,806
	Springs	23,910	144,001	167,911
	Reservoirs	11,522	34,178	45,700
	Natural lakes	419	2,320	2,739
	Water wells	359,554	26,698	386,252
	All sources (total)	711,921	241,487	953,408

Source of data Hrvatske vode 2016

[1]Excluding withdrawal in hydropower usage

[2]Water used within the manufacturing facility for preparing, conditioning, processing and producing, including water used for cooling, or transporting products. Does not include bottled water (which is included under “Other”)

[3]Bottled water, water extracted and allocated for medicinal and recreational purposes (spas, swimming pools) and water extracted and allocated for freshwater aquaculture

usual high quality of existing surface waters in the Dinaric area. As the temperate zone karst is characterised by limited surface waters, reservoirs are also important in the water supply. They are significant in securing the fresh water, especially in summer time when tourism and activities related to it are significantly amplifying the water demands, exerting peak pressures on water resources and water supply systems.

According to the purpose of water withdrawal, almost half of the total registered water withdrawal in Croatia is attributed to the needs of public water supply (460.8 million m^3/year). Groundwaters are of primary importance in high-quality mass water supply in general and in Croatia as well. Of all the water withdrawn for public water supply, 49% is extracted from water wells and additional 35% from springs, adding up to a total of 84% (or some 385 million m^3/year) referred to groundwater.

Registered withdrawal does not include extraction from individual users or groups of users extracting water according to the general freedom of water usage in Croatia. This unregistered water withdrawal includes off the grid or self-suppliers, outside of the system of public water-supply. Mostly they use spring-water, water wells and to a lesser extend rainwater collection, in many cases running individual or group (local) small waterworks. Some 16% of the total population of Croatia is not connected to the public water supply system. Using an average annual consumption of 40 m^3 of water per inhabitant, it is estimated they annually extract some 27,5 million m^3 of water (Hrvatske vode 2016). Local waterworks are important in certain rural areas in providing drinking water to the population. As they are often poorly maintained, distribution losses can be estimated as high,[7] and therefore the actual unregistered water withdrawal for household consumption is certainly somewhat higher. Most of it is groundwater, and most of it is extracted in the Pannonian region. Unregistered water withdrawal also includes a number of family farms extracting water from different sources for livestock watering and small-scale irrigation. The amount of unregistered water used for irrigation is estimated[8] at 10 million m^3 annually (much more than the registered water withdrawn for irrigation–see Table 5.3) and for livestock watering at 13.5 million m^3 water (Hrvatske vode 2016). In total, unregistered water withdrawal in Croatia amounts to at least 50 million m^3 annually (27,5 mil. m^3 household consumption, 10 millions m^3 irrigation and 13,5 millions m^3 livestock watering), and most of it can be attributed to the extracted groundwaters. Unregistered withdrawal clearly does not endanger water resources, nor groundwaters in general, however, they can exert significant pressure on them locally, especially in the case of regionally

[7]The distribution losses in small local waterworks are not known, since there is no metering but they can be assumed to be equal or more to the distribution losses in public water supply systems in Croatia. If we compare the amount of water extracted in Croatia for communal supply (460.8 mil m^3 in 2012) to the amount delivered (268.3 mil m^3 in 2012) the distribution losses are around 42% (Hvatske vode 2016).

[8]Assuming irrigation consumption of 2000 m^3 of water per hectare annually taking into account that family farms mostly grow vegetables on irrigated land, on parcels of about 0.5 hectares in size.

expressed irrigation. If added to the registered water withdrawal, the total water withdrawal in Croatia amounts to at least 1 billion m^3 of water annually.

Turning the attention back to groundwater, all the registered groundwater withdrawal can be attributed to a particular groundwater body, thus enabling a comparison to its renewable groundwater reserves (Biondić et al. 2016; Nakić et al. 2016; Hrvatske vode 2016). Expressing the (registered) groundwater withdrawal at particular groundwater body as the percentage of its renewable groundwater reserve (Tables 5.4 and 5.5, Fig. 5.5), it is obvious that most of the (grouped) groundwater bodies in Croatia are far from being overused.

The highest share of renewable groundwaters reserve being extracted is registered at Zagreb groundwater body (48,72%). This is expected as the city of Zagreb, capital of Croatia, lies there. The main contributing factor is the extraction form the Zagreb well fields (1997–2007 period average was 107 mil. m^3 annually) in the Sava River alluvial plain. It exceeds the annual renewable groundwater reserves (pumping in the same period averaged some 125 mil m^3 annually), the difference leading to the gradual depletion of permanent groundwater reserves (Bačani et al. 2010). However, this is not the only, nor the main reason for the long-term lowering of the groundwater level[9] in the Zagreb area (Nakić et al. 2013).

The most important reasons are deepening of the riverbed due to river regulation, gravel exploitation and extensive riverbed erosion, in part caused by hydropower dams in the upper part of the river basin.[10] Gravel exploitation is not limited to the riverbed, it was extensive (and partly illegal) in the Sava River alluvial plain, opening up many gravel pits and exposing the groundwater to evaporation and potential pollution. Another contributing factor to the lowering of groundwater level is the Zagreb area flooding protection system stopping occasional floods and thus infiltration to the groundwater. Finally, there is also the influence of climate changes on water budget. Unfortunately, at the same time, the groundwaters in Zagreb area are under pressure from pollutants. The groundwater quality was affected by industrial development and the growth of the Zagreb agglomeration, but also by the agricultural production in the rural-urban fringe. Researchers have identified pesticides, nitrates, potentially toxic metals, pharmaceuticals and chlorinated aliphatics as the main contaminants (Nakić et al. 2013).

Of all other groundwater bodies in the Danube River basin area, somewhat higher shares of renewable groundwaters reserve being extracted are registered in the Varaždin area groundwater body (12,05%) where there are similar problems as in Zagreb area. Varaždin area is a densely populated area, industrially developed

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[9]The analysis of the data on groundwater levels (Vujević and Posavec 2018) has shown that since the 1970's the groundwater levels have declined in the area of the Zagreb aquifer in average by 1–2 m in its western part, 2–5 m in its central part, and 1–3 m in the eastern part of the aquifer.

[10]There are 29 existing hydropower plants (HPP) in the upper part of the river basin, including a series of 8 HPP built on the Sava River in Slovenia. Those are causing significant downstream problems through disruption of sediment flow resulting in river bed incision as well as surface and groundwater level decrease (Schwarz 2016). Several more are planned in Slovenia as well as in Croatia.

Table 5.4 Renewable groundwater reserves and registered groundwater withdrawal in (grouped) groundwater bodies in Danube River drainage area

Groundwater body code	Groundwater body name	Renewable groundwater reserves (m^3 annually)	Registered groundwater withdrawal	
			in m^3 annually	as share of the renewable reserves (%)
CDGI-18	Međimurje	$1.13 * 10^8$	$6.39 * 10^6$	5.65
CDGI-19	Varaždin area	$8.80 * 10^7$	$1.06 * 10^7$	12.05
CDGI-20	Bednja drainage area	$5.20 * 10^6$	$2.13 * 10^6$	4.10
CDGI-21	Legrad-Slatina	$3.62 * 10^8$	$8.83 * 10^6$	2.45
CDGI-22	Novo Virje	$1.80 * 10^7$	0	0
CDGI-23	Eastern Slavonia–Drava and Danube drainage area	$4.21 * 10^8$	$2.23 * 10^7$	5.30
CSGI-24	Sutla and Krapina drainage area	$8.20 * 10^7$	$7.44 * 10^6$	9.07
CSGN-25	Lonja–Ilova–Pakra drainage area	$2.19 * 10^8$	$3,48 * 10^6$	1.59
CSGN-26	Orljava drainage area	$1.34 * 10^8$	$3.83 * 10^6$	2.86
CSGI-27	Zagreb	$2.73 * 10^8$	$1.33 * 10^8$	48.72
CSGI-28	Lekenik–Lužani	$3.66 * 10^8$	$3.51 * 10^6$	1.00
CSGI-29	Eastern Slavonia–Sava drainage area	$3.79 * 10^8$	$1.60 * 10^7$	4.22
CSGI-30	Žumberak–Samoborsko gorje	$1.39 * 10^8$	$3.77 * 10^6$	2.71
CSGI-31	Kupa	$2.87 * 10^8$	$1.19 * 10^7$	4.15
CSGI-32	Una	$5.40 * 10^7$	$3.42 * 10^5$	0.63
CSGI-14	Kupa	$1.43 * 10^9$	$1.61 * 10^6$	0.11
CSGN-15	Dobra	$7.58 * 10^8$	$1.10 * 10^6$	0.15
CSGN-16	Mrežnica	$1.32 * 10^9$	$3.70 * 10^6$	0.28
CSGI-17	Korana	$8.70 * 10^8$	$0.38 * 10^6$	0.04
CSGI-18	Una	$1.59 * 10^9$	$1.17 * 10^6$	0.07

Source of data Hrvatske vode 2016

and with extensive agricultural production, especially in the Drava River alluvial plain, so there are high demands for water. The natural hydrogeologic regime in the region was significantly affected by the construction of the dams of the hydro-electric power plants ("Varaždin" in 1975, "Čakovec" in 1982, and "Dubrava" in 1989). Groundwater levels upstream of their dams, surrounding their reservoirs, have permanently increased and the groundwater level fluctuations have diminished (Grđan and Kovačev-Mrinčić 1992). Although the renewable groundwater reserves are not at risk at Varaždin area groundwater body, their quality is affected by

Table 5.5 Renewable groundwater reserves and registered groundwater withdrawal in (grouped) groundwater bodies in Adriatic Sea drainage area

Groundwater body code	Groundwater body name	Renewable groundwater reserves (m^3 annually)	Registered groundwater withdrawal	
			in m^3 annually	as share of the renewable reserves (%)
JKGI-01	Northern Istra	$4.41 * 10^8$	$18.3 * 10^6$	4.16
JKGN-02	Middle Istra	$7.71 * 10^8$	$4.98 * 10^6$	0.65
JKGN-03	Southern Istra	$3.15 * 10^7$	$1.3 * 10^6$	4.08
JKGI-04	Rijeka bay	$5.81 * 10^8$	$1.17 * 10^6$	0.20
JKGI-05	Rijeka–Bakar	$9.73 * 10^8$	$24.16 * 10^6$	2.48
JKGI-06	Lika–Gacka	$3.87 * 10^9$	$8.99 * 10^6$	0.23
JKGN-07	Zrmanja	$1.68 * 10^9$	$19.3 * 10^6$	1.15
JKGN-08	Ravni kotari	$2.99 * 10^8$	$3.63 * 10^6$	1.21
JKGN-09	Bokanjac-Poličnik	$7.24 * 10^7$	$10.06 * 10^6$	13.88
JKGI-10	Krka	$1.24 * 10^9$	$20.47 * 10^6$	1.65
JKGI-11	Cetina	$1.83 * 10^9$	$55.63 * 10^6$	3.05
JKGI-12	Neretva	$1.30 * 10^9$	$13.18 * 10^6$	1.01
JOGN-13	Islands	$1.22 * 10^8$	$3.22 * 10^6$	0.26

Source of data Hrvatske vode 2016

nitrates, due to the agricultural production. However, the nitrate concentration at the well fields in system of aquifers is not exceeding the maximum admissible concentration, except at the Varaždin well field, where the concentration has been heightened for several decades (Kovač et al. 2017).

Among the groundwater bodies in the Adriatic drainage area highest share of renewable groundwaters reserve being extracted is registered at Bokanjac-Poličnik groundwater body (13,88%). This groundwater body is situated in Ravni kotari region mainly in the hinterland of the city of Zadar. The groundwater reserves there are water-fed by locally infiltrating rainwater and thus not very abundant. On the other hand, water demands are relatively high. The needs are not limited to the propulsive city of Zadar, but also to the many tourist settlements on the coastal strip and to the agriculture in Ravni kotari region, one of the most important agrarian zones in the coastal Croatia (Šiljković et al. 2000). The water supply of the coastal part of the Zadar region is based on the Zrmanja River, from beyond Ravni kotari, but there are several water intake sites in the local Bokanjac-Poličnik groundwater body. Since this area is close to the Adriatic Sea coast, some of these water supply sites are subjected to the underground seawater influence. Although currently not overused, the groundwater body has been found in risk from the combined saltwater intrusion and decreases of recharge due to the climate changes (Terzić et al. 2015; Biondić et al. 2016).

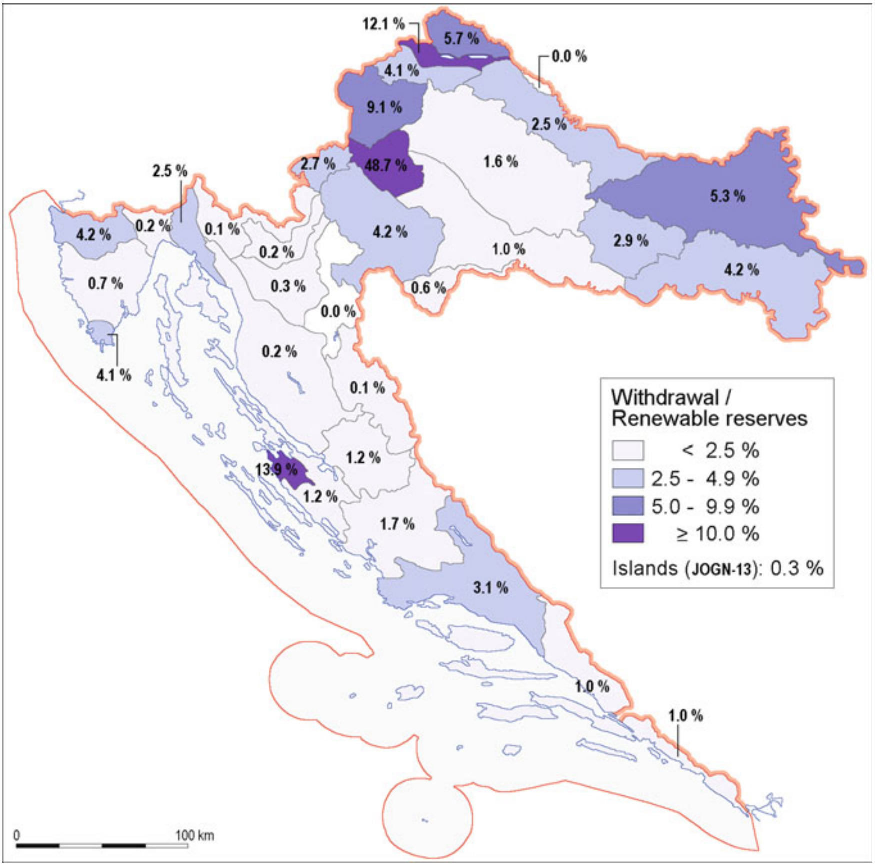

Fig. 5.5 The share of registered water withdrawal in renewable groundwater reserves at groundwater bodies in Croatia *Source of dat*a Hrvatske vode 2016; cartography by I. Rendulić

5.5 A Strategic View on Groundwater Reserves

In order to protect the groundwaters from mounting pressures, and in order to improve planning on their utilisation in accordance with the principles of sustainability, groundwater reserves in Croatia where assessed strategically into four orders (Fig. 5.6; Hrvatske vode 2009).

Strategical groundwater reserves of the first order are those in karst aquifers (Gorski kotar, Lika and Dalmatian hinterland), water-fed from drainage basins entirely inside Croatia, and of high groundwater quality. Groundwater reserves of the second type are made up of groundwaters from Drava and Sava alluviums, naturally of somewhat lower quality, and which are harder to protect as they are in the areas of intense development and utilisation.

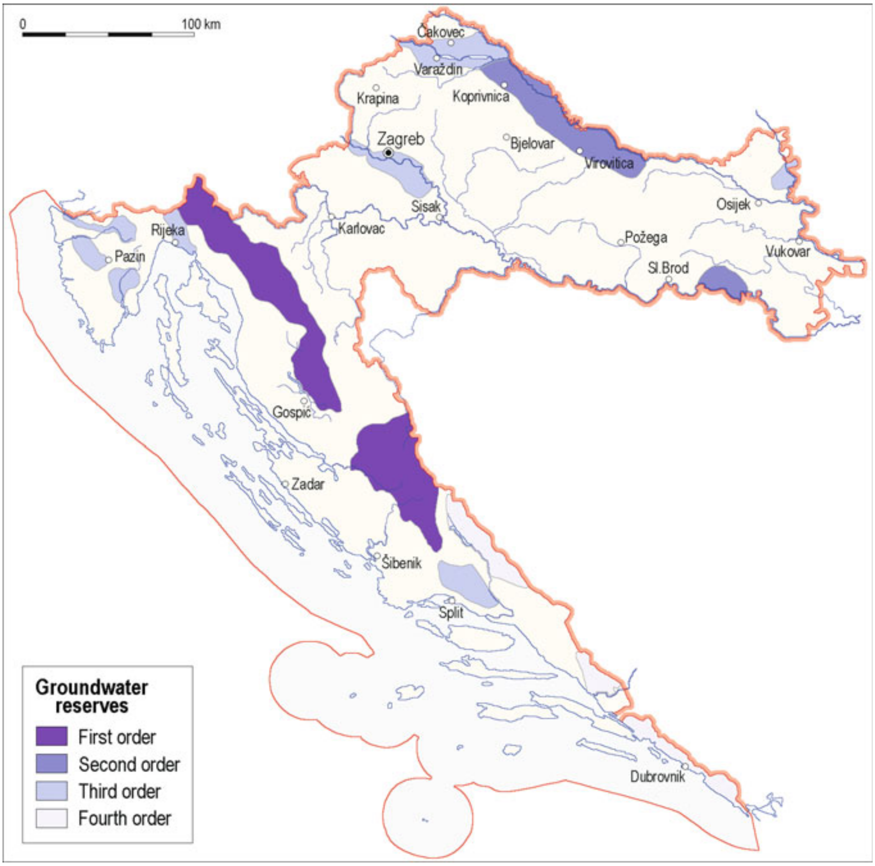

Fig. 5.6 Strategical groundwater reserves in Croatia *Source* Hrvatske vode 2009; cartography by I. Rendulić

The third order groundwater reserves are in areas of high pressures on groundwaters, where the groundwater is intensely used, even overused, and so the groundwater quality is endangered. Those are situated in main urban areas (Zagreb, Osijek, Rijeka, Split) and in some other areas of diverse pressures (upper Drava valley and Istrian peninsula), and they are hardest to protect. There is a possibility that some of the intake structures feeding on those reserves may in future be excluded for municipal water supply. Therefore, their protection is pivotal in all future planning. Strategical groundwater reserves of the fourth order are found in groundwater abundant karst aquifers in middle and south Dalmatia, of high groundwater quality, but their drainage areas are mostly outside Croatian boundaries, hindering their direct protection and making them strategically vulnerable.

5.6 Conclusions and Recommendations

The relative abundance and rather good quality of water resources in Croatia, and of groundwater resources, in particular, can be misleading if not considering the vulnerability of the very best aquifers and their water resources and if not taking into the account that a considerable portion of the groundwater resources is shared with neighbouring countries. In the water rich karst underground water moves fast trough fissures, fractures, channels and caverns but equally so could potential pollutants. Karst waters can be easily polluted, and the natural auto purification is very poor in the absence of clastic rocks acting as filters. Large parts of karst groundwater bodies are in neighbouring countries, so this adds to the problem as there is a considerable degree of dependency. A fair share of renewable groundwater resources is found in the Pannonian region as well, but they are also vulnerable. Namely, primary aquifers are the alluvial aquifers in Drava and Sava river valleys, best of them being unconfined, exposed to the surface. Those valleys, in particular, are densely settled, this is where some of the largest settlements in inland Croatia are situated, and those valleys are hosting most important axis of transportation (Sava valley being internationally important transport corridor). Moreover, they are agriculturally important too, and Drava River is used in hydropower. In large stretches both Sava and Drava rivers are border rivers with transboundary aquifers. It can be concluded that the most important inland aquifers are under environmental pressure. They are still mostly in good condition regarding their quantity and quality. In order to manage groundwater reserves in a sustainable way it is higly important to protect and preserve them.

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Chapter 6
Water Quality Status of Croatian Surface Water Resources

Lidija Tadić, Marija Šperac, Barbara Karleuša and Josip Rubinić

Abstract The Croatian territory is divided into two big river basins. The continental part of the country belongs to the Danube River Basin, and the coastal area is part of the Adriatic Sea Basin. These two basins have completely different hydrological, topographical and geological characteristics including the vegetation cover as well. Related to their geographical diversities, pressures on water quality are also different. In the continental part of the country the main threats come from diffuse pollution of agriculture and farming. The Adriatic coast is mainly karst region vulnerable to any pollution. Besides the basic geographical characteristics, impacts on water quality depend on the significance of anthropogenic activities and sizes of catchment areas. Smaller rivers are more exposed to pollution of any kind than large rivers. Croatian lakes are also exposed to different sources of pollution. In recent time, climate change has also had some impact on water quality during periods of low discharges. Many scientific papers on surface water quality have been published during the last decades. Also, implementation of the Water Framework Directive, the Nitrate Directive, and national strategies has significantly decreased the pollution of surface waters. Much effort has been made in establishing a very extensive monitoring network together with legislation and measures to improve water quality status. Water quality is continuously improving as a result of comprehensive activities, especially the construction of sewage water treatment plants. In this chapter, the status of water quality of small rivers, large rivers and lakes in Croatia will be described.

L. Tadić (✉) · M. Šperac
Faculty of Civil Engineering and Architecture Osijek, Josip Juraj Strossmayer University of Osijek, Osijek, Croatia
e-mail: ltadic@gfos.hr

M. Šperac
e-mail: msperac@gfos.hr

B. Karleuša · J. Rubinić
Faculty of Civil Engineering, University of Rijeka, Rijeka, Croatia
e-mail: barbara.karleusa@gradri.uniri.hr

J. Rubinić
e-mail: jrubinic@uniri.hr

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Keywords Water quality · Small rivers · Large rivers · Lakes

6.1 Introduction

The area of the Republic of Croatia is 56 566 km^2 with a population of 4 284 889 inhabitants (2011). The total national territory belongs to the Danube River basin (62%) and the basin of the Adriatic Sea (38%) (Fig. 6.1a) (Croatian River Basin Management, CRBM 2016–2021). The total length of open watercourses is 67 500 km, and the total area of natural lakes is 167.1 km^2. According to Croatian legislation, water quality protection and improvement are among the most important activities in national water management. Main activities include stopping further deterioration of water quality, protection, and improvement of water ecosystems, promotion of sustainable water management and reduction of pollution emission (Kurečić et al. 2015).

The Danube River Basin has a large surface water potential with watercourse network density of 0.3 km/km^2 (considering only watercourses with catchments larger than 10 km^2) and density of 1.6 km/km^2 (considering all watercourses) (Fig. 6.1b). Estimation of average annual total water resources, for the period 1960–1990, is about 84*10^9 m^3, or 27 000 m^3/year/person, or ¾ of the total national water potential.

The Adriatic Sea Basin has a poor surface water network, but significant groundwater resources in the karst region (Fig. 6.1). The average annual total water budget is about 28*10^9 m^3, or 20 100 m^3/year/person (1960–1990) (Croatian Water Management Strategy 2009).

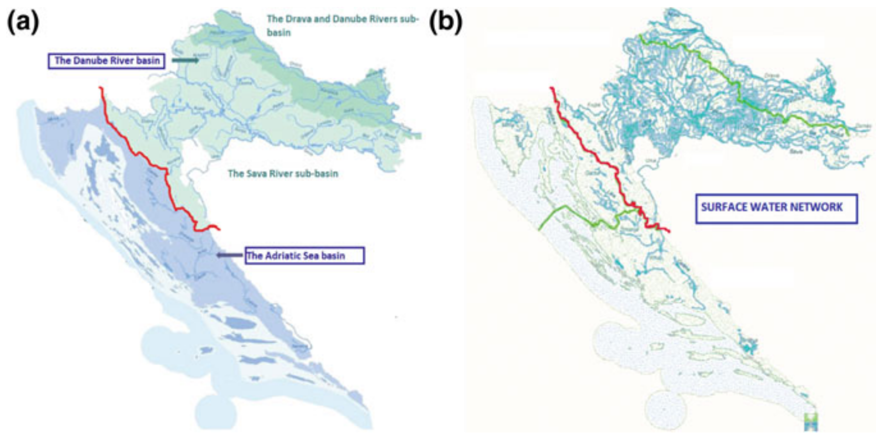

Fig. 6.1 **a** Division of Croatian territory into two large Basins (CRBM 2016–2021). **b** Surface water network of Croatia (CRBM 2016–2021)

After 2013, the national legislation related to water was harmonized with the European directives, first of all, the Water Framework Directive. This includes the adoption of River Basin Management Plans. Their major tasks are water protection and improvement of water chemical and ecological status in a certain period. At this moment, a plan for the period 2016–2021 is active based on the reference year 2012 (CRBM 2016–2021).

Within this paper, on a global scale, a recent state of the water quality of rivers and lakes on the territory of Croatia is presented. For some selected rivers and lakes more detailed presentation of water quality is given that characterizes the observed processes of change in water quality on a longer time scale, caused by anthropogenic impacts and pressures, as well as changes related to natural processes in aquatic systems and above all the climate change/variations. In all selected localities, the same water quality parameters (BOD_5, COD, and nitrate and phosphorus content) were analysed.

6.1.1 Water Quality Status of Croatian Rivers

A comprehensive and reliable monitoring network is essential for obtaining water quality status and efficiency of the applied measures. There are also scientific monitoring projects with specific targets which are not included in the regular national monitoring system (Coordination of Water Monitoring Programme 2016).

In the reference year, 2012, water quality was observed at 321 sampling stations on rivers with catchments larger than 10 km^2, reservoirs (artificial lakes) and natural lakes with an area larger than 10 km^2. In the Danube River Basin, there were 246, and 75 stations in the Adriatic Sea Basin.

Ecological characteristics of surface water depend on many factors, natural and anthropogenic. Due to geographical diversity, surface water typology has been introduced together with water quality evaluation considering its deviation from type-specific reference values.

Rivers of the Danube River Basin (80% of the total surface water network) are divided into 18 types. However, rivers of the Adriatic Sea Basin (20% of the total surface network) are divided into 17 types, which shows a very rich ecological and morphological diversity (Table 6.1).

Table 6.1 Typology of surface waters (CRBM 2016–2021)

	Danube River Basin	Adriatic Sea Basin	Republic of Croatia
Watercourses—total length (km)	56 858.123	7 869.040	64 727.168
Characterised surface water body type > 10 km^2 (km^2)	10 611.940	2 272.484	12 884.430
Not characterised surface water body type > 10 km^2 (km^2)	110.220	48.241	158.263
Number of types	18	17	25

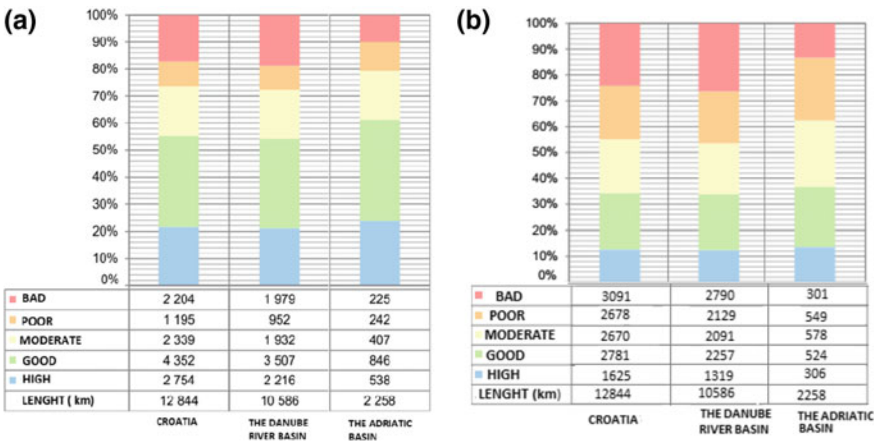

Fig. 6.2 **a** River quality status evaluated on the basis of physicochemical parameters (BOD5, total nitrogen—N and total Phosphorus -P) (CRBM 2016–2021). **b** Ecological river status (CRBM 2016–2021)

Water quality status has been evaluated on the basis of physicochemical parameters (BOD_5, total nitrogen—N and total phosphorus-P) and specific pollution compounds. More than 70% of the total watercourse length had those parameters evaluated as good or high (Fig. 6.2a), (CRBM 2016–2021).

Generally, water quality status of surface water in the Adriatic Sea Basin, according to organic pollution and nutrients, is much better compared to the Danube River Basin. The most common indicator of bad physicochemical status is a high concentration of total phosphorus (Barbalić 2015).

However, ecological surface water status is much worse, because it includes physicochemical, chemical, hydromorphological and biological quality elements (Fig. 6.2b). On the national level, 25% of the total river length has no satisfactory ecological status due to the problem related to the quantity and dynamics of water flow, connection to groundwater body, river continuity, etc. (CRBM 2016–2021).

6.1.2 Water Quality Status of Croatian Lakes

The natural lake typology was done for the lakes with an area larger than 0.5 km^2. Most of them are situated in the Adriatic Sea Basin and only two in the Danube River Basin. In total, they are divided into 6 types (Table 6.2).

Physico-chemical status of lakes is defined only on the basis of total phosphorus concentrations (observed in 2012). Most of the lakes in the Adriatic Basin do not fulfill the prescribed standards (Fig. 6.3a) (CRBM 2016–2021).

Table 6.2 Typology of natural lakes (CRBM 2016–2021; Grizelj Šimić 2016)

	Danube River Basin	Adriatic Sea Basin	Republic of Croatia
Total area of lakes, fishponds and swamps type > 0.5 km^2 (km^2)	124.76	40.13	164.89
Total number of lakes, fishponds and swamps > 0.5 km^2	33	4	37
Characterised surface water body type > 0.5 km^2 (km^2)	1.34	40.13	41.47
Number of types	2	4	6

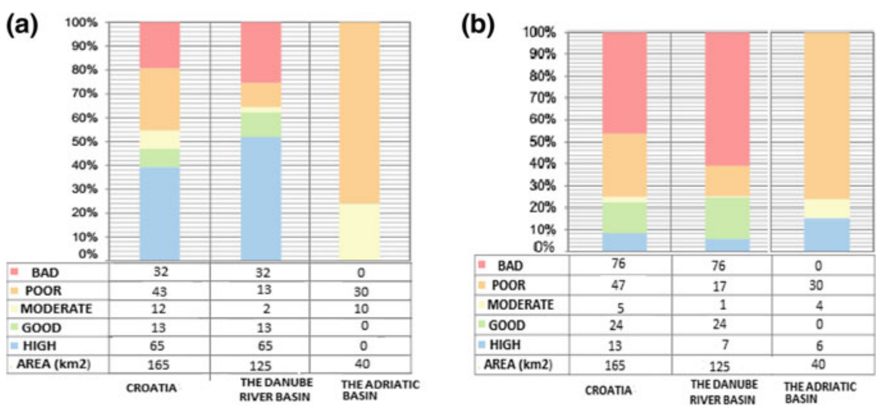

Fig. 6.3 **a** Lake physicochemical status evaluated on the basis of total Phosphorus-P (CRBM 2016–2021). **b** Ecological lake status (CRBM 2016–2021)

The ecological status of natural lakes integrates biological, physicochemical, chemical and biological parameters. This evaluation has a rather low level of confidence because there is not much data of biological status (except for the lakes in the Adriatic Sea Basin) (Fig. 6.3b) (CRBM 2016–2021).

6.1.3 *Water Quality Pressures*

Water quality status is under a continuous and direct effect of human activities causing diffuse and point pollution of different sources. Also, in some coastal lakes in the Adriatic Sea Basin that are crypto-depressions and where the karstic aquifers which fill the lakes are connected to the sea, occurrences of increased salinization are more frequent. It is a result of the sea level rise and the reduction of natural inflows.

6.1.3.1 Point Pollution

The main point pollution sources are sewage systems which discharge sewage water directly into the environment. Indicators of pollution originating from these sources are BOD_5 and COD, and nutrients: total N and total P. Pollution can be from industry as well and in that case-specific compounds are monitored. In Croatia, only 35% of the population is connected to urban wastewater treatment facilities. Still, about 50% of the population has no connection to the urban sewage system. Wastewater of these settlements is treated as diffuse pollution (Fig. 6.4a), (CRBM 2016–2021). In the Danube River Basin secondary wastewater treatment prevails, with the removal of about 50% of organic pollution, 25% of nitrogen and 17% of phosphorus. In the Adriatic Sea Basin the preliminary level of wastewater treatment dominates with much lower efficiency of removal of organic matter (10%), nitrogen (5%) and phosphorus (3%) (Fig. 6.4b).

6.1.3.2 Diffuse Pollution

Diffuse pollution is hard to quantify due to catchment characteristics (size and slope), hydrological regime (precipitation intensity and frequency), vegetation cover, soil properties and complex relationships among them. Generally, the most common diffuse pollution sources are wastewater of settlements without sewage systems, agricultural fields, roads and farms, (CRBM 2016–2021).

Diffuse pollution originating from agriculture is usually stressed as the most significant. In the Republic of Croatia, total consumption of mineral fertilizers was 421,915 tonnes in 2012, with active matters of N, P_2O_5, and K_2O. Also, the application of pesticides contributes to the deterioration of water quality status. In 2012, 2 025 tonnes of different pesticides were applied on agricultural fields, (CRBM 2016–2021).

In the last few years, there have been a number of measures implemented to improve water quality status—construction of urban wastewater facilities, reduction of fertilizers applied on agricultural fields, improving monitoring network, the definition of water quality standards, etc. In the following sections, the results of these measures will be presented and discussed.

6.2 Water Quality Status of Water Bodies in the Danube River Basin

In the Danube River Basin (rivers, reservoirs and natural lakes) there are 246 water quality sampling stations, (Barbalić et al. 2017). During the period of the last 20 years, many scientific papers have been published about surface water quality. Most of them have dealt with basic physical, chemical and microbiological

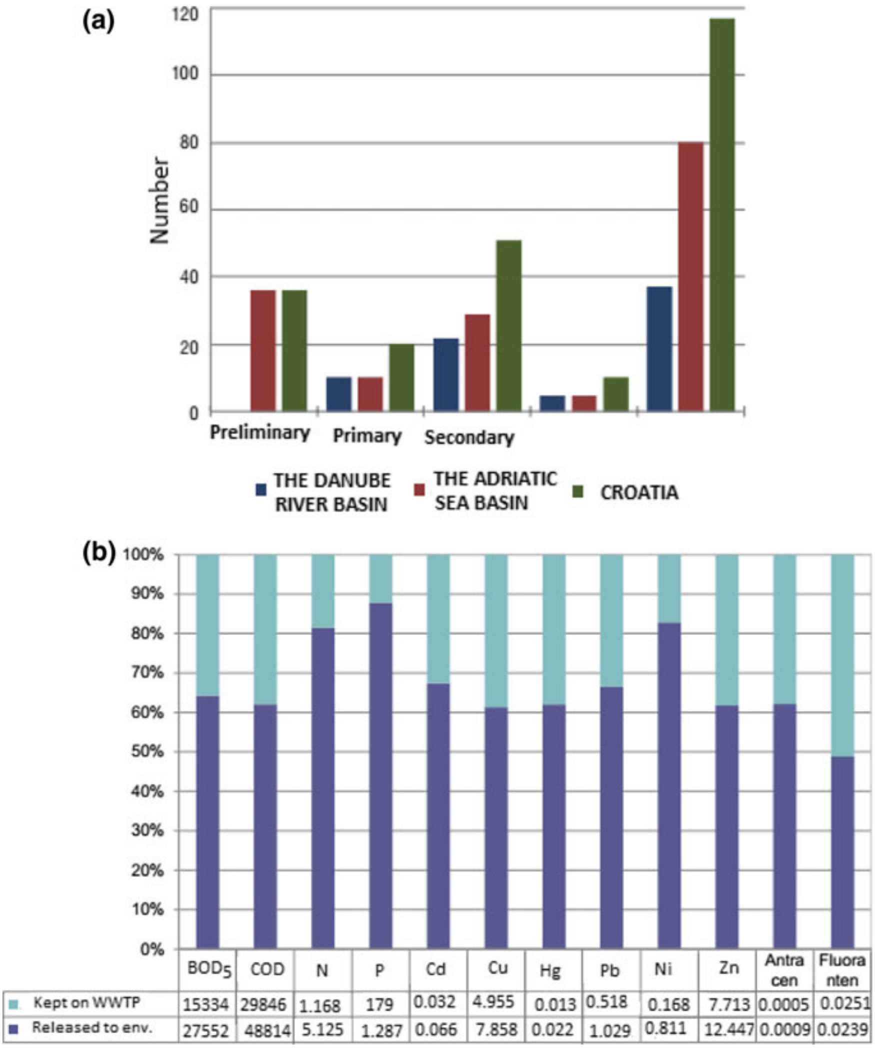

Fig. 6.4 **a** Number of wastewater treatment plants in 2012 (National Environmental Report 2014). **b** Pollution compounds kept by wastewater treatment plant (WWTP) and released into the environment (t/year), (CRBM 2016–2021)

parameters of water quality, but there are also investigations of specific dissolved trace elements, macro elements, or biological parameters. The first important conclusion of many investigations is that water quality of any watercourse highly depends on the geographical characteristics of the catchment area (slope, size, shape, precipitation regime, vegetation cover, soil properties, geological structure, etc.). The second conclusion is extremely significant water quality dependance on human impacts (population density of the area, industry, agriculture, etc.).

Furthermore, there are a number of papers dealing with processes related to climate change: increasing of air temperature, and frequency of extreme hydrological events, droughts and floods, and their impacts on water quality status. Water temperature, as one of the most important physical characteristics of surface water, strongly affects all other physical, chemical and biological processes in the river system and the water-air temperature relationship is very strong. For example, changes in water temperature along the Kupa, Sava, Drava and Danube Rivers measured in Croatia during the last 20–60 years have been confirmed. Also, there is evidence of increasing minimum and mean annual water temperatures of the Danube River and its main tributaries in Croatia (the Kupa, Sava, and Drava Rivers) started in 1988, (Bonacci et al. 2008; Tadić et al. 2011).

In the following sections some research results related to the water quality status of the small/medium and large rivers, natural lakes and artificial reservoirs in the Danube River Basin will be discussed.

Figure 6.5 presents locations of the analysed water bodies. They are all situated in the continental part of Croatia and belong to the Danube River Basin. The most important characteristic of this area is a large portion of agricultural land which significantly affects water quality status.

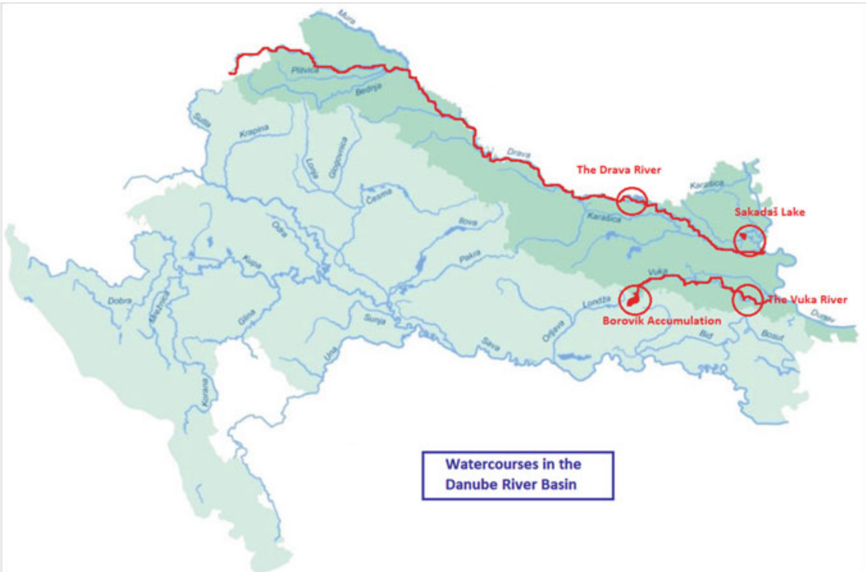

Fig. 6.5 Rivers and lakes representative for the Danube River Basin

6.2.1 Small and Medium Rivers

The most vulnerable are small rivers, due to their small discharges and contribution of drainage water collected by surface and subsurface drainage system of the agricultural land.

According to Dragun et al. (2011), the Sutla River, a river of medium size, mostly forming the state border between Croatia and Slovenia. Its discharge in 2009 varying between 0.73 and 68.8 m^3 s^{-1} is endangered by several sources: smaller industrial capacities, thermal bath water from the neighbouring spa, household wastewater and a diffuse source of water contamination by agriculture. Although metal concentrations still have not exceeded the limits considered as hazardous for aquatic life or eventually for human health, the observed prominent increases of both metal concentrations and bacterial counts in the river water should be considered as a warning. The presented results emphasize the incidence of increased water contamination in the rivers with a low dilution capacity, even under moderate anthropogenic influence. This is a problem of general significance, since it may be equally represented in any small or medium watercourse in the world, (Dragun et al. 2011).

An example of two small rivers, the Karašica and Vučica Rivers, is very interesting from the water quality point of view because they flow through the area with intensive agricultural production. Munjko et al. (1980) were researching the content of eutrophic salts in the water of those two rivers during the period between 1972 and 1980. They obtained mostly satisfactory water quality with the occasional pollution coming from the distaff industry. Downstream sections of the rivers had significant organic and inorganic pollution. Chemical oxygen demand (COD) was between 5 and 105 mgO_2/l and biological oxygen demand (BOD_5) between 1.4 and 26 mgO_2/l. The Vučica River had mild alkaline water (pH between 7.4 and 8.1), COD was 6–22 mgO_2/l, BOD_5 was 3–7 mgO_2/l, and the concentration of phosphates was increased, (Munjko et al. 1980).

Vidaček et al. (1999) were researching concentrations of nitrates, heavy metals and herbicides in the soil, surface, and groundwater during 1997 and 1998. The nitrate concentration varied depending on fertilizing intensity, precipitation, and drainage functioning and nitrate crop consumption. Nitrate concentrations were between 0.56 and 5.06 mg NO_3^-/100 g of soil and regularly higher on the plots of land with the more intensive application of nitrogen fertilizers. The surface and groundwater occasionally exceeded the maximum allowed concentrations, with the highest obtained value of 126 mg NO_3^-/100 l, (Vidaček et al. 1999).

Compared to the previous investigations, a recent analysis of the Karašica and Vučica rivers water quality (2000–2015) showed improvement. The concentration of chemical oxygen demand (COD) was less than 5 mg O_2/l, biological oxygen demand (BOD_5) less than 5 mgO_2/l and nitrates less than 3 mgN/l on the most downstream sampling station, (Amić and Tadić 2018).

The Vuka River (Fig. 6.5), also situated in the Danube River Basin in the mostly agricultural area, has similar geographical and hydrological features. The most

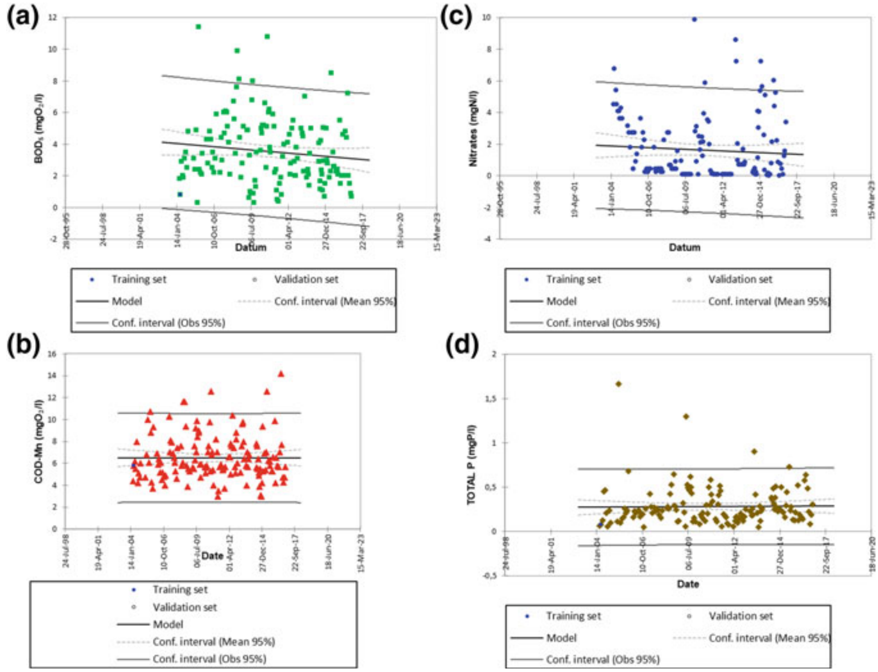

Fig. 6.6 Linear regression with a five years' prediction period of the Vuka River water quality parameters, **a** BOD_5, **b** COD, **c** nitrates and **d** total P

important sources of pollution are mineral fertilizers, coming from fields and occasionally uncontrolled effluents from farms. In the river catchment, there is no significant industry or manufacture. A linear regression analysis with a prediction period of five years were applied on the available data series (1995–2016). BOD_5, COD, nitrates and total phosphorus (P) concentrations shows an insignificant decreasing trend of nitrates (Fig. 6.6c) and no trend of BOD_5, COD and total P (Figs. 6.6a, b, d). The trend existence has been checked by the Mann-Kendall test and the seasonal Mann-Kendall test, and the only difference in results between these two tests is in the nitrate concentration. The seasonal trend does not exist, which is an important conclusion because the nitrate concentration in surface water is much higher in winter and rainy periods when leaching from the surrounding area becomes intensive.

6.2.2 Large Rivers

Large rivers, such as the Drava, Danube, and Sava, have a more extensive monitoring schedule with a wider data set of analysed parameters. It is also worth mentioning a problem of the monitoring schedule. On the whole territory of Croatia, the monitoring schedule is regulated by law. The number of water quality gauging stations, the frequency of water sampling and a number of analysed parameters depend on the river size and its importance. A problem occurs due to the fact that the natural water regime does not correlate with regular water sampling. Very often the results of water quality monitoring can lead to the wrong conclusions because samples were taken during the extreme discharges. Of course, increasing of monitoring intensity can overcome this problem. Besides, monitoring with a specific purpose as a part of scientific research gives us valuable information about specific types of pollution and processes which generate them.

The largest Croatian river is the Sava River. The study of total dissolved trace metal concentrations in the surface water of the Sava River in Croatia in the period from March to June 2006 were published. There are presented the highest levels of total dissolved metals for Fe, Mn, and Zn (12.6 ± 7.8 μg L^{-1}, 3.44 ± 3.95 μg L^{-1}, and 2.27 ± 1.53 μg L^{-1}, respectively), the intermediate concentrations for Ni, Cu, and Cr (0.59 ± 0.14 μg L^{-1}, 0.54 ± 0.14 μg L^{-1}, and 0.32 ± 0.06 μg L^{-1}, respectively), and the lowest levels for Co, Pb, and Cd (0.064 ± 0.022 μg L^{-1}, 0.055 ± 0.051 μg L^{-1}, and 0.011 ± 0.004 μg L^{-1}, respectively). For four trace metals (Mn, Pb, Zn, and Fe), the high temporal variability within one season was observed, (Dragun et al. 2009). However, the study proves that according to the levels proposed by European regulations, concentrations of the total dissolved trace elements are not significantly above the natural level.

These results were proved a few years later by Maldini et al. (2011) and their research of ecotoxic metals of the bordering rivers, Danube, Drava, Dragonja, Kupa, and Sava, in the period between 2008 and 2010 [16]. Besides, chemical indicators of organic pollution (COD-Mn, BOD_5, and TOC) of the Sava River showed lower water quality in the upstream sections than in the downstream river sections, (Tomas et al. 2011).

Investigation of a large number of pollutants that belong to the group of pesticides and pharmaceuticals which are not regulated by law, at 11 sampling stations along the Sava River showed their presence, (Repac et al. 2015). The limit values of these pollutants are not defined, which makes them potentially very dangerous.

Another research of the large river water quality was undertaken on the Drava River, in the lower Drava region. The main goal was to analyse 13 physicochemical and microbiological parameters of the Drava River water at three sampling sites, over two distinct periods: the pre-war period between 1985 and 1992 and the post-war period between 1993 and 2008. Over both periods, most parameters were kept within the tolerable water quality limits, while NO_3-N, NH_4-N, and BOD_5 were higher. The lower Drava showed slight organic pollution with high concentrations of dissolved oxygen. High levels of total coliforms and heterotrophic bacteria in the post-war period were only found downstream of the town of Osijek, whereas upstream of Osijek the river showed a tendency for improvement, (Gvozdić et al. 2011).

The most part of the Drava River (Fig. 6.5) is a bordering river between Croatia and Hungary and a water quality monitoring system is part of the Transnational

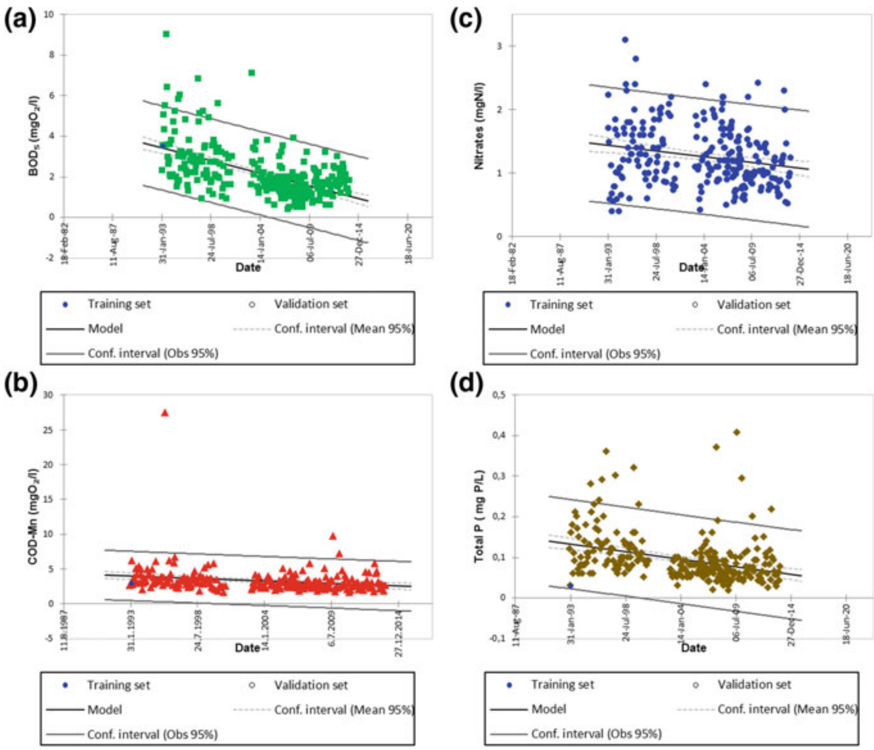

Fig. 6.7 Linear regression with a five years' prediction period of the Drava River water quality parameters, **a** BOD_5, **b** COD, **c** nitrates and **d** total P

Monitoring Network. Urban and industrial sewage systems mainly pollute the Drava River water without wastewater treatment plants. There are still a few towns and villages along the Drava River without constructed wastewater treatment plants. However, some towns have wastewater treatment plants which do not fulfill EU standards and have only a mechanical stage of treatment. A linear regression analysis with a prediction period of five years applied on the available data series (1982–2013) of BOD_5, COD, nitrates and total phosphorus (P) concentrations shows a decreasing trend of all parameters (Figs. 6.7a–d). The trend in existence has been checked by the Mann-Kendall test and the seasonal Mann-Kendal test. Their application on water quality parameters shows an even higher decreasing trend especially BOD_5. The overall analysis suggests that generally water quality of the Drava River improves regarding its self-purification abilities. It is more significant during high water periods and larger discharges.

6.2.3 Lakes and Reservoirs

In the continental part of Croatia belonging to the Danube River Basin, there are not many natural lakes, except the well-known Plitvice Lakes that have since 1979 been on the UNESCO's World Heritage List. These lakes are formed on tufa barriers of the high karst that are not typical for the Danube Basin, but for the Dinaric ecoregion, so Sakadaš Lake has been chosen as a representative lake. However, there are many artificial lakes/reservoirs built to ensure enough water for irrigation water and improve flood protection.

One of the natural lakes in the Danube River Basin is part of the Kopački Rit wetland. It is Sakadaš Lake, the deepest lake in the complex wetland ecosystem of the Kopački Rit Nature Park (on the Ramsar list of wetlands of international importance since 1993). The improvement of water quality and a decrease in eutrophication were registered in the period from its revitalisation (controlling wastewater and sediment removal) till the beginning of 1991. However, investigations during 1997 and 1998 proved high eutrophic to the hypertrophic condition of Sakadaš Lake, (Mihaljević and Novoselić 2000). Since then, activities on nutrient reduction have been undertaken, which can be seen in Figs. 6.8c, d. First of all, application of fertilisers on the surrounding agricultural land has been reduced and drainage water entering the lakes is less polluted. According to linear regression analysis, nitrate and total phosphorus concentrations have decreasing trends. Biochemical parameters, BOD_5 and COD also decrease due to the construction of sewage systems and wastewater treatment plants in the surrounding villages (Figs. 6.8a, b). Analyses were done for the data obtained close to the bottom (1 m above the bottom) and they are generally worse than samples taken just below the surface.

In the continental part of Croatia belonging to the Danube River Basin, there are many multi-purpose artificial lakes/reservoirs. They have been constructed primarily as a part of the flood protection system. Their other purposes are irrigation, sports and recreation, hydropower production, fishing and providing minimum discharges during droughts.

One of the artificial lakes in the area is reservoir Lapovac and research of its water quality started in 1997 to define its ecological status. Water samples were taken on a monthly basis between May and October at two sampling sites. The results showed a significant concentration of nutrients and the possibility of fast eutrophication, (Mihaljević 2000). Similar results were obtained in reservoir Borovik. Data series sampled in the period 2000–2016 and statistically analysed shows similar results as in natural Sakadaš Lake. Nutrients are decreasing, BOD_5 as well, only COD concentration has no significant trend (Figs. 6.9a–d). Reservoir Borovik is surrounded by forest, and there is no agricultural land in its vicinity. So, most of the pollution originates from leaf decomposition, which is a natural process.

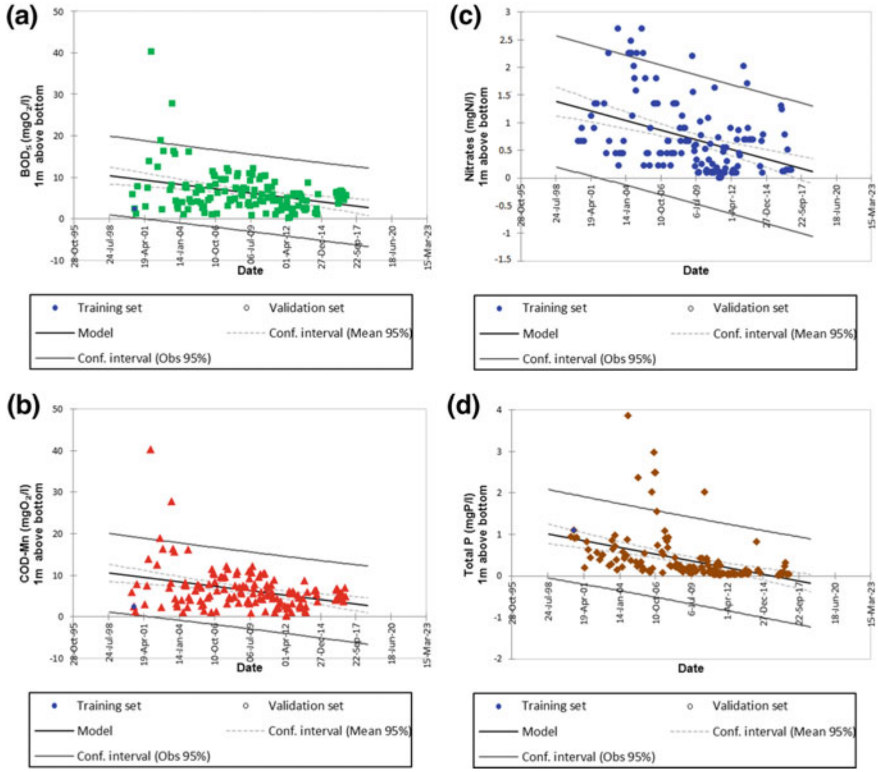

Fig. 6.8 Linear regression with a five years' prediction period of the Sakadaš Lake water quality parameters, **a** BOD_5, **b** COD, **c** nitrates and **d** total P

6.3 Water Quality Status of Water Bodies in the Adriatic Sea Basin

In the Adriatic Sea Basin two natural geographical units are distinguished: Dinaric mountainous area and Adriatic area. The Dinaric mountainous area consists of the highest Croatian mountains (1,800 m amsl.) and karst fields among them. It is made of carbonate rocks with typical karst hydrogeology. Along the surface and subterranean watercourses, a multitude of canyons, gorges, caves, and barriers have been created. The Adriatic Sea Basin is part of the Dinaric karst, and it is made up of islands and a narrow strip of land, separated from the interior by high mountains. Mountains, peninsulas, and islands are mostly made of limestone rocks, while lower areas are made of less resistant and impermeable deposits of flysch and dolomites, (CRBM 2016–2021).

The Adriatic Sea Basin because of its karstic characteristics is poor with surface waters (Fig. 6.10), but there are significant groundwater flows. The majority of

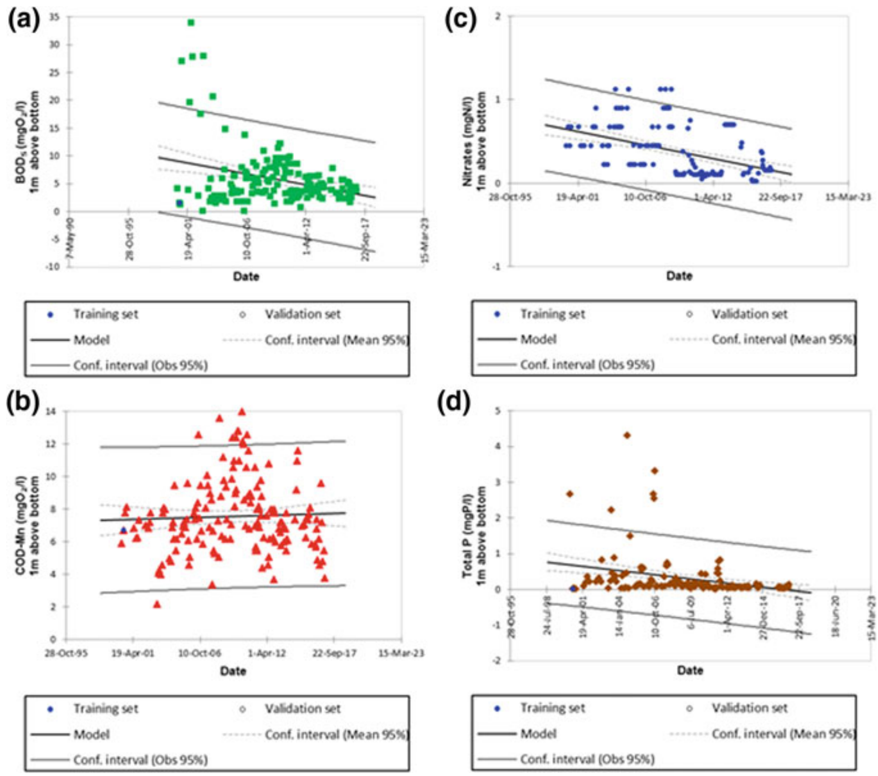

Fig. 6.9 Linear regression with a five years' prediction period of the Borovik reservoir water quality parameters, **a** BOD_5, **b** COD, **c** nitrates and **d** total P

precipitation percolates deep into the karstic ground up to the impermeable layers where it forms the groundwater reserves. There are also numerous karst springs. Watercourses are formed in areas where karstic phenomena are less expressed, that is in alluvium and flysch areas and where the groundwater circulation is not very deep. On islands, there are mostly no surface waters except occasional torrents or small springs. The only exceptions are Vransko Lake on Cres Island, Jezero Lake and reservoir Ponikve on the island of Krk, and two saltwater lakes on Mljet Island. In the coastal areas, there are many coastal springs and "vruljas"—submarine springs, (CRBM 2016–2021).

Main rivers in the Adriatic Sea Basin are: Dragonja, Mirna, Raša, Boljunčica, Rječina, Lika, Gacka, Zrmanja, Krka, Cetina, Neretva and Ljuta, Jadro and Ombla, natural lakes are: Vransko Lake near Biograd, Vransko Lake on Cres Island, Baćina Lakes (6 lakes, near Ploče), Prokljan Lake and Visovac Lake on the Krka River, Jezero Lake on the island of Krk, Red and Blue Lakes (near Imotski), and the most significant artificial lakes/reservoirs are: Butoniga, Bajer, Kruščica, Štikada, Peruča, Đale, Pranjčevići, Ričice, and one reservoir on the island of Krk, Ponikve.

Fig. 6.10 Rivers and lakes representative for the Adriatic Sea Basin

Between the coastal sea and the mainland, there are transitional waters (160.7 km^2) and coastal waters (13 750 km^2). The seawater impact is present on mouths of the rivers Neretva (with 50% of the area of transitional waters in Croatia), Zrmanja (23%), Krka (14%), Cetina (10%), Dragonja, Raša, Mirna, Rječina, Jadro and Ombla, (CRBM 2016–2021). In the following sections, some research results related to the water quality status of the rivers, natural and artificial lakes in the Adriatic Sea Basin will be discussed. Figure 6.10 presents locations of the water bodies that are analysed in more detail.

6.3.1 Small and Medium Rivers

Table 6.3 presents monitoring data for the year 2012, as a reference year for water quality status assesment, for several small and medium rivers in the Adriatic Sea Basin. The most important rivers are: the Dragonja River (total catchment 141 km^2, in Croatia 55.6 km^2, total length 26 km, in Croatia 12 km), the Raša River (catchment area 279 km^2, length 23 km), the Rječina River (total catchment area

Table 6.3 Water quality status of main small and medium rivers in the Adriatic Sea Basin based on monitoring data collected for 2012, (CRBM 2016–2021)

Water quality status	The Dragonja River	The Rječina River	The Raša River	The Gacka River	The Mirna River
Average annual discharge (m^3/s)	1.3	12.9	1.6	13.3	7.91
Biological status	Moderate to bad	Moderate	Poor	No data	Moderate to poor
BOD_5	High	High	High	High and good	Mostly good
Total N	High	High and good	Mostly moderate	High	Mostly high
Total P	High	High and good	Good and moderate	High and good	High and good
Specific pollutants	Good	Good	Good	Good	Good
Hydromorph. status	Good	Varies from high to bad	Varies	Mostly good	Varies from high to bad
Ecological status	Poor	Varies from high to bad	Mostly moderate and poor	Mostly moderate	Mostly moderate and poor
Chemical status	Good	Good status not achieved on part of water course	Good status not achieved on most part of water course	Good status not achieved on part of water course	Good status not achieved on parts of water course

360 km^2, in Croatia 300 km^2 with the length of 19 km), the Gacka River (catchment area 584 km^2, length 61 km) and the Mirna River (catchment area 541 km^2, in Croatia 494 km^2 with the length of 53 km), (CRBM 2016–2021).

The most northern river of the Adriatic Basin on the border with Slovenia is the Dragonja River, (CRBM 2016–2021). Surface water quality of Dragonja was deteriorating due to the lack of sewage systems and development of intensive agricultural activities in the nearby vineyards [22, 23]. The analyses of the chemical status of the water in the period 2002–2006 at monitoring station Podkaštel have shown the good chemical status of water, (Brilly and Globevnik 2003).

Water from the source of the Rječina River is used for drinking water supply of the town of Rijeka. The only quality parameters at the source that do not meet the quality of water for human consumption are microbiological parameters, and occasionally, during rainy periods, the increase in turbidity, (Ambrožič et al. 2008).

The water of the Gacka River at the source is of high quality and used for drinking water supply. There is an increase in the content of organic and nutrient substances, microbiological pollution as well as the concentration of anionic detergents as the result of wastewater disposal from the treatment plant of Otočac town, (Water and Sea Protection Study of Lika-Senj County 2004).

The largest river on the Istrian peninsula is the Mirna River, (CRBM 2016–2021). The water of the Mirna tributaries Butoniga, Dragući Stream and Račički stream fills the artificial lake Butoniga that is used for water supply and flood protection. In the Basin, there are significant karstic springs Sv. Ivan, Bulaž, and Gradole that are also used for drinking water supply.

Results of data analyses from three water quality monitoring stations on the Mirna River (Mirna upper part of a watercourse, Mirna-Kamenita Vrata, Mirna—Portonski most, the lowest station) from 1997 to 2003 are presented in paper, (Rubinić et al. 2006).

The quality of water of the Mirna River depends on the hydrological conditions in the Basin. During rain occurrence, the water quality changes very fast, with the increase in turbidity and almost all other parameters, (Rubinić et al. 2006). Bacteriological parameters are high during rainy periods. High COD and BOD_5 values of the Mirna River have been occurring periodically from August to October, depending on the occurrence of the high content of suspended soils caused by a sudden increase in flow during rainy periods and increased overflow of springs in the Mirna River Basin.

The upper part of the Mirna River in the summer months dries out, so after the summer drought the nutrients content and bacteriological pollution increase so the quality of water is degraded according to biological indicators. The middle part of the Mirna River (station Kamenita Vrata) is below the town of Buzet and the wastewater treatment plant and has the worst water quality. Nitrogen and phosphorus values at Kamenita Vrata station vary and are caused by the disposal of treated wastewater of the town of Buzet. The impact of wastewater on the quality of the Mirna River is most evident from August to the beginning of autumn rains when the hydrologic conditions improve. The lower part of the Mirna watercourse (station Portonski most) because of a number of tributaries is of better quality than the middle part. Generally, nitrogen values were mostly under 2 mgN/l, while phosphorus values indicate the anthropogenic impact on water quality, (Rubinić et al. 2006).

Analysing data presented in Fig. 6.11 about parameters BOD_5, COD, nitrates, and phosphorus collected by Croatian Waters during measurement at the lowest monitoring station Portonski most for the period 2000–2016 it can be concluded that the quality of water has improved recently because all trends BOD_5, COD, nitrates and phosphorus are slowly declining. The improvement is the result of an increased number of wastewater treatment plants (for small settlements) in the Mirna River Basin, but also because of measures stated in (Irrigation Plan of Dubrovnik-Neretva County 2006), that support organic farming, which means production without the use of fertilisers, pesticides, hormones and similar products.

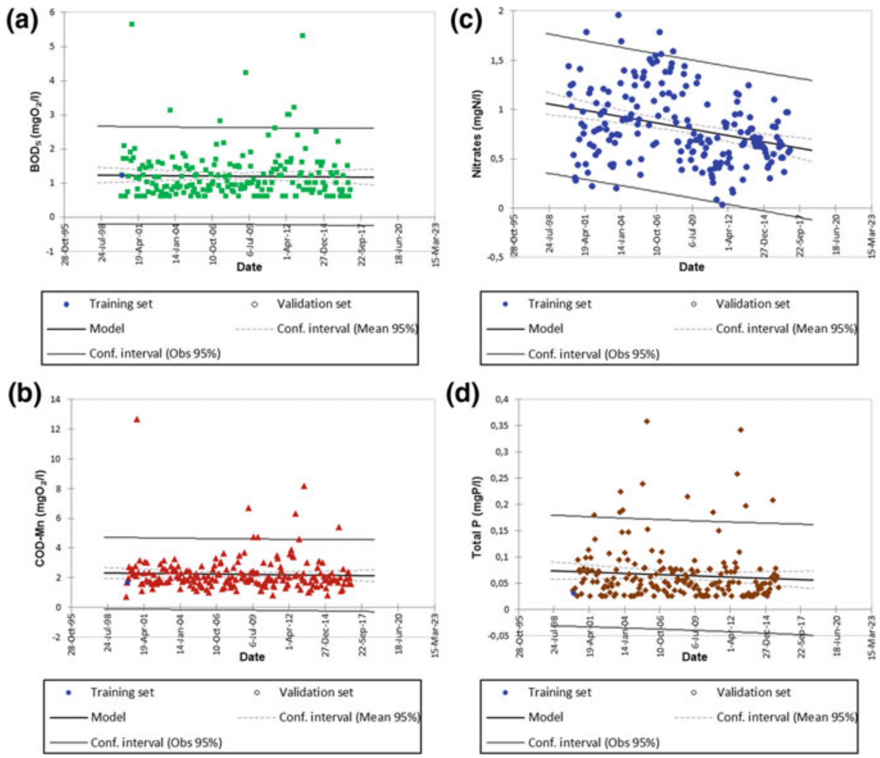

Fig. 6.11 Linear regression with a five years' prediction period of the Mirna River water quality parameters, **a** BOD_5, **b** COD, **c** nitrates and **d** total P

6.3.2 Large Rivers

The largest river in the Adriatic Sea Basin is the Neretva River, with a catchment of 10 520 km^2, but only 22 km of total 215 km of the river length is in Croatia; most of the catchment area (95%) is in Bosnia and Herzegovina. Within the catchment, there are many karstic springs and rivers, (CRBM 2016–2021). In the lower part of the watercourse, there is a strong influence of the sea, (Rubinić 2011).

The other rivers with catchments of more than 1 000 km^2 (but less than 10 000 km^2) are Lika, Zrmanja, Krka, and Cetina, (Štambuk et al. 2006).

The quality status of the Neretva, Lika, Zrmanja, Cetina and Krka rivers is presented in Table 6.4.

The Krka River water quality status will be discussed in more detail. Its spring is near Knin, and the mouth is in Šibenik. The catchment is 2,657 km^2; the whole watercourse is 72 km. It is used for hydropower production. It is known by tufa barriers, and the part of watercourse up to Skradin is a national park, (CRBM 2016–2021). The ecosystem of

Table 6.4 Water quality status of large rivers in the Adriatic Sea Basin based on monitoring data collected for 2012, (CRBM 2016–2021)

Water quality status	The Neretva River	The Lika River	The Zrmanja River	The Cetina River	The Krka River
Average annual discharge (m^3/s)	342	7.33	37	99	54.6
Biological status	Poor	Varies from good to poor	High to moderate	Mostly good and moderate	Mostly good and moderate
BOD_5	Good	High and good	High	Mostly high	High
Total N	Moderate	Mostly high	Mostly high	Mostly high	Mostly high
Total P	–	Varies from high to bad	Mostly high and good	Mostly high and good	Mostly high and good
Specific pollutants	Good	Good	Good	Good	Good
Hydromorph. status	Poor	High to bad	Mostly high and good	Varies from high to bad	Varies form high to good
Ecological status	Poor	High to bad	High to bad	Varies from high to bad	Varies form high to bad
Chemical status	Good	Good	Good	Good	Good

the Krka River is very sensitive to anthropogenic impacts. The water quality in the Krka Basin is monitored at 7 stations, (Štambuk et al. 2006).

Data of parameters BOD_5, COD, nitrates and total phosphorus collected by Croatian Waters during measurement at the most downstream monitoring station Skadinski Buk on the Krka River in the period 2000–2016 are presented in Fig. 6.12. The authors concluded that all four analysed water quality parameters (BOD_5, COD, nitrates and total P) have a descending trend. Since many values of parameters were lower than the detection threshold, their value was replaced with the value of the threshold.

6.3.3 Lakes and Reservoirs

The lakes and reservoirs in Croatia that are located on the Adriatic coast have very diverse characteristics of water quality that originate from their natural features (their formation, hydrogeological conditions, hydrological conditions, connection with the sea) and anthropogenic impact on the Basin. As an example of natural lakes of the Dinaric ecoregion, Vransko Lake at Biograd was selected. It covers an area of about 31 km^2 and is the largest lake in Croatia. It is a lake where earlier

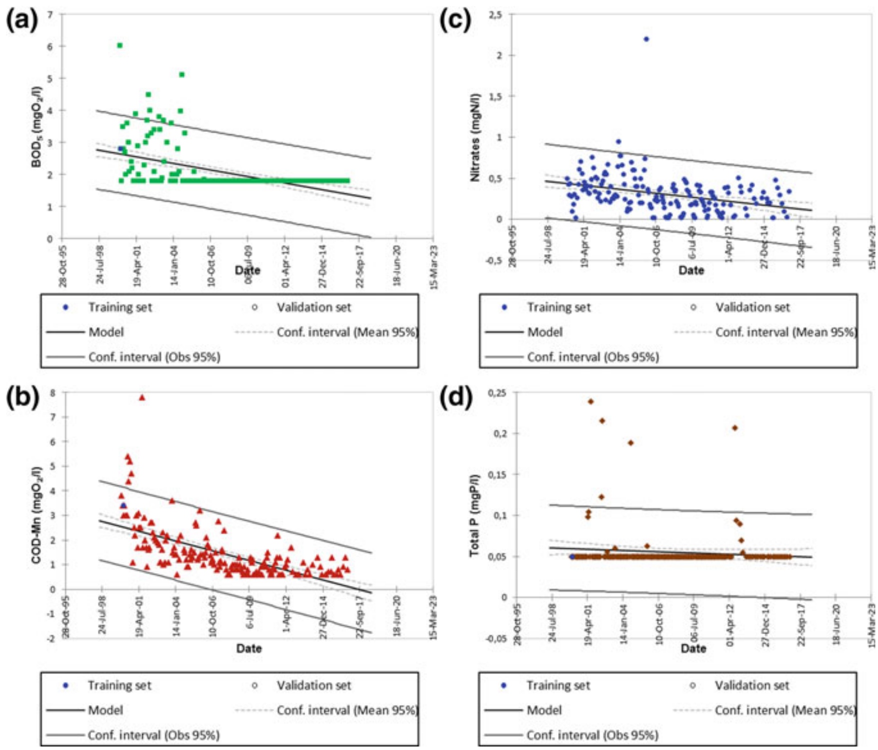

Fig. 6.12 Linear regression with a five years' prediction period of the Krka River water quality parameters, **a** BOD_5, **b** COD, **c** nitrates and **d** total P

standardized chemical indicators of water quality (Fig. 6.13) show stagnation (BOD_5 and COD), nitrate content shows a decreasing trend, while total phosphorus content shows increasing trend. Besides, in the period 2011–2013, exceptionally high values of those parameters were recorded in the lake system. They were caused by extremely low levels of water in the lake, reduced discharges and intrusion of the seawater into the lake. Therefore, in these years not only the chloride content, with an increase of over 8.0 mg/L, changed significantly compared to an average of about 1.0 mg/L (Rubinić and Katalinić 2014), but also negative changes in other quality elements occurred, (Tomas et al. 2013). It is a sensitive system of the shallow coastal lake, which was included in the Ramsar list of wetlands of international importance in 2013. Critically dry hydrological conditions with increased water temperatures induce the process of eutrophication and the creation of anoxic conditions in the lake (Katalinić Bach et al. 2017), death of fish as well as significant changes in the structure of the ichthyofauna, (Mustafic et al. 2017). Vransko Lake is an example of an aquatic system in Croatia where the negative consequences of the present climate change/variation are already intensively manifested, intensified by anthropogenic pressures, above all the influence of agriculture in Vransko polje.

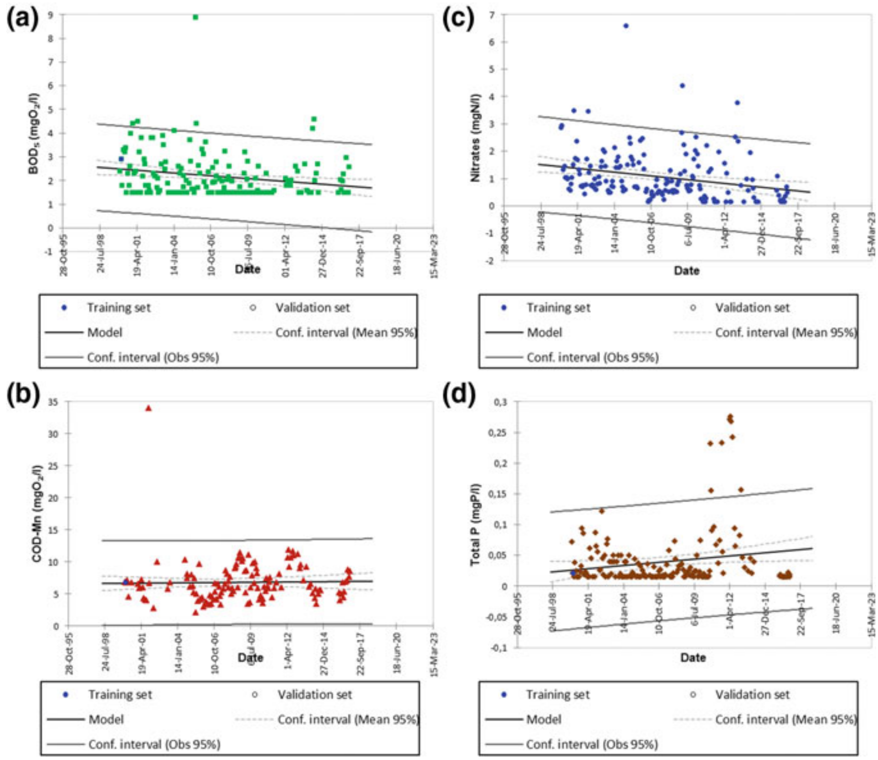

Fig. 6.13 Linear regression with a five years' prediction period of the Vransko Lake water quality parameters, **a** BOD_5, **b** COD, **c** nitrates and **d** total P

Most of the artificial lakes/reservoirs in the Adriatic Sea Basin were built in the 1950s and 1960s with a priority to be used for hydropower function. Due to their volume and exchange of water, most of these hydroelectric reservoirs have no problems with water quality assurance, and some of them are also used for water supply as water intended for human consumption. Butoniga artificial lake is an example of a multi-purpose reservoir that is designed to provide water for human consumption, flood protection, and irrigation, but because of water balance problems, it is not used for irrigation. The relatively young and shallow reservoir is formed on the watercourse Butoniga, (Hajduk Černeha et al. 2006). The catchment of the Mirna River in Istria in the late eighties of the last century, due to its geometry, lower inflows, higher water temperatures, and pollution pressures had significant problems with water quality and eutrophication processes. At the bottom of the reservoir, there are increased concentrations of manganese, iron, and ammonia, as well as a generally poor quality condition with higher values of mostly all parameters, (Hajduk Černeha et al. 2006; Zorko 2017). Trends of selected water quality indicators show different directions, depending on whether monitoring is done at the surface where they all have a decreasing trend or at the bottom of the

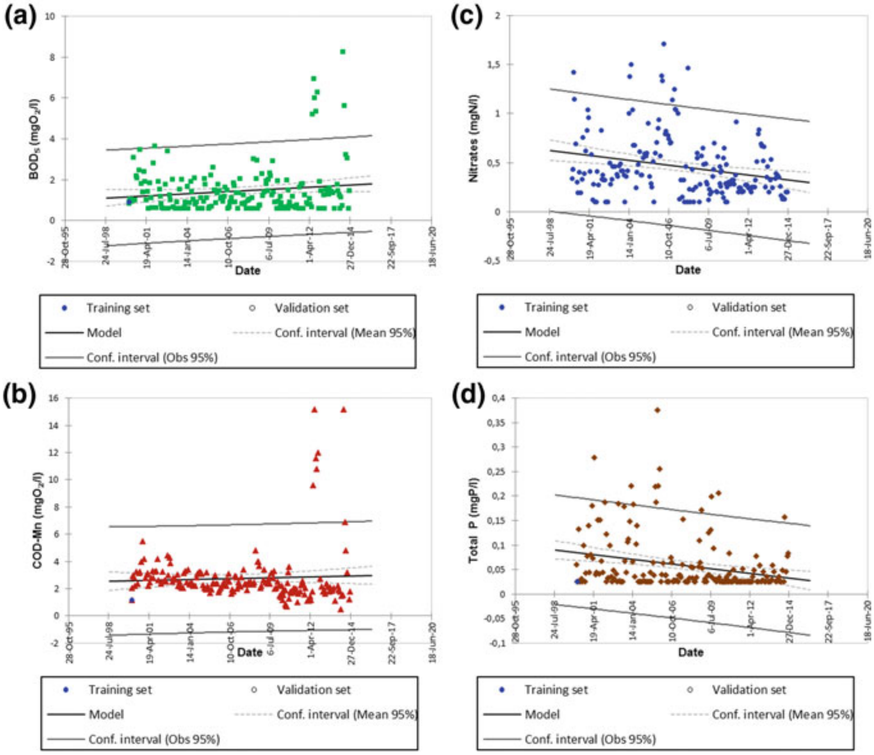

Fig. 6.14 Linear regression with a five years' prediction period of the water quality parameters 1 m above the bottom of Butoniga reservoir, **a** BOD_5, **b** COD, **c** nitrates and **d** total P

reservoir (Fig. 6.14) where BOD_5 and COD have increasing trends, while the nitrates and the content of total phosphorus show decreasing trends. From Figs. 6.14a–d it is obvious that some high concentrations of the analysed quality parameters are present, especially during the dry years such as in 2012, when the minimum levels of water in the reservoir, since the water is used for water supply, were recorded.

6.4 Conclusion

In order to give general water quality status of Croatian surface water resources, several rivers, natural and artificial lakes have been analysed. Besides, a brief overview of recent research and published documents were given. Water quality analysis of different Croatian rivers and lakes (natural and artificial) shows an important influence of the catchment area including geographical features, hydrological regime, land use, population, etc. In some cases, it is very difficult to define the dominant sources of pollution and catchment processes, but we have tried to stress the main trends of water quality in Croatia. The proposed analysis of Croatian surface water quality status made on the basis of the recorded data shows improvement of the most analysed parameters. They are the result of the implementation of the Water Framework Directive, the Nitrate Directive and improvement of sewage water system by the construction of wastewater treatment plants. However, there are still some improvements which can be done. There are also periodic occurrences of very high values of all parameters which coincide with critically dry hydrological conditions, which proves that water bodies are extremely vulnerable to pollution during drought periods which have been more frequent in the last decade.

6.5 Recommendations

The presented results achieved in the past years, shows improvement trends of water quality. They have to be kept or even enhanced. Besides the action plans and measures defined by water management strategies, it is necessary to continue development of established water quality monitoring programmes. It encompasses increasing of sampling station numbers and/or sampling frequency. It is main reccomendation, because existing monitoring system is still not reliable enough. Frequency of sampling frequency and accuracy of observed data can not assure reliable water quality categorization, especially on small and medium rivers in carst region of the Adriatic Sea Basin. Widening of existing water quality monitoring network will take time and other resources, but certainly will contribute to the final goal—having safe and clear surface water.

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Chapter 7
Surface Water Resources and Their Management in Croatia

Ivan Čanjevac and Danijel Orešić

Abstract Croatia is a middle-sized country at the south of Central Europe, a member state of the European Union (since 2013), with a land area of 56,594 km^2 and total population of around 4.2 million. Despite the size, it has very heterogeneous physical-geographical characteristics. Croatia is ranked third (or fourth if one counts Russia) in Europe by the Total Renewable Water Resources per capita (TRWR). Nevertheless, water resources are characterized by many spatial and temporal differences and variability which are the result of countries rich geological, geomorphological and climatological diversity. This chapter focus on water balance components, and surface water resources in Croatia, analyses main water use sectors, water resources management system and flood protection in Croatia.

Keywords Croatia · Surface water resources · Management · Utilization · Variability · Diversity

7.1 Introduction

Croatia is a middle-sized country at the south of Central Europe, a member state of the European Union (since 2013), with a land area of 56,594 km^2 and a total population of around 4.2 million (Croatian Bureau of Statistics 2017). Despite the size, it has very heterogeneous physical-geographical characteristics. Croatia is ranked third (or fourth if one counts Russia) in Europe by the Total Renewable Water Resources per capita (TRWR) (FAO 2018). Nevertheless, water resources are characterized by many spatial and temporal differences and variability which are the result of countries rich geological, geomorphological and climatological diversity.

I. Čanjevac (✉) · D. Orešić
Department of Geography, Faculty of Science, University of Zagreb,
Trg Marka Marulića 19, HR-10000 Zagreb, Croatia
e-mail: canjevac@geog.pmf.hr

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7.2 Water Balance Components

Croatia's climate is primarily determined by its geographical position in the northern mid-latitudes. The most important climate modifiers are the Adriatic Sea, the Dinaric Alps with their form, altitude and position relative to the prevailing air flow and in inland the openness to the Pannonian plain (Zaninović et al. 2008).

According to the Köppen climate classification (Fig. 7.1), most of Croatia has a Cfb climate (temperate humid climate with warm summer; no dry periods, the warmest month of the year has an average temperature lower than 22 °C). In the northern part of the Croatian coast, lower coastal strip and islands (Krk, Cres, Lošinj, Rab, Pag) have Cfa climate (temperate humid climate with hot summer; no dry periods, the warmest month of the year has an average temperature lower than 22 °C). On the islands and in the coastal area of Dalmatia (middle and southern coast), there is a prevalent Csa climate (Mediterranean climate with hot summer - olive climate; the dry period is in the warm part of the year, the warmest month of the year has an average temperature lower than 22 °C) and in the lower-lying Dalmatian hinterland the climate changes to Cfa and on the high mountains to Cfb. Only the highest mountain areas in Croatia (higher than 1200 m amsl) belong to the Df climate (humid snow-forest climate, the average temperature of the coldest month is lower than −3 °C) (Filipčić 1998).

The mean annual amount of precipitation in Croatia (Fig. 7.2) ranges from 300 mm to slightly over 3500 mm. About 800–900 mm of precipitation can be expected on the islands and the coast of central and northern Dalmatia as well as on the west coast of the Istrian Peninsula. The amount of precipitation increases towards the coast, especially near the mountainsides due to the forced elevation of air masses. The largest annual amounts of precipitation (from 3000 to 3500 mm) in Croatia fall in high mountains of Gorski Kotar and on highest parts of Mount Velebit. The annual amount of precipitation in continental Croatia decreases from west to east because the moist air masses coming from the west and south-west lose their humidity on the way.

The mean annual air temperature in Croatia is mainly dependant on altitude, and of the position of the Dinaric ranges separating the coast from the interior, acting as a barrier and diminishing the influence of the Adriatic Sea. The low-lying coastal strip and the islands have the highest mean annual air temperature in Croatia, above 13 °C in the north and rising down south to over 16 °C. The influence of the altitude is clear in the mountainous area of Croatia, where at the highest peaks mean annual air temperatures drop below 4 °C. Most of the interior part of Croatia has rather uniform mean annual temperature of around 10–11 °C and somewhat higher (12 °C) in the east, as a result of very warm summers in this, most continental, part of Croatia. Lower mean annual temperatures occur on Pannonian island mountains.

Evaporimeters of different types can measure evapotranspiration, but the actual measurements are scarce (only seven stations have measured it in the 1961–1990 period) even to this date. However, evapotranspiration was calculated by Palmer method, and a model covering all of Croatia prepared for agronomic needs by

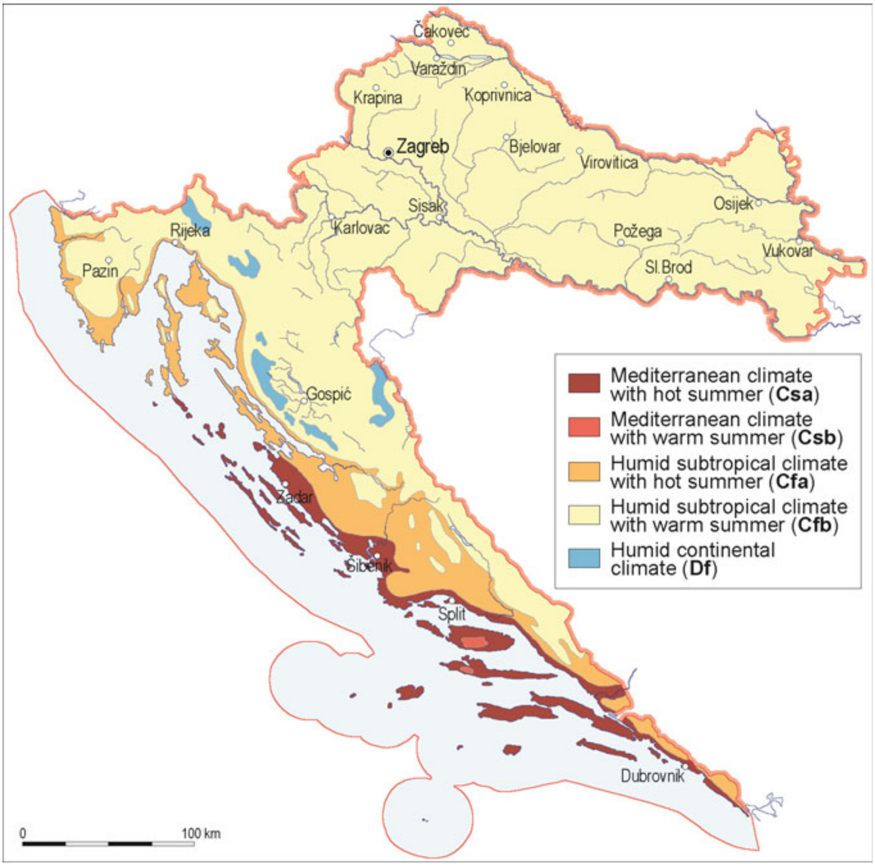

Fig. 7.1 Köppen climate classification for Croatia (cartography by I. Rendulić)

Meteorological and Hydrological Service of Croatia (Zaninović et al. 2008). Ferina (2011) calculated both real evapotranspiration (ET) and potential evapotranspiration (PET)[1] on the country level. Annual PET is at the highest level in Dalmatia, where most of the hinterland has values over 1000 mm, the coastal zone around 1300 mm and highest values of around 1500 mm are calculated for Split, Makarska and Dubrovnik areas. The coast and islands are having high temperatures, but are also relatively windy during the year, contributing to the evaporation. Values of PET are around 800 mm annually on Istrian peninsula. Values in the rest of the country are half of those in Dalmatia, mostly in the range 650–750 mm annually.

[1]Potential evapotranspiration (PET) is the evaporation that would occur given a sufficient amount of water, so it is practically the same as evaporation from a free water surface. Real evapotranspiration (ET) is the evaporation from plants and soil, which depends on the amount of water available from precipitation and soil water reserves.

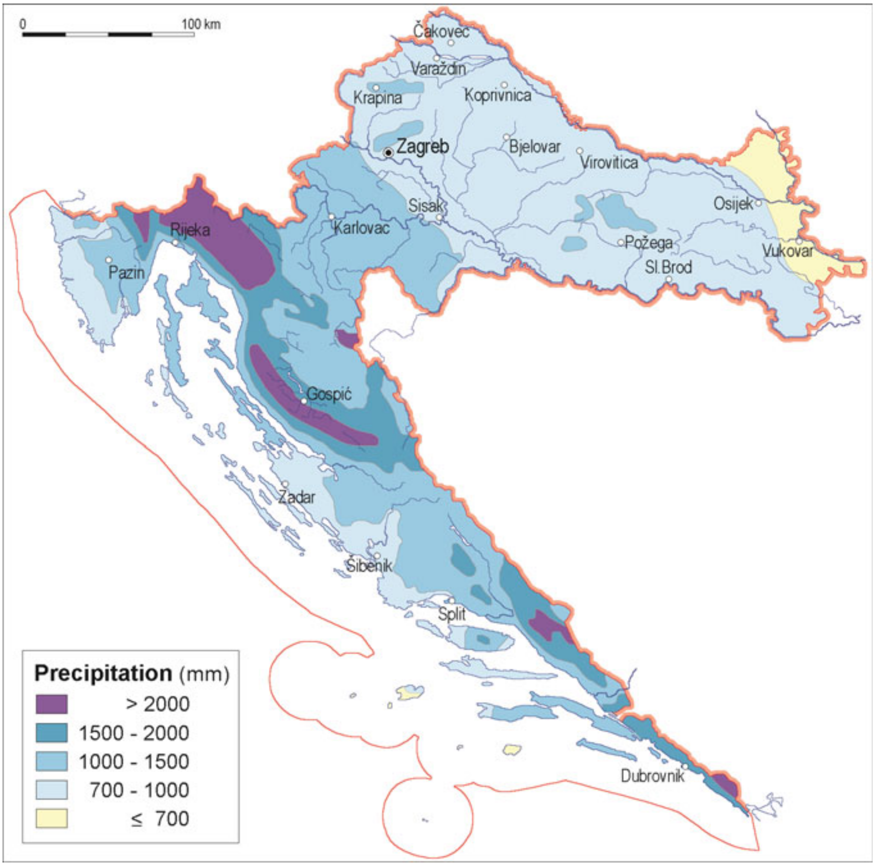

Fig. 7.2 Mean annual precipitation in Croatia for the 1961–1990 period (*source of data* Croatian Meteorological and Hydrological Service; cartography by I. Rendulić)

The distribution of PET in vegetation period is similar (but with lower values, especially in Dalmatia where they reach a maximum of around 1300 mm) reaching 70–80% of the annual value of PET (Ferina 2011).

The real evapotranspiration (ET) varies much less in Croatia, and it is mostly in the range of 550–650 mm annually. On the Kvarner coast (especially Senj area) and parts of Dalmatian coast (especially Dubrovnik area), it is reaching highest values, some 900–1000 mm annually. This is primarily the result of strong winds (like famous bora in the Senj area), but also relatively high air temperatures as well as relatively high precipitation. ET values at Dalmatian coast and islands are however significantly lower than PET values. The reason is that there is a lack of moisture in the soil (and lack of soil per se) in a karst area, and not enough precipitation in the coastal strip and on island, especially those lying-low and further from the coast. In those areas, the real evaporation is reaching only 50% of annual PET, and around

30% of PET in vegetation period. Although the highest amount of precipitation is received by the mountain area of Gorski Kotar, the values of ET are lowest there and are almost the same as the PET values (Ferina 2011).

In continental Croatia there is precipitation throughout the year, there is an even higher amount of precipitation in the warmer part of the year. There are no significant differences between PET and ET, and in the colder part of the year, the ET is at minimum, and it is becoming equal to PET. However, low precipitation in the inland lowlands, especially in the east, in combination with high temperatures, means low runoff in most of the Pannonian Croatia. Mountains, on the other hand, receive the highest precipitation, and they have the lowest values of PET and ET, so they are represented by highest runoff values in Croatia, especially the area of Gorski Kotar (Fig. 7.3). The characteristic of the coastal and island zone is minimum precipitation in the warm part of the year and maximum in the cold part of the year.

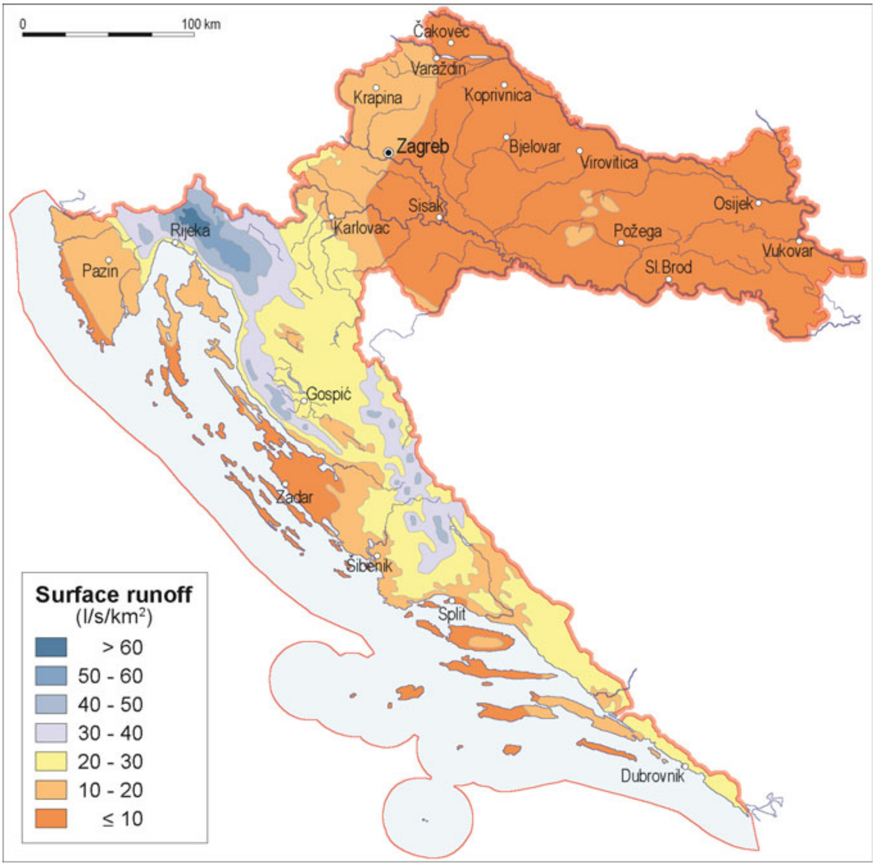

Fig. 7.3 Annual specific runoff (l/s/km^2) in Croatia (*source of data* Hrvatske vode 2016; cartography by I. Rendulić)

High temperatures and lower relative humidity are the main reason of high PET values in warmer part of the year (and annually). Summer time, with low precipitation and low soil humidity, on karst, where water is easily percolating deep underground, is ideal for low ET, which combined with high PET means there are occasional droughts.

According to the water balance analysis (based on data from standard climatologic period 1961–1990), it can be stated that Croatia is a water abundant country, but water resources are spatially and temporary unequally distributed (Hrvatske vode 2016).

Large quantities of transit waters are the main reason for the relative abundance of the total renewable water resources in the Danube River drainage area (Table 7.1).

Total renewable freshwater resources in the Danube River drainage area are round 84 billion m^3 annually, which is equal to about 29,000 m^3 per year per inhabitant. This amount represents 3/4 of total renewable freshwater resources in Croatia. However, most of it is inflowing from abroad, and own water resources are round 12 billion m^3 annually or about 4000 m^3 per year per inhabitant. The lowest runoff is in the eastern Slavonian lowland (some 20%) where the precipitation is low and evaporation high, while the largest runoff is in mountainous Gorski Kotar where more than 50% of precipitation is contributing to runoff.

Total renewable freshwater resources in the Adriatic Sea drainage area are round 28 billion m^3 annually (Table 7.2), which is equal to about 20,600 m^3 per year per inhabitant (census 2011 data on population). In own water resources, Adriatic Sea drainage area supersedes the Danube drainage area and is round 14 billion m^3 annually or about 10,300 m^3 per year per inhabitant. The highest runoff is characteristic for the high karstic mountains, with plenty of precipitation, low temperature and where precipitation is quickly evacuated underground and so doesn't have time to evaporate. More than half of the precipitation is forming runoff, most often between 60 and 70%. Values are less in the lower-lying coastal zone, and usually very low on islands.

Table 7.1 Renewable water resources in the Danube River drainage area, long-term average values (10^9 m^3/year)

	Sava River sub basin	Drava River sub basin	Danube River drainage area	Croatia
Average precipitation	27.8	7.3	35.2	65.7
Real evapotranspiration	17.5	5.8	23.3	39.6
Own water resources	10.4	1.5	11.9	26.1
Water entering the country[a]	19.1	52.8	71.9	86.1
Total renewable freshwater resources	29.5	54.3	83.8	112.2

[a]Includes 50% of Danube inflow and 50% of inflow in Sava from Una tributary downstream
Source Hrvatske vode (2016)

Table 7.2 Renewable water resources in Adriatic Sea drainage area, long-term average values (10^9 m^3/year)

	Adriatic Sea drainage area	Croatia
Average precipitation	30.5	65.7
Real evapotranspiration	16.3	39.6
Own water resources	14.2	26.1
Water entering the country	14.2	86.1
Total renewable freshwater resources	28.4	112.2

Source Hrvatske vode (2016)

The total renewable freshwater resources in Croatia are thus estimated to be about 112 billion m^3 annually, and this is equal to about 26,059 m^3 per year per inhabitant placing Croatia high among European countries. Media often (mis)use this information overemphasizing the abundance of water. It is the fact that even in own water resources it still has plenty of water resources, some 26 billion m^3 annually, or 6086 m^3 per year per inhabitant, but this is informing us that there is a very high dependency ratio in water resources (Fig. 7.4). Croatia is still among the countries where the water resources are not overused and where problems regarding availability and quality of water so far are not restricting the overall development. At the same time, water in karst is naturally vulnerable and can be locally hard to exploit. Most important water reserves in the Croatian interior (mostly non-karst area) are the groundwater in Sava and Drava Rivers alluvial aquifers, which are in part affected by small thickness of soil above the aquifer, and in general under pressure by high population density, urban settlements and its waste products, intensive transport and agricultural practices.

7.3 Rivers

Croatian territory (total area 56,594 km^2) with the total length of open watercourses of around 67,500 km (Hrvatske vode 2016), belongs to two basins. The larger part of around 62% belongs to the Danube River, i.e. Black Sea basin (Fig. 7.4). The Danube River basin area in Croatia has a very well developed surface drainage network with watercourse network density of 0.3 km/km^2 (considering only watercourses with catchments >10 km^2) and density of 1.6 km/km^2 (considering all watercourses). Major rivers (Sava, Drava, Danube, Mura, Kupa) are positioned marginally and form long part of natural borders to Slovenia, Hungary, Serbia and Bosnia and Herzegovina.

The longest river (within national borders) in Croatia is the Sava River (562 km long in Croatia with a catchment area of 23,243 km^2 in Croatia) which is the largest tributary of Danube in means of flow contribution and 8th by water volume in Europe. It enters Croatia from Slovenia upstream of the Croatian capital Zagreb and flows predominantly in NW-SE direction. The Sava River in Croatia has a

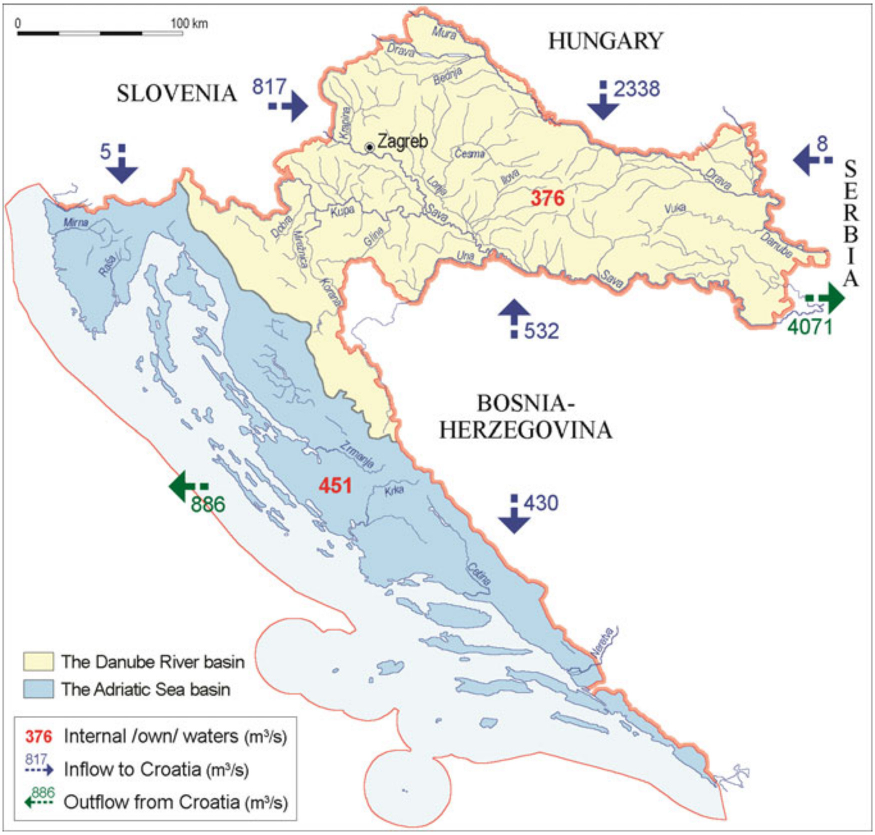

Fig. 7.4 Surface river network with the data about inflowing and own water resources of Croatia (*source of data* Hrvatske vode 2009; cartography by I. Rendulić)

Peripannonian pluvial-nival regime which along the Sava River middle course gradually changes into Pannonian pluvial-nival regime (Čanjevac 2013).

The Sava River valley is historically an important communication route between central Europe and south Europe and today it is among major European transport corridors. The Sava River valley today is under tremendous anthropogenic pressure, and its remaining natural habitats are endangered but still retained a quite outstanding biological and landscape diversity. Its open aquifer is especially under pressure, although it is a major source for water supply of all the large cities along its course and even for the settlements quite far from it (Orešić et al. 2017). Sava's middle course in Croatia hosts the largest complex of alluvial wetlands in the Danube River basin, and there are considerable lowland forests preserved. Main left tributaries of the Sava River in Croatia are Sutla (92 km), Krapina (75 km), Lonja-Trebeš (133 km) and Orljava (89 km) and main right tributaries are rivers Kupa (296 km) and Una (120 km in Croatia). The Kupa River (having Dinaric snow-rain regime) is an important right tributary of Sava in means of flow contribution and flood risk management.

To establish sustainable water management in the basin, the Sava River basin sharing states concluded the Framework Agreement on the Sava River Basin (FASRB) which is an international agreement integrating all aspects of water management and established the (joint) International Sava River Basin Commission (ISRBC) for the implementation of the FASRB, with legal status of an international organization. The FASBR was signed in 2002, and it entered into force in 2004 after all states involved ratified the agreement. Interim Sava Commission (with the main office in Zagreb, Croatia) is working since 2003, and a permanent ISRBC was formally established in 2005 (ISRBC 2018).

Second longest river (505 km in Croatia) is the Drava River which forms a large natural border to Hungary. It also has predominantly NW–SE direction and an Alpine snow-rain discharge regime which is well used for electricity production in three lowland hydropower plants in Croatia.

Coastal and parts of mountainous Croatia (in total around 38% of the national territory) belong to the Adriatic Sea basin. That, predominantly karst area has a poorly developed surface drainage network with rich underground flow and water resources. In addition, it contains classic karst river phenomena such as strong karst springs, ponors, canyons, sinking and intermittent rivers.

Longer rivers (from north to south) are the Mirna River (53 km) in the Istria peninsula, the Lika (78 km; the second-longest sinking river in Europe) and Gacka Rivers in the Lika region, and the Zrmanja (69 km), Krka (73 km), Cetina (101 km) and Neretva (20 km in Croatia) in Dalmatia. In addition, there are several relatively short rivers with strong karst springs such as the Rječina and Ombla rivers. Most of bigger karst rivers (especially their spring zones) are used for water supply. Given the abundance of water and a relatively big drop in small area they are extensively used for hydropower production.

The Cetina River is the longest watercourse in the Adriatic Sea basin in Croatia. It has a source in the foothills of Croatia's highest mountain Dinara, flows in an NW-SE direction forming a composite valley. After the town of Trilj it enters a canyon and after the town of Zadvarje turns and flows to the west till the mouth in the town of Omiš. Topographical watershed (1463 km^2) of the Cetina River is entirely in Croatia but a bigger part of the hydrological watershed (total around 3725 km^2) is in Bosnia and Herzegovina. It is an important watercourse for water supply and electricity production (in total 5 HPP).

7.4 Lakes

Lakes in Croatia with a surface area bigger than 0.5 km^2 cover around 167.1 km^2 (PUVP 2016–2021). Most of them (28) are artificial lakes largest of them being Lake Dubrava on the Drava River (17 km^2). They are used for multiple purposes such as hydropower production (e.g. Peruća on the Cetina River, Varaždin and

Dubrava lakes on the Drava River, Kruščica lake on the Lika River), water supply (Butoniga lake in Istria) or irrigation (lakes in Slavonia).

All larger natural lakes are located in the karst area. Most known are 16 cascade lakes in the source area of the Korana River within the Plitvice Lakes national park, made by the growth of characteristic tufa barriers. Largest natural lake in terms of the surface is the Vrana Lake in Dalmatia (around 31 km^2) and in terms of volume the Vrana Lake on the Cres island (around 220×10^6 m^3) (Rubinić and Ožanić 1992; Rubinić and Katalinić 2014). Both lakes are karstic kryptodepressions. In addition, there are several lakes in karst which reflect karst diversity and peculiarity in the largest sense, such as Red and Blue lakes in the town of Imotski or Baćina Lakes near Ploče.

Natural lake systems, especially in karst are very sensitive to anthropogenic pressures and present challenge for water management. Given the high number of visitors and concentration on activities within the national park, Plitvice lakes are under significant anthropogenic pressure, and large efforts are put to reduce the negative impact of tourism, build sewage infrastructure and remove water supply out of the limits of the national park. Given the shallow water (max. 4 m) and proximity to the sea and connection to seawater (possibility of intrusions), Lake Vrana in Dalmatia also has fragile natural conditions with the large pressure from agriculture and tourism activity. Lake Vrana on the Cres island is used for the water supply of Cres, Lošinj and neighbouring islands and presents a unique natural freshwater reserve.

7.5 Water Resources Utilization

7.5.1 Communal Water Supply

According to recent planning documents, 95% of the countries territory is covered by and around 85% of inhabitants are connected to the communal water supply (Hrvatske vode 2016). Water losses in the communal water supply system are still quite high, in total larger than 40%, with significant regional differences (Bajo and Filipović 2008). As a result of specific hydrogeological properties in Croatia, 90% of water withdrawals for the water supply is from groundwater. Only 10% of the water is taken from streams (e.g. Danube at Vukovar) or artificial lakes (e.g. Butoniga in Istria).

On the one hand, in the Danube River basin in Croatia water is largely pumped from alluvial sediments in Sava and Drava valleys. Croatia's capital city Zagreb agglomeration area (around 1 million. inhabitants) uses groundwater from a thick mainly gravel alluvial deposits. In Slavonia, many towns use water from sandy alluvial aquifers. In addition, water supply in Kupa River basin upstream of Karlovac is mainly from karst springs and aquifers. On the other hand, in the Adriatic Sea basin in Croatia communal water is secured by catchments of karst springs or via deep water supply galleries. The water supply of numerous islands (48 permanently inhabited) in Croatia is a specific challenge for water management. Some of the islands have own (limited) freshwater reserves, e.g. Cres, Vis, parts of Pag, Krk, Korčula. Most of big islands have pipe connections with mainland: Krk, Pag, Brač, Hvar, Šolta, Korčula, Mljet. Only Lastovo and Mljet have desalination plants (Hrvatske vode 2009). A special challenge for the coastline towns and islands water supply (and wastewater management) is a summer touristic season when there are five to eight times more water users (Slavuj et al. 2009; Grofelnik 2017).

7.5.2 Agriculture

National irrigation plan (NAPNAV 2005) recognized 484 026 ha of Croatian territory suitable and highly suitable for irrigation. This is the result of soil, water and climate research project having in mind the areas which could not be included in the irrigation scheme (such as protected areas, areas undermines etc.). At the moment 1.4% or around 23,500 ha of used agriculture area in Croatia is under irrigation (Đuroković et al. 2016). The aim of the NAPNAV is 6% or 65,000 ha of the irritating area till 2020. Till the end of 2016 total of 23,500 ha of systems has been built or reconstructed with the acceleration in the past couple of years (Đuroković et al. 2016). Most of the agriculture area under irrigation is in the eastern part of Croatia, i.e. Slavonija and Baranja given that it is the lowland area with rich soils and lack of precipitation. In addition, irrigation project has been developed in the northern (Međimurje), western (Istria) and southern (Neretva) Croatia.

7.5.3 Hydropower

In the structure of the electricity system, hydro power plants account for more than a half of the sources (HEP Proizvodnja 2018). Today, there are 25 hydro power plants in operation in Croatia today, of reservoir or natural flow type (Fig. 7.5). The oldest hydro power plant in Croatia is HPP Jaruga, built on the Krka River at the Skradinski buk waterfall in 1895. It started operating only two days after the Niagara Falls, making it the second oldest HPP producing alternating current in the world and the oldest in Europe. Most of large power plants with reservoirs where built after the World War II.

Three lowland hydro power plants were built on the Drava River in Croatia: Varaždin (1975), Čakovec (1982) and Dubrava (1989). They are multi-purpose hydro power plants. In the Lika and Gorski Kotar karst mountainous areas smaller and larger HPP where built with many artificial water diversions and reservoirs. Examples are Senj hydropower system which uses water from Lika and Gacka rivers or Vinodol complex hydropower system using many streams in Gorski Kotar

Fig. 7.5 Larger hydropower plants in Croatia (*source of data* HEP Proizvodnja 2018; cartography by I. Rendulić)

area and diverting them with a gross head (drop) of 658 m (one of the highest achieved in Europe) (HEP Proizvodnja 2018). In Dalmatia, the largest system is in the basin of the Cetina River (with Peruća, Orlovac, Đale, Zakučac—with the highest installed capacity of 486 MW and Kraljevac HPPs) which spreads into Bosnia and Herzegovina, the basin of the Krka River and Zrmanja River (together with the waters from Gračac Plateau). The youngest larger HPP is Lešće on the Dobra River, built in 2010. All HPPs are owned by the State company HEP Proizvodnja and production is coordinated with other electricity production sources.

Rather long operation of many of power plants rose nature protection concerns. During the time negative consequences, especially on river and sediment flow are observed. Recently, there is a significant trend in small HPP (less than 5 MW) investment and building which raises large concern for the nature protection given that many sights are in pristine or in fragile karst areas.

7.5.4 Inland Waterways

The most important inland waterways in Croatia are Danube and Sava. Croatia's inland waterway ports are Vukovar (on the Danube River), Osijek (on the Drava River), Slavonski Brod and Sisak (both on the Sava River). All of the mentioned ports are mainly characterized by freight transport and with minor passenger infrastructure. The Port of Vukovar is the largest according to the handled freight quantity (393.860 tons in 2015; about 64% in the total transhipped freight). Passenger transport has the highest rate also in the city of Vukovar (30 000 in 2013; 90% of total passenger inland waterways transport) and is still growing (Danube passenger cruisers). Freight transport is mainly influenced and connected to the industry and agriculture located in the wider region of the mentioned inland waterway ports. Dangerous goods (crude oil) is transported with ships from the Port of Slavonski Brod to the Port of Sisak, primarily for the supply of the Sisak's refinery (Transport Development Strategy of the Republic of Croatia 2017–2030).

7.6 Water Resources Management System

It is regarded that organized water management on the territory of Croatia started in Osijek in 1876 with the foundation of first Society for regulation of the Vuka River. In 1891 the first Water Act was declared. Further development of water management system and legislation followed historical movements and development of Croatia.

With accession to the European Union (EU) and the already prior acceptance and progressive implementation of the Water Framework Directive (WFD), Croatia undertook changes in water resources management legislation. Beside the Water Management Strategy and Water Act, it started developing River Basin Management Plans (RBMP) for the Danube River basin and the Adriatic Basin in Croatia. Active RBMP for the period 2016–2021 is based on the data from the reference year 2012. The RBMP includes two parts, i.e. water Management Plan and the Flood Risk Management Plan. National monitoring system for the ecological status of waters has been built and is under continual revision and improvement.

National water management strategic body is National Council for waters, a Croatian parliament body mainly in charge of guidelines and strategic discussions. Main government body is a Directorate for Water Management, today part of the Ministry of Environment and Energy. Operational water management is done by the Croatian Waters (Hrvatske vode), a legal entity for water management established by the Water Act. The Republic of Croatia is the founder of Croatian Waters, and as a *sui generis* legal entity, they are subject to regulations that apply to institutions. Croatian Waters are in charge for all the aspects of water management such as preparation of planning documents for water management, flood protection, amelioration drainage, water use, water protection, irrigation, management of public water estate, management of special projects in water management etc. Croatian Waters have regional offices responsible for the operative water management in within river basins and subbasins (Hrvatske vode 2018).

7.7 Flood Protection in Croatia

It is estimated that around 15% of the territory of Croatia is under flood hazard (Hrvatske vode 2013). Natural floods in Croatia occur as river floods (snow melt or intensive rainfall), flash and urban floods (short intensive rainfall), seasonal floods in karst poljes, underground floods in lowlands, ice jam floods (Drava and Danube rivers) and sea floods (storm surges). Most of the area of Croatia has some kind of flood protection with a different level of security. Technical (civil engineering) flood protection mainly consist of dyke systems and inundation areas and retentions on smaller streams.

In the Sava River basin, the biggest city Zagreb is well protected (1000 years' water) with a complex system of lowland retention and bypass channel (protection of Sava floods) and with mountains retentions (protection from Medvednica mountain streams). Other areas in the Sava valley are less protected and suffer flooding from time to time with flood protection plans to be finished in the future. One of the biggest, most efficient and environmentally friendly flood protection system in this part of Europe is the so-called Middle Sava flood protection system which will when completed provide better flood protection in the middle and lower course of Sava. It already includes several natural retention areas such as Lonjsko and Mokro polje, important Ramsar wetland sites in Croatia. In the wider Sava basin river floods occur in the Sutla, Kupa and Una Kupa valleys and flash floods threaten areas in the Krapina and Orljava watersheds. Biggest effort on flood protection is done in the Kupa valley, especially for the protection of the city of Karlovac.

Flood protection in the Drava and Danube watershed in Croatia is based on embankments and inundation areas. In addition, a wetland area of Kopački rit on the confluence of Drava to Danube is used for control of flood waters which are a threatening region of Baranja. Icebreaker ships are used on Danude in order to reduce flood risk around this transboundary river.

In the Adriatic Sea basin in Croatia biggest flood hazard is from flash floods on shorter and longer karst rivers with natural high variability. In addition, natural seasonal flooding of karst poljes presents flood protection challenge which has been handled since XIX century. The area with the highest river flood risk is the Neretva River delta. This natural wetland is moderately populated but intensively agriculturally used which rises the flood vulnerability of the whole area.

Non-engineering flood protection measures in Croatia include warning and flood handling operative systems which are under the authority of Croatian Waters, divided in regional centres. Flood prediction data and modelling is done within the

Croatian Meteorological and Hydrological Service. In addition, according to Croatian legislation, the area of and around streams and lakes is a part of public water estate (vodno dobro) and has to be maintained according to the instructions given by Croatian Waters in order to secure optimal flood protection.

7.8 Conclusion and Recommendations

Croatia is ranked third (or fourth if one counts Russia) in Europe by the Total Renewable Water Resources per capita (TRWR). Nevertheless, water resources are characterized by many spatial and temporal differences and variability which are the result of countries heterogeneous physical-geographical characteristics. Water resources management has a rather long history in Croatia and is still mainly led by the civil engineering sector. That is reflected in technically oriented (grey) solutions for flood protection and, even more in river regulations, which have been proved to be inadequate in many European countries. With the progressive implementation of the EU Water Framework Directive, Croatia is slowly changing management practice towards more environmental friendly solutions. This kind of solutions demand an interdisciplinary approach and cooperation of different scientific disciplines and stakeholders. This is already taking place in the broader hydrological scientific field but is reflected too slow in the water management sector in Croatia.

Accession to the EU encourages Croatia and the water resource management system to accept new paradigms and approaches, which will lead to an integral and sustainable management of water resources. Scientific cooperation, interdisciplinary and stakeholder participation is a challenge which Croatia's water management sector should accept in order to improve and manage fragile water resources in a more sustainable way.

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Part IV
Water Resource Management in Bosnia and Herzegovina

Chapter 8
Water Resources in Bosnia and Herzegovina

Emina Hadžić and Alma Imamović

Abstract Water resources management has century's long tradition in Bosnia and Herzegovina. More than half country's border are rivers (Sava, Una and Drina), and the far south, Bosnia and Herzegovina have access to the Adriatic Sea, a length of 20 km. Hydrographically, Bosnia and Herzegovina (B&H) belong to Black (75%) and Adriatic Sea (25%) basins. Due to the location in the southeast of Europe and the central part of the Balkan Peninsula, there are three climate zones. Average yearly precipitation in the territory of B&H is 1.250 l/m^2 which theoretically results with an average yearly potential outflow of 2.030 m^3/s. However, it is estimated that only 57% of total precipitation water (1.155 m^3/s) outflows from the territory of B&H (403 m^3/s outflows towards the Adriatic Sea and 722 m^3/s outflows towards the Sava river basin and to the Black Sea). The relative annual availability of water resources per capita rank B&H in the countries of "average water availability" between 5.000–10.000 m^3/capita. Rivers in B&H are characterized by high gradients and relatively high flow rate (22 l/s/km^2). Since the Dayton Agreement, there is no clear organized structure for water management at the state level. This is certainly a major challenge since the entities in B&H have their own separate constitutions and separate legislation, including water management legislation. Differences in entity's water management structures make water resources management complex and often inefficient.

Keywords Water resources · Surface water · Groundwater · Water management

E. Hadžić (✉)
Faculty of Civil Engineering, University of Sarajevo, Patriotske lige 30, 71000 Sarajevo, Bosnia and Herzegovina
e-mail: eminahd@gmail.com

A. Imamović
Ministry of Agriculture, Water Management and Forestry of the FB&H, Sarajevo, Bosnia and Herzegovina

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8.1 Historical Overview of Water Management in Bosnia and Herzegovina

Water resources management and building of the water infrastructure has century's long tradition in Bosnia and Herzegovina (BH). According to the research results (Sarić 2004), the first water management facilities were mainly used for settlements water supply and the irrigation. Significant remnants of such facilities are usually very limited or do not exist at all, but the evident is given through the historical records. The waters of the sulfuric spring at Ilidža were used even in the pre-Roman times, since the city, at that time, was located at the road's intersection (Bublin 2016). According to research (Bublin 2016), there is a belief that the Romans in the first century organized at the area of Ilidža a settlement with spas, hotels and other contents that were characteristic tor that period.

During the era of the Roman Empire channels for irrigation of the Imotski field were built, and near city of Ljubuški channels for drainage and irrigation were built in the ancient period. Most of the settlements of medieval Bosnia (Kovačević-Kojić 1978), such as Bobovac, Borač, Biograd near Konjic, had built water well facilities. According to Sarić (2004), with assault Huns and Avars most water structures were destroyed and could not be renewed until the arrival of the Austro-Hungarian administration in these areas.

The first major water management facilities were built during the Ottoman Empire, and then with the arrival of the Austro-Hungarian Empire. Water supply facilities were mostly built during the Ottoman period, while the Austro-Hungarian monarchy considerable attention paid to works on river regulation and melioration works. First water supply system was built in Sarajevo in 1462, e.g. in the time when just 2–3 cities in Europe had built the public water supply system.

The first organized state-level water management service was established during the Austro-Hungarian administration. The General Austrian Civil Code rules were applied unless they were contrary to other applicable regulations. The water service was part of the Construction Department of the National Government for Bosnia and Herzegovina.

As early as 1905, the Office for Melioration was formed, which later transformed into the Independent National Office for Melioration and Water Construction with an area of activity in the territory of BH (Sarić 2004). In 1914, drafts of legal bases (projects) for the implementation of land reclamation were adopted, as well as the legal basis for the implementation of water supply facilities in some Herzegovinian districts (Ljubinskog, part of Bilećkog, Trebinjskog, Gatačkog, Nevesinjskog, Mostarskog, Ljubuškog).

During the Kingdom of Yugoslavia (the Kingdom of Serbs, Croats and Slovenians), previously applied regulations and relations in the water sector were valid. It is important to note that in July 1919 the Ministry of Agriculture and Water was established for the territory of the whole country. In 1920, a great deal of jurisdiction in the water sector[1] was handed over to the General Directorate of Water for Bosnia and Herzegovina. It is worth pointing out that in 1931 the Law on the Use of Hydropower was adopted, according to which the state manages the hydropower of public waters (Sarić 2004).

After the occupation in the year 1941, the territory of the Kingdom of Yugoslavia was divided into areas of interest between Germany and Italy. As the demarcation line went through the territory of Bosnia and Herzegovina, there are no significant archival materials from which it could be concluded about the organization of the water management in the territory of BH.

The period after the Second World War in Yugoslavia (SFRJ—Socialist Federal Republic of Yugoslavia), was characterized as a very prolific period for the development of the water management sector in the entire state, but also in NRBiH.[2]

The first legal act after the liberation of the state was the General Plan for the Flood Protection in 1945 and 1946. In 1949, the Water Management Administration of the Government of the NRBiH was established, among other things, with the task of implementing the Government's guidelines on the proper use of water and the regulation of water flows, and harmonized the work of state bodies related to these activities. In 1952, the first scientific research institute in the field of water management, the Institute for Water Management, was established. Considering that the post-war period was accompanied by accelerated economic development, with a focus on the development of the basic economy, there was a great pollution of the rivers, primarily the Bosna river. Thus, in 1961, the Law on Water Protection was adopted, and in 1965, the Water Law of Bosnia and Herzegovina. During this period, the consolidation of water management organizations is being done, which leads to the establishment of the Water Management of Bosnia and Herzegovina, at the end of 1976. The new Water Law was adopted in 1975, and therefore the previous law on water ceased to be valid. It is believed that during the 1970s and 1980s, Bosnia and Herzegovina had more developed water resources management than other republics within ex-Yugoslavia.

After the break-up of Yugoslavia and the acquisition of independence, Bosnia and Herzegovina have again become a sovereign state. However, in contrast to its historical heritage and past-state practice, as well as newly-formed states in the region, instead of a single system of water management, water management in BiH is becoming decentralized, with almost three independent system, without mutual coordination.

[1]According to Saric, this is the entire inventory and cashier's office.

[2]People's Republic of Bosnia and Herzegovina-name of the state in the period 1943–1992.

8.2 Natural Features of B&H

Bosnia and Herzegovina is located in South-East Europe at the Western Balkans peninsula. The total area of the country is 51.209,2 km^2, of which 51.197 km^2 is land, and 12,2 km^2 is the area of the sea. The total border of Bosnia and Herzegovina with the neighboring countries is 1.538 km, of which the land border is 774 km long, 751 km in the river and 13 km inland. Borders with Croatia in the north, northwest and south (total length of the border: 932 km), Serbia to the east (357 km) and Montenegro to the southeast (249 km) (Statistical yearbook 2009). At the far south, Bosnia and Herzegovina have access to the Adriatic Sea, 20 km long (The World Factbook 2006), located at te territory of the municipality Neum. The borders of Bosnia and Herzegovina are mostly natural and those are the rivers Drina, Sava and Una, and the mountains such as Dinara in the southwest of the country. According to the 2013 census, there are about 3.531.159 inhabitants in Bosnia and Herzegovina, and the average population density is 69/km^2 (178.7/sq mi).

Hydrographically, Bosnia and Herzegovina belongs to Black (75%) and Adriatic Sea (25%) basins.

The relief of Bosnia and Herzegovina is very different, both in shape and age and way of origin. Most of the reliefs of the country consist of the mountains of different heights. The other part is flatland, and consists of parts of the Pannonian plain, large basins and river valleys, (Statistički godišnjak 2009) as well as the narrow belt of the Adriatic coast.

4/5 of the Bosnia and Hercegovina are mountains. "Of the total land area, 5% are lowlands, 24% hills, 42% mountains and 29% karst" (The World Factbook 2006). Almost 80% of the territory of BiH spreads between 200 m and 1500 m above the sea level (see Fig. 8.1).

The climate of Bosnia and Herzegovina is determined by a complex of physical and geographical factors, of which the most significant are: latitude, relief, proximity to the large ocean and marine areas and large land masses (Lepirica 2013).

The largest part of the territory of Bosnia and Herzegovina belongs to the extreme southern branches of the northern moderate belt and the extreme northern parts of the subtropical belt. The territory of Bosnia and Herzegovina is sectorally belonging to the influence of the winter western cyclone and summer azoric anti-cyclone with increased tropical influences. The climate of Bosnia and Herzegovina is significantly influenced by the penetration of supertropic air masses, known as warm and dry African air. Often, especially during the summer, they influence the countryside. Circulating over the Mediterranean, these air masses moisten and cool down in their upward ascend towards the Dinaric Alps (Lepirica 2013), discharging copious precipitation. If this warm air penetrates deep to the north, it brings about a long and very warm period in the land.

A significant influx of cold arctic air over the earth takes place during winter. In this period over the Eurasian land a high air pressure zone is established, and the air flows south towards the Mediterranean, over which, at the same time, a zone of low air pressure is formed.

Fig. 8.1 Topographic map of Bosnia and Herzegovina (Hodžic and Abdurahmanovic 2017)

8.3 Climate Characteristics of BiH

8.3.1 Air Temperature

Due to the location of Bosnia and Herzegovina in the southeast of Europe and the central part of the Balkan Peninsula, there are three climate zones. The climate varies from the moderate continental in the northern part of the Pannonian Plain along the Sava River and the foothill zone, to the Alpine climate in the mountainous regions, and the Mediterranean climate in the coastal region and the region of the lowland Herzegovina in the south and southeast.

In the northern part of Bosnia and Herzegovina, the average air temperature generally varies between −1 and −2 °C in January, while the average July temperature varies between 18 and 20 °C. In high altitudes, over 1000 m, the average temperature varies from −4 to −7 °C in January, while the July temperature varies between 9 and 14 °C. On the Adriatic coast and in low Herzegovina, the air temperature varies from 3 to 9 °C in January, and from 22 to 25 °C in July (period 1961–1990).

The lowland regions of northern Bosnia and Herzegovina have an average annual temperature of between 10 and 12 °C, and in areas above 500 m, the temperature is below 10 °C. The mean annual air temperature in the coastal area is between 12 and 17 °C (UNDP BiH 2013).

Research on temperature changes for the period 1961–2010 showed that there is an increase in temperature in all parts of the country (UNDP BiH 2016). As an illustration, two diagrams for the city of Sarajevo (belonging to the continental climate zone) and the city of Mostar (belonging to the Mediterranean climatic zone) could be seen in Fig. 8.2.

Comparative analysis of temperature change for the period 1981–2010 in relation to the period 1961–1990 showed that the highest average temperature increase, in the summer period, recorded in the southern part of the Herzegovina territory (Mostar 1.2 °C) and in the central parts (Sarajevo 0.8 °C). The largest increase in spring and winter period was recorded in the northern and central parts of the country (Banja Luka 0.7 °C). The slightest increase is during autumn and ranges from 0.1 to 0.3 °C (see Table 8.1).

The annual increase in air temperature ranges from 0.4 to 0.8 °C, while the temperature rises in the vegetation period (April–September) goes up to 1.0 °C (UNDP BiH 2013).

Analysis of meteorological data from the period 1961–2014 shows that the mean annual temperature retains a continuous increase (see Table 8.2). An analysis of the long-term data set (1961–2014) showed a positive linear trend in the mean annual temperature, which was particularly pronounced in the last 30 years, since 1982.

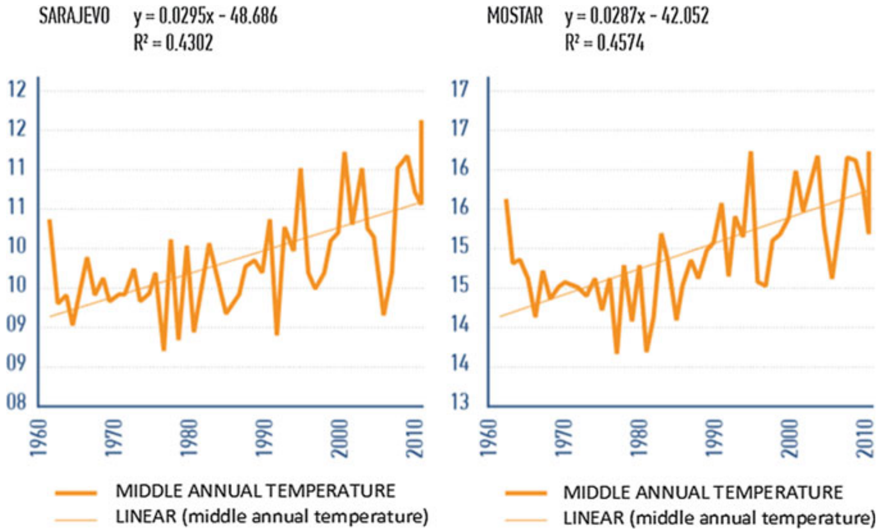

Fig. 8.2 Trends in air temperature changes in BH (Hadžic and Dreškovic 2012)

Table 8.1 Changes in average air temperatures (°C) for different periods of the year in Banja Luka, Sarajevo and Mostar, 1961–2010 (Hadžic and Dreškovic 2012)

		Annual	Vegetation period	Spring	Summer	Fall	Winter
Sarajevo	1961–1990	9,7	15,7	9,7	18,3	10,4	0,4
	1981–2010	10,1	16,2	10,0	19,1	10,5	0,7
	Deviation	0,4	0,5	0,3	0,8	0,1	0,3
	2001–2010	10,4	16,5	10,5	19,6	10,6	1,1
Mostar	1961–1990	14,6	20,3	13,6	23,5	15,3	5,9
	1981–2010	15,2	21,2	14,3	24,7	15,5	6,2
	Deviation	0,6	0,9	0,7	1,2	0,2	0,3
	2001–2010	15,5	21,8	14,9	25,3	15,5	6,5
Banja Luka	1961–1990	10,6	16,9	10,9	19,7	10.9	0,8
	1981–2010	11,4	17,9	11,6	21,0	11,5	1,5
	Deviation	0,8	1,0	0,7	0,3	0,6	0,7
	2001–2010	11,9	18,4	12,3	21,7	11,8	2,2

Table 8.2 Changes in air temperature for a period 1961–2014 (Hadžic and Dreškovic 2012)

	Sarajevo	Mostar	Banja Luka
Max. 2001–2014	11,7	16,17	13,07
Min. 2001–2014	9,14	14,58	10,71
Aver. 2001–2014	10,62	15,67	12,12
Max. 1961–2014	11,7	16,21	13,07
Min. 1961–2014	8,68	13,63	9,72
Aver. 1961–2014	9,85	14,97	11,12

For the data above (see Table 8.2), annual temperature trends at all analyzed stations are statistically significant, and the changes are more pronounced in the continental part (Hadžic and Dreškovic 2012).

It is interesting that in the period from 1981–2010 there was an increase in temperature in the entire territory of BH, with the largest increase during the summer and winter period and it is around 1 °C (UNDP BiH 2013).

8.3.2 *Precipitation*

Precipitation is a key component of the water balance (water cycle). Due to the spatial uneven distribution of metering stations in the state, and due to discontinuity in observation, it can generally be concluded that they are not satisfactorily monitored throughout the country. Only 32 rain gauge stations for the entire territory of BH can be identified for monitoring the rainfall component of the water balance

(IWMS RS 2014). Due to the discontinuation of the observation in 1991 and the subsequent very slow recovery of these measurements, the observations of the precipitation regime can be used before 1991, in which the observation period is about 30 years, most often from 1961 to 1990. Analyzes done over the last 10 years are also considered very useful in order to obtain a general picture of the climatic conditions.

The annual rainfall varies from 800 mm in the north along the Sava River, up to 2,000 mm in the central and southeastern mountain regions (period 1961–1990). For the same observation period, the average precipitation amounts to 32 rain gauge stations in BiH are 1121 mm. The spatial distribution of average annual precipitation (mm) for the territory of the Federation of Bosnia and Herzegovina and Bosnia and Herzegovina is given on the following map of isohium (see Fig. 8.3).

Fig. 8.3 Map of isohium—The spatial distribution of average annual precipitation (mm) for the territory of Bosnia and Herzegovina (WMS FBH 2011)

For the same observation period (1961–1990), in the southern parts of BH, with the Mediterranean climate, the annual rainfall varies between 1000 and 1500 l/m^2. In the continental part of BH, the main part of annual precipitation occurs in the warmer half of the year, reaching the maximum in June. The central and southern part of the country, with numerous mountains and narrow coastal areas, is characterized by an altered Mediterranean pluviometric regime under the influence of the Adriatic Sea, so that the monthly maximum amounts of precipitation are late in autumn and early winter, mostly in November and December.

Figure 8.4 shows the average monthly precipitation forecast for the different parts of BH. It is evident from the picture that in the southernmost part of BH (Herzegovina) the intraday precipitation schedule is inverse in relation to the northern part of the country, so that the highest precipitation occurs in the autumn and winter months, and the least precipitation occurs in the summer months (Trebinje and Bileća).

New processing, which includes data for the last 7–8 years, for the period 1961–2014, show that most of the territory of Bosnia and Herzegovina is characterized by a slight increase in annual precipitation (see Table 8.3). Although analyzes have been made in the documents of the recent period (UNDP BiH 2013, 2016), they have shown that changes in precipitation are more pronounced in seasons than on an annual level. The trend of precipitation is different in the seasons: in the central part of BH it is negative during the spring and summer (the most pronounced in the Herzegovina area—up to 20%), while in the autumn there was a rise in rainfall,

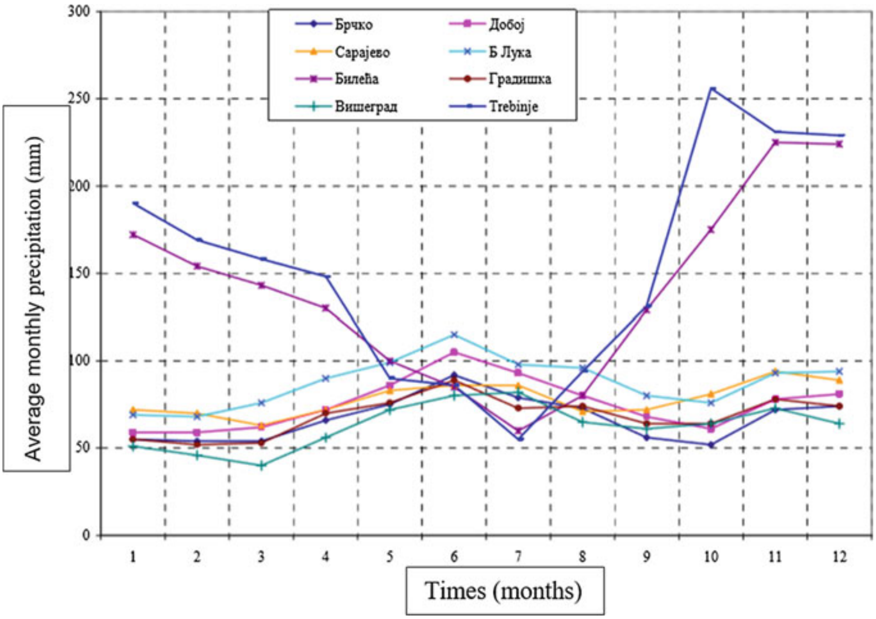

Fig. 8.4 Average monthly precipitation for different parts of BH (Vodoprivreda 1994)

Table 8.3 Precipitation fluctuations for the three cities in BiH, for the period 1961–2014. (UNDP BiH 2016)

	Sarajevo	Mostar	Banja Luka
Max. 2001–2014	1187	2491	1561
Min. 2001–2014	692	873	589
Aver. 2001–2014	984	1527	1054
Max. 1961–2014	1249	2491	1561
Min. 1961–2014	625	841	589
Aver. 1961–2014	945	1499	1042

especially in the northwestern and central parts. Although significant changes in precipitation are not recorded, the pluviometric regime, or annual distribution, is largely disturbed. Due to the increased intensity of precipitation and its higher variability, as well as due to the increased share of heavy rains in the total rainfall, the risk of flooding has increased, especially in the northeastern part of BH, where during May 2014 the most disastrous floods in history were recorded (UNDP BiH 2016).

Results of the precipitation analysis in the period 1961–1990, 1981–2010 and 2001–2010 for three cities (Sarajevo, Mostar i Banja Luka) is given in Table 8.4. In the period 1981–2010. The significant decrease in precipitation was recorded at the annual level in Mostar, while for the other two cities, the average rainfall values remained approximately equal.

According to data (UNDP BiH 2013) in the period 1961–2010 on a large part of the BH territory was a slight increase in precipitation at the annual level (see Fig. 8.5). The largest positive change in annual precipitation was recorded in central mountain areas (Bjelašnica, Romania) and Doboj region, while the biggest deficit was recorded in the south of the country (Bileća, Mostar). The greatest increase in precipitation was recorded in the autumn period, while the greatest

Table 8.4 Precipitation changes (mm) for period 1961–2010. (UNDP BiH 2013)

		Annual	Vegetation period	Spring	Summer	Fall	Winter
Sarajevo	1961–1990	932	468	226	242	241	223
	1981–2010	936	472	221	236	266	213
	Deviation	+4,0	+4,0	−5,0	−6,0	+25,0	+10,0
	2001–2010	1014	514	226	252	304	226
Mostar	1961–1990	1523	522	379	196	450	497
	1981–2010	1405	502	335	173	458	439
	Deviation	−78,0	−20,0	−39,0	−23,0	+8,0	−58,0
	2001–2010	1514	534	339	188	472	506
Banja Luka	1961–1990	1027	562	262	298	246	221
	1981–2010	1034	540	258	270	278	227
	Deviation	+7,0	−22,0	−4,0	−28,0	+32,0	+6,0
	2001–2010	1078	546	263	271	280	221

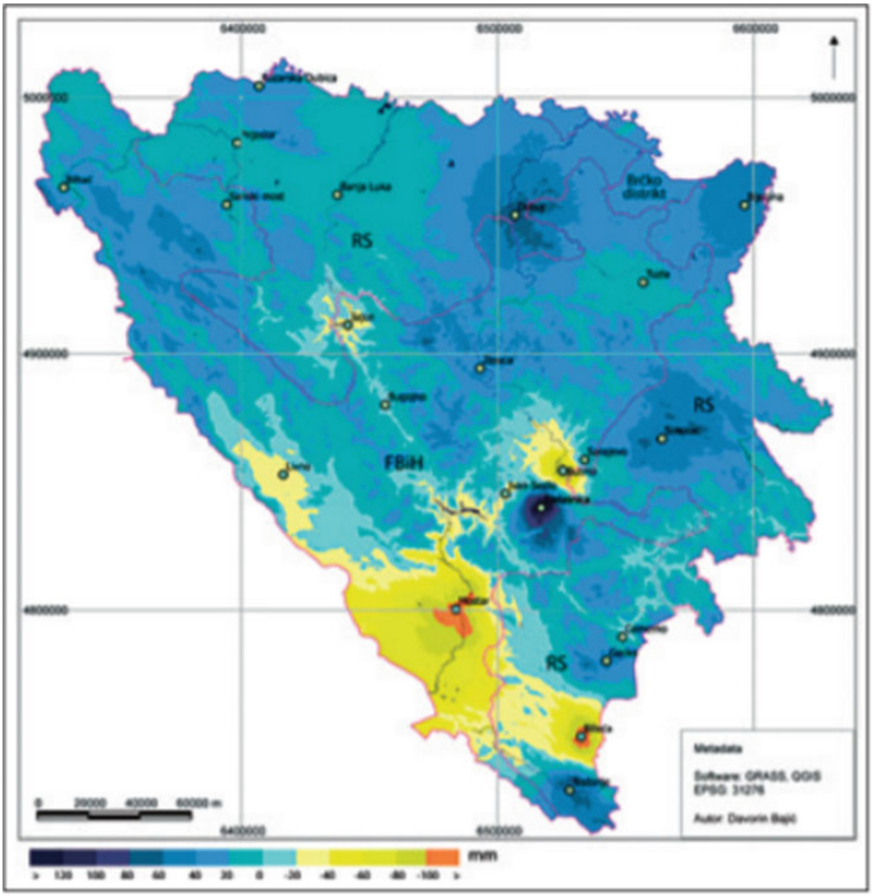

Fig. 8.5 Changes in annual precipitation in BH (the period 1981–2010 compared to 1961–1990) (UNDP BiH 2013)

decrease is during the spring and summer, and spatially, it is the most pronounced in the field of Herzegovina.

The number of days with precipitation exceeding 1 mm has decreased at almost entire territory, while the percentage of annual rainfall due to the occurrence of precipitation greater than 95 percent for the period 1961–2010 has been increased. In other words, although significant changes in precipitation are not observed at the annual level, the decrease in the number of days with intense precipitation greater than 1 mm and an increase in the number of days with intense precipitation is severely disturbed by the pluviometric regime. The pronounced change in the annual rainfall schedule with the increase of temperature is one of the key factors that condition the more frequent and more intense events of drought and floods in the territory of BiH (UNDP BiH 2016; Hadžic and Dreškovic 2012).

In all climate zones the precipitation inversion dominates in relation to demands—both in space and in time. Precipitation is at least in zones where the highest quality land resources (Semberija, Posavina, with an average of about 700 ÷ 750 mm) are present, and at least in the period of high demands for water in the summer months (Hadžic and Dreškovic 2012).

This phenomenon, expressed in all climatic areas, points to the need to regulate water by reservoirs. Also, the analysis of the intensity of 60-minute precipitation indicates high precipitation intensities (over 60 l/s·ha for a one-year return period, or over 100 l/s·ha for a five-year return period). The phenomenon of precipitation unevenness over time, as well as the high intensity of precipitation, indicate the necessity of building complex water drainage systems, especially in valley zones and karst fields, as well as the need for adequate disposition resolution and dimensioning of the rainwater drainage of the settlements. In all climatic areas, the actual evaporation is in the range of about 390 mm (Čemerno), to about 600 mm in some areas of Herzegovina (Trebinje—about 590 mm). Potential evapotranspiration is about 25% higher than the actual, while evaporation from the water surface is about 25% higher than potential evapotranspiration (Trebinje 860 mm) (Zavod za vodoprivredu R).

8.4 Basic Characteristics of Waters of Bosnia and Herzegovina

8.4.1 Introductory Considerations

Analysis of the water management in a country, according to Bonacci (Bonacci 2014), it is necessary to first define by which criterion the country water resources will be determined. Is this the amount of water per capita, the total amount of water in the state, whether it is precipitation falling on the territory of that country, its own water, surface water, underground renewable or non-renewable water, transit water, green, blue or some other water etc. Each of these criteria gives different results.

When assessing the available water in a certain area (Zavod za vodoprivredu Bijeljina 2006), a clear distinction must be made between terms: water resources and water present in a given area. In order for the water present to be included in the water resource category, it must satisfy four criteria. It should be defined by the position in the area-as a geophysical category. But it must have a fourth, extremely important role—the existence of conditions for the abstraction and use of water.

Conditions for the abstraction and use of water, and also water protection, are interconnected and make them a mix of activities ranging from solving purely technical problems to economic, social, and political ones.

Conditions for water use change over time and the water resources must be treated as a dynamic category. Generally, there is a tendency to reduce the water as a resource over time, due to the ever more stringent environmental, urban and social constraints. Water resources that can be assessed and quantified in an area are several times less than the water present in the river basin as the physical and temporal extent of unevenness strongly reduce water utilization. Very often, the possibilities for the water reservoirs are limited, particular those with high relative volumes, which serve for annual flow regulation. Constrains are usually related to environmental and social conditions.

8.4.2 Hydrographic Characteristics of Bosnia and Herzegovina

Bosnia and Herzegovina have significant water resources that represent one of the base economic potentials. Hydrographically, Bosnia and Herzegovina belongs to Black and the Adriatic Seas basins. (see Fig. 8.6).

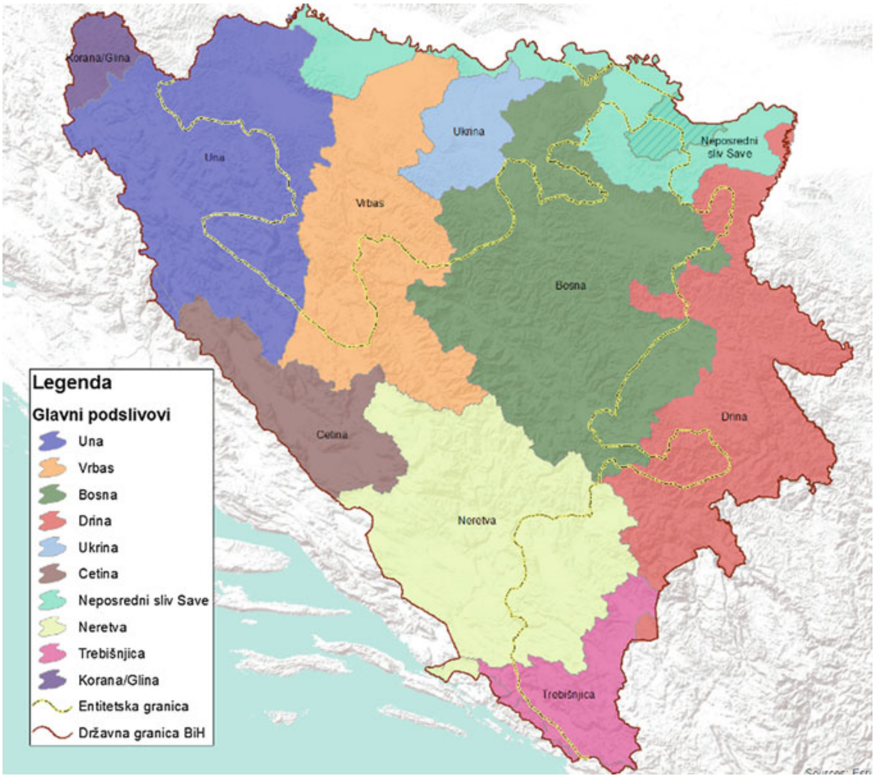

Fig. 8.6 Major River Basins and the related sub-basins in BH (Vodoprivreda 1994)

According to the World Bank report (World Bank 2003), the relative annual availability of water resources per capita rank Bosnia and Herzegovina in the countries of "average water availability" between 5.000–10.000 m^3/capita.

Average yearly precipitation in the territory of BH is 1.250 l/m^2 which theoretically results with an average yearly potential outflow of 2.030 m^3/s. However, it is estimated that only 57% of total precipitation water (1.155 m^3/s) outflows from the territory of BH (403 m^3/s outflows towards the Adriatic Sea and 722 m^3/s outflows towards the Sava river basin and to the Black Sea), (see Table 8.5).

Figure 8.6 shows the main water districts and the associated river basins. The largest tributaries of the Sava River are Una (214 km), Vrbas (240 km), Bosna (271 km), and Drina (346 km). The largest river basin of the Adriatic Sea is the river Neretva (218 km).

To present a clear view of water resources of Bosnia and Herzegovina characteristic hydrological parameters for the main river basins are given in Table 8.6.

Table 8.5 Water Balance of Bosnia and Herzegovina (Vodoprivreda 1994)

Area BiH (km^2)	Precipitation (mm)	Outlow (mm)	Outflow coefficient (%)	Evaporation (mm)	Volume of annual outflow $m^3 \times 10^9$
51.129	1.250	750	60	500	38

Table 8.6 Characteristic hydrological parameters for the main river basins of BH

Basin	Area of the basin (km^2)	Length of watercourses longer than 10 km	No. of inhabitants (1991)	Average flow (m^3/s)	Minimal flow $Q_{min.mont95\%}$ (m^3/s)
Immediate Sava river basin	5.506	1.693,2	635.353	63	1,5
Una in BH	9.130	1.480,7	620.373	240	41,9
Vrbas	6.386	1.096,3	514.038	132	26,3
Bosna	10.457	2.321,9	1.820.080	163	24,2
Drina in BH	7.240	1.355,6	422.422	124	24,1
Black Sea Basin	38.719	7.947.7	4.012.266	722	
Neretva and Trebišnjica	10.110	886.8	436.271	402	56,5
Cetina in BH	2.300	177	79.089	31	1,8
Adriatic Sea Basin	12.410	1.063,8	515.360	433	
Bosnia and Herzegovina	51.129	9.011,5	4.527.626	1.155	

The Una River is the right tributary of Sava river, and it forms the border between Croatia and Bosnia and Herzegovina. The catchment area is 9.130 km^2 and an average flow is 240 m^3/s. Vrbas has a basin of 6.386 km^2 and an average flow of 132 m^3/s. Bosna river has a catchment area of 10.457 km^2 and an average flow of 163 m^3/s. The Drina River is the border between Bosnia and Herzegovina and Serbia and Montenegro. The Drina River basin in BH is 7.240 km^2 and the average flow is 124 m^3/s. The Neretva River basin is the most important cross-border basin in the catchment area of the Adriatic Sea. Of the total length of the Neretva River of 222 km, only about 25 km runs through Croatia.

Rivers in BH are characterized by high gradients and relatively high flow rate (22 l/s/km^2). All rivers flow through the mountainous areas in the upper stream, while in the downstream sections near the confluence, run through the plains and often flood the areas. It is very important to emphasise that a large part of the BH watercourse and river basins belongs to the category of international, whether they constitute the border of state or just cross the borders. As already mentioned, the Sava River throughout its length in BH is the northern border, and the Una River is partly the western border to Croatia. The eastern border of BH towards Serbia is the Drina River. Interstate streams that cut borders are Lim and Jadar towards Serbia, Ćehotina towards Montenegro, and from the larger rivers towards Croatia are Neretva, Korana and Glina.

Last demographic census in BiH was conducted in 2013 when it was estimated that about 3.531.159 people lived Bosnia and Herzegovina. The number of inhabitants is about 1.000.000 lower than the pre-war one. However, more serious water balance analyzes have not been conducted after 1991. Assuming that, there were no significant changes in the water balance, for the purpose of this report the data from that period are used. Therefore, to the 1991 census, around 4.012.266 inhabitants lived in the area of the Sava River Basin, and in the area of the Adriatic Sea Basin, there were about 515.366 inhabitants.

Based on date given in the Table 8.7 it could be concluded that ¾ area of Bosnia and Herzegovina discharge towards the Black Sea has two times less average discharge (18 l/s/km^2) compared to ¼ of the country area that belongs to the Adriatic Sea, where the average discharge is 35 l/s/km^2. Also, around 88% of the

Table 8.7 Specific discharges of average and minimum water flow in Bosnia and Herzegovina, [1,12,14] (Sarić 2004; WMS FBiH 2011; Bonacci 2014)

Basin	Area (km^2)	No. of inhabitants (1991)	Average Discharge			Minimal Discharge		
			m^3/s	l/s/ km^2	l/s/ capita	m^3/ s	l/s/ km^2	l/s/ capita
Black Sea	38.719	4.012.266	722	18	0,18	118	3	0,03
Adriatic Sea	12.410	515.366	433	35	0,84	58	4,7	0,11
Bosnia and Herzegovina	51.129	4.527.626	1.155	23	0,25	176	3,5	0,04

population lives on the territory of the Black Sea Basin, and the average discharge is about 0.18 l/s/capita, which is five times less than in the Adriatic Sea Basin, where the average discharge is about 0.84 l/s/capita.

From the previous tables, it is obvious that the Bosna River Basin, bearing in mind the number of inhabitants, has the poorest values of water resources, while Neretva and Trebišnjica River Basin has the highest values. Observing sub-basins or smaller units within the basins, the problem of areal inequality becomes even more pronounced (Fig. 8.7).

The highest values of the average surface runoff are in the Neretva and Trebišnjica River Basin, then in the Vrbas River Basin, the Una River Basin, the Drina River Basin, and the Bosna River Basin. Basins with poor water resources (Bosna River basin, the immediate Sava River Basin, the upper Vrbas River Basin) have even poorer parts of the basin, such as the Spreča river basin, parts of the

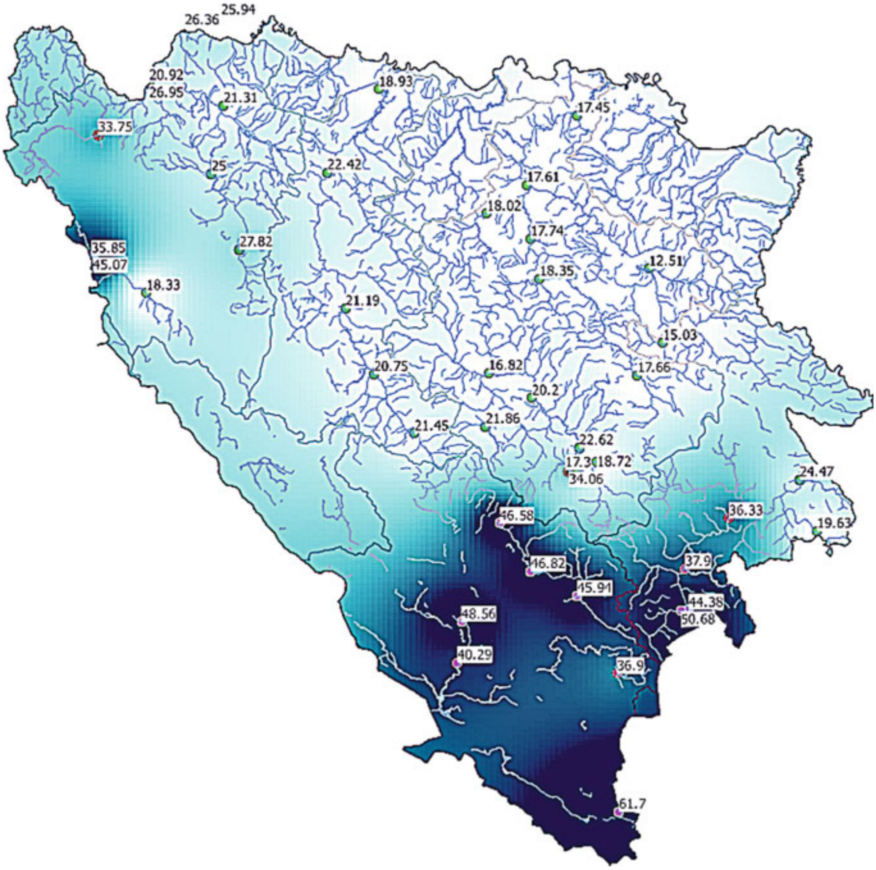

Fig. 8.7 The average surface runoff in BiH (l/s/km^2), according to the flows registered in the profiles of surface watercourses (UNDP BiH 2016)

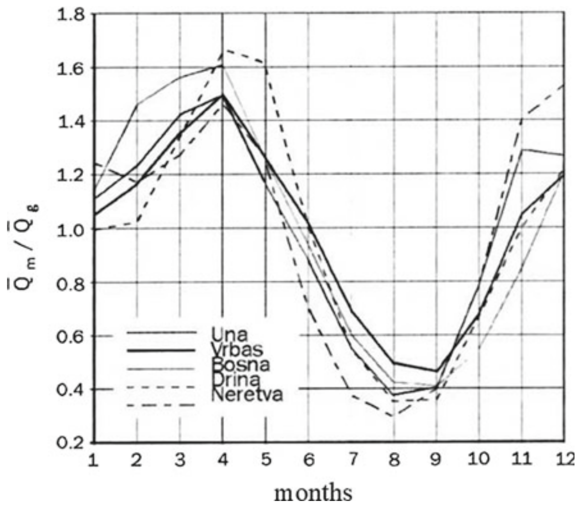

Fig. 8.8 The ratio of the multiannual average flow of the average monthly flows to the annual flow (Hrelja 2007)

immediate Sava River Basin, the sub-basins of Bosna River Basin, especially its middle and lower flows, the Miljacka and Lašva, Vrbanja, etc. (Vodoprivreda 1994).

Another, very important aspect that characterizes the water resources of an area is the temporal unevenness of the flow, which is reflected both in the annual and in the multi-annual irregularity. (see Fig. 8.8).

Although there are variations in the inter-annual vacillation of different watercourses, the Fig. 8.8 indicates that the multiannual average of the mean monthly flows during the summer months descends to merely 30–40% in relation to the mean annual flow values. On that way is reducing the amount of water of the main watercourse to merely 9–14% of the total mean annual mass during the three driest months (July–September). On the other hand, on average the most water-abundant months have around 50–60% higher flows than the mean annual values (Vodoprivreda 1994), so that around 34–39% of water mass within a mean year flows through the watercourse in this period (Table 8.8).

There are several natural lakes in Bosnia and Herzegovina. Lakes created as an extension of the riverbed or due to natural dams in riverbeds are mainly located on Pliva, Uni and Trebižat. Mountain lakes are of glacial origin and are found on the Dinarides, ranging from 0.01 to 3.5 MCM volumes. They are significant for their biodiversity, tourism and livestock breeding. Besides the natural lakes, there are about 30 artificial reservoirs in Bosnia and Herzegovina, mainly on Neretva and Trebisnjica and Drina River Basins. Most of them are made for hydropower production and have important roke for flood protection as well for the drinking water supply and irrigation. The total volume of reservoirs is about 3.9 BMC, with about 90% belonging to the Adriatic Sea Basin and the rest to the Black Sea Basin (Šeperovic and Imamovic 2011).

Table 8.8 Characteristic flows along river basins (Vodoprivreda 1994)

Basin	Average flow Q_{av} (m^3/s)	Specific average flow		Minimal flow	
		Average flow per Area Q_{av}/A (l/s/km^2)	Average flow per capita Q_{av}/capita (l/s/capita)	Average flow per Area Q_{av}/A (l/s/km^2)	Average flow per capita Q_{av}/capita (l/s/capita)
Immediate Sava river basin	63	11,4	0,099	0,272	0,002
Una in BH	240	26,3	0,387	4,589	0,067
Vrbas	132	20,7	0,257	4,118	0,051
Bosna	163	15,6	0,089	2,314	0,013
Drina in BH	124	17,1	0,293	3,329	0,057
Neretva and Trebišnjica	402	39,7	0,921	5,588	0,129
Cetina in BH	31	13,5	0,392	0,782	0,023

Drinking water supply is about 90% from underground resources. It was estimated that 16 m^3/s of groundwater could be exploited from all areas. Water requirements in 2020 are estimated at 35 m^3/s. Groundwater in Bosnia and Herzegovina is located in three geographically different areas with specific characteristics. In the northern part of the country, reserves of groundwater are on alluvial sediments along the Sava River and its tributaries at a depth of about 50 m. Artesian water is at 100–200 m. In the central part of the country, groundwater accumulates in cracks and pits of limestone massifs and appears on the surface as limestone wells in the Una, Sava, Bosna, Drina and Neretva basins. In the catchment area of the Adriatic Sea, the southern part of the country, where geology is primarily Karst, groundwater is mostly found in wells in the Cetina, Neretva and Trebišnjica basins. Wetlands in Bosnia and Herzegovina provide (Imamovic and Trožic-Borovac 2013) rich biodiversity but are under constant threat of habitat loss; changes in the hydraulic regime; water pollution; and erosion and saltation.

One of the most popular touristic destinations of natural lovers and tourists is wetland Hutovo Blato, the transboundary swamp located in the delta of the Neretva River, shared by Bosnia and Herzegovina and Croatia.

According to all the above, Bosnia and Herzegovina is a country that is perceived as rich in water resources. However, one must notice the big difference between the water fall and water that flows from the basin. There is the big difference in annual rainfall in the territory of BH and the distribution of runoff. If we consider areal and temporal irregularity of water availability and the unevenness water demand, it is very easy to conclude that status of the country rich in water resources could be just an illusion.

Additionally, analysis has shown that it is necessary to start researching the impact of climate change on hydrology and water resources in BiH as soon as possible. This is especially important from the aspect of the development of water management plans (Imamovic and Trožic-Borovac 2013) which must include appropriate measures for adaptation to climate change.

8.4.3 Water Use

Drinking water and sewage. The public drinking water supply system serves approximately 50% of households and other consumers in Bosnia and Herzegovina. Others use other types of alternative water supply that are outside the scope of water management and public health sector. Water supply sources are mainly based on the exploitation of groundwater (89% of total water supply), rivers (10.2%) and water from natural lakes and artificial reservoirs (0.8%). The urban population mostly has water from the water supply in their homes (96%), while in rural areas 29% of the population has water in the yard, 21% in the house and 18% use the pump. Water-borne epidemics usually occur seasonally, in smaller water supply systems not controlled by public health institutions. The water supply system can not meet the needs of consumers during the dry season when demand is not satisfactory in terms of quantity or quality due to the combination of inadequate water resources and inadequate infrastructure capacity. There are frequent breaks in supply.

Drinking water and sewage. The public drinking water supply system serves approximately 58% of households and other consumers in Bosnia and Herzegovina. Others use other types of alternative water supply that are outside the scope of water management and public health sector. Water supply sources are mainly based on the exploitation of groundwater (89% of total water supply), rivers (10.2%) and water from natural lakes and artificial reservoirs (0.8%). The urban population mostly has water from the water supply in their homes (96%), while in rural areas 29% of the population has water in the yard, 21% in the house and 18% use the pump. Water-borne epidemics usually occur seasonally, in smaller water supply systems not controlled by public health institutions. The water supply system can not meet the needs of consumers during the dry season when demand is not satisfactory in terms of quantity or quality due to the combination of inadequate water resources and inadequate infrastructure capacity. There are frequent breaks in supply.

Irrigation. In Bosnia and Herzegovina, there are no developed irrigation systems. Only about 0.65% of agricultural land is irrigated. Up to 1992 irrigation systems in BiH covered the total of 19,570 ha: (i) the Sava RBD—12,600 ha (Semberija—6,800 ha, central Posavina—800 ha and Lijevče polje—5,000 ha) and (ii) the Adriatic Sea RBD—6,970 ha (The Neretva river basin—5,540 ha, the Trebišnjica river basin—1,130 ha and karst poljes—300 ha). Many of the systems were not in function completely. After 1996 the situation got even worse due to war

Table 8.9 Percentage of population connected to public water supply (DEU BiH 2016)

Percentage of population connected to public water supply	FBiH (%)	RS (%)	BD (%)	BiH (%)
Percentage of population covered with public water supply systems which has, according to EU Drinking Water Directive "the continuously satisfactory water quality	36	34	25	35
Percentage of population covered with public water supply system which has occasional deviation from water quality standards given in EU „Drinking Water Directive	24	23	12	13
Total:	60	57	37	58

damage and negligence. If the arable land in BiH (without natural meadows) was about 1,100,000 ha at that time, it means that irrigation systems were made on 1.8% of arable land and that 191,620 ha or 17.4% were to be irrigated (IWMS RS 2014).

Hydropower Estimated hydro potential is about 6,800 MW, out of which some 35% is used in terms of capacity, or about 38% (about 9,000 GWh) in view of maximum possible electric power generation. According to "Strategic plan and programme of energy sector development in the Federation BiH" (2009), this is the lowest rate of hydro potential tapping in Europe. The construction of hydro-power structures has considerable effects on the non-power sector where these effects are most often not evaluated, or at least not in the right way. Hydropower potential for Bosnia and Herzegovina according to the present level of technical solutions for their use is 22.050 GWh (IWMS RS 2014). The most important rivers for the future development of hydropower are rivers Drina, Neretva and Trebišnjica (Table 8.9).

Flood protection. In Bosnia and Herzegovina, there is a constant flood risk. Floods threaten about 60% of the plain area of BiH. Floods appear more often in the plains through which the main rivers flow and where intensive agricultural production takes place. Despite numerous flood protection and flood mitigation facilities, many areas are often hit by floods. Damage from floods largely exceeds the capital value of buildings that should be built to prevent floods. In this sense, it is important to reserve places for reservoirs and retention.

However, the reconstruction of damaged buildings and the provision of necessary funds is a priority in relation to the construction of new flood protection facilities and mitigation of its consequences. Flood management is a cross-border issue, especially on the Sava River.

In December 2010, Bosnia and Herzegovina experienced the largest amount of precipitation recorded in the last 100 years, which resulted in massive floods on the entire territory. According to competent authorities, the hardest hit areas were on Drina River, in Central and Eastern Herzegovina. In these areas alone, more than 4.000 people were evacuated.

In May 2014, severe floods hit Bosnia and Herzegovina, Croatia and Serbia. Recently many countries in Western Balkan (Albania, North Macedonia) did also suffer from flooding. The series of floods pointed to the fact that flood prevention capacities in the countries in the Western Balkans are limited. Figure 8.9 presents a

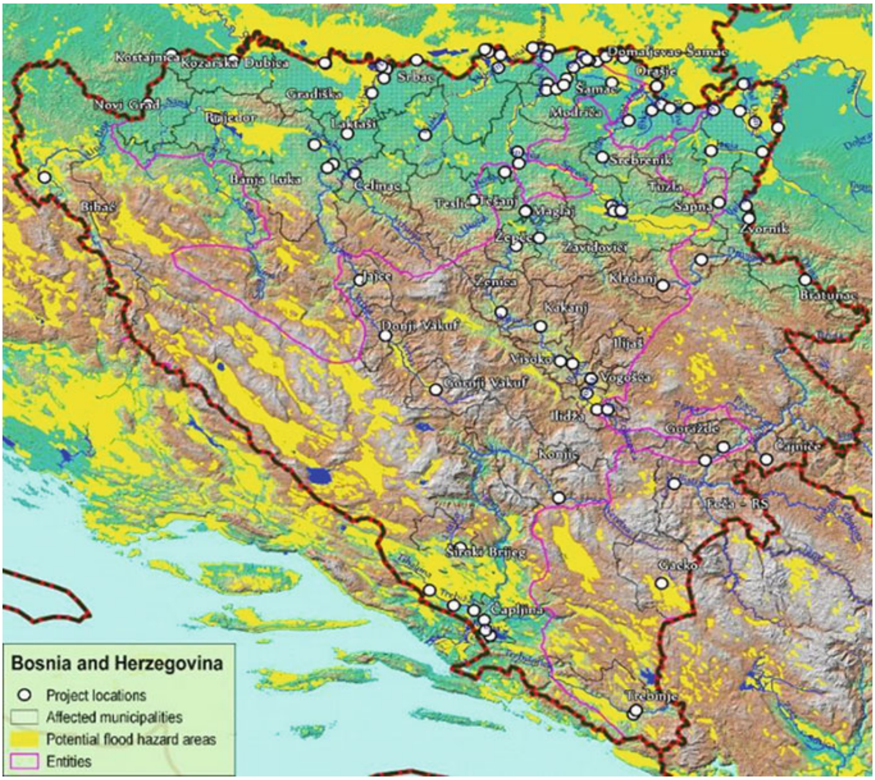

Fig. 8.9 Potential flood hazard areas (DEU BiH 2014)

map with the potential flood hazard areas and proposed flood protection structural projects. The analyses indicated that the private sector (small family business as well as mid-size and bigger companies), agricultural sector and a huge number of citizens suffered the most damage.

8.4.4 Water Quality Protection

Assessment of surface water quality is made on the basis of regular controls and analyses at selected locations. Controls and analyses of surface water quality in Bosnia and Herzegovina were systematically carried out from 1965 to 1991 at 58 gauging stations of river basins and sub-basins. Physico-chemical parameters of water quality were standard physicochemical parameters: temperature, appearance, pH values, alkalinity, dissolved oxygen and saturation percentage, hardness, total solid and suspended matters, COD and BOD, orthophosphates and total iron.

Compounds of nitrogen, ammonia, nitrates and nitrites were regularly checked at 10 sections. Microbiological and biological quality controls were carried out at most stations (WMS FBiH 2011).

Out of 58 gauging stations for the observed period, water quality was within required category only at 15 profiles. In certain parts of the river Bosna sub-basin, there are zones of total water quality deterioration as a consequence of the then industrial effluent pollution (IWMS RS 2014).

Comprehensive, systematic and continuous monitoring of water quality in the region of the Federation BiH, in the Sava river basin district, was resumed in 2005 at 39 gauging stations.

Pollution of surface and ground waters is higher in the Sava River Basin water district than in the Adriatic Sea water district. According to the RBM Plan for the Sava River Basin, Bosnia and Herzegovina have the largest number of agglomerations with more than 2,000 PE (248) compared with the other countries in the basin. They generate a pollution load of 2,363,009 PE, representing more than 1/3 (39%) of the generated pollution load across the entire Sava River Basin. Approximately the same pollution percentage (36%) was generated in 104 agglomerations in Croatia. The smallest input, less than 1%, is from Montenegro (seven agglomerations of size above 2,000 PE); together they produce 72,500 PE (ISRBC 2014).

Due to the lack of reliable data on population numbers and population allocation with public wastewater collection systems, the level of these connections was assessed on the basis of past projects and studies. Data show that only 36% of the population in RS and 47% of people in the FBiH and BD BiH are connected to the wastewater drainage system in the Sava River Basin. The existing wastewater collection systems cover mostly the central parts of urban areas and involve, almost, as a rule, two or more direct discharges into the nearby watercourses (Table 8.10).

The sewage system covers about 56% of the urban population, while coverage is much lower in smaller cities and rural areas—about 10%. The existing infrastructure is significantly damaged. Before the war, only seven cities in Bosnia and Herzegovina had facilities for purification of wastewater, of which only five are now in operation. Of the 122 plants for the treatment of industrial wastewater, only a few are operational due to war devastation and lack equipment (DEU BiH 2016). There are numerous operational and physical barriers to the improvement of water

Table 8.10 Percentage of population connected to public sewerage systems and wastewater treatment plants in 2011 (DEU BiH 2016)

Percentage of connection	FBiH (%)	RS (%)	BD (%)	BiH (%)
Percentage of population connected to public sewerage system in agglomerations (>2000 PE)	46	46	33	46
Percentage of population connected to wastewater treatment plants in agglomerations (>2000 PE)	5	2	0	3.5

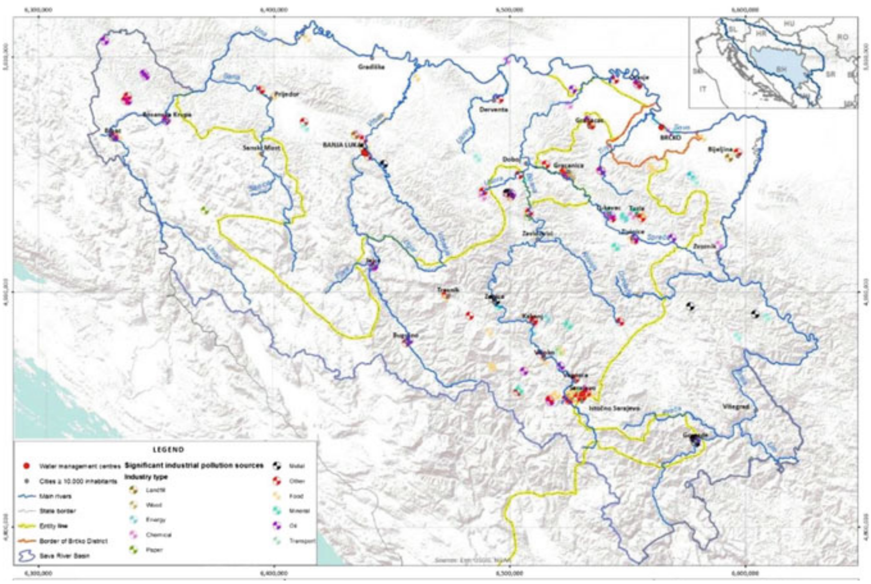

Fig. 8.10 Major industrial polluters in the Sava River Basin in BiH (DEU BiH 2016)

supply services, including the lack of autonomy of water utilities, poor organization of water utilities, neglect of maintenance; and large losses in the system (50%).

The analysis of anthropogenic pressures in the Sava River Basin in BiH showed 1,450,000 (44%) people living in 4382 (95%) settlements of less than 2,000 residents.

Total industrial pollution in the Sava River Basin in BiH amounts to 3,034,274 PE (population equivalent). One should note that 98% of that pollution (2,975,534 PE) is produced by 228 major polluters. The locations of those major industrial polluters are given in Fig. 8.10.

Data on the physical-chemical properties of surface water quality in Bosnia and Herzegovina since 2005 could generally be characterized by the fact that the largest source of pollution is waste water produced from urban areas (Sarajevo, Tuzla, Banja Luka, Zenica, Mostar, Bijeljina). There are also large industrial pollution, particularly from industrial plants in the Tuzla region (the river Spreča), while the industrial centers Zenica and Maglaj produce significantly less pollution than in the period until 1991. Concerning organic pollution, nitrogen and phosphorous pollution load in the Sava River basin, the results of the analysis (DEU BiH 2016) are presented in Fig. 8.11, Fig. 8.12 and Fig. 8.13 respectively.

Presently, according to the estimated in the Federation of BiH, there are 12 new or reconstructed urban waste water treatment plants with a total capacity of approximately 527,000 population equivalent. It is estimated that by the year 2021 about 25% of the population will be covered by wastewater treatment.

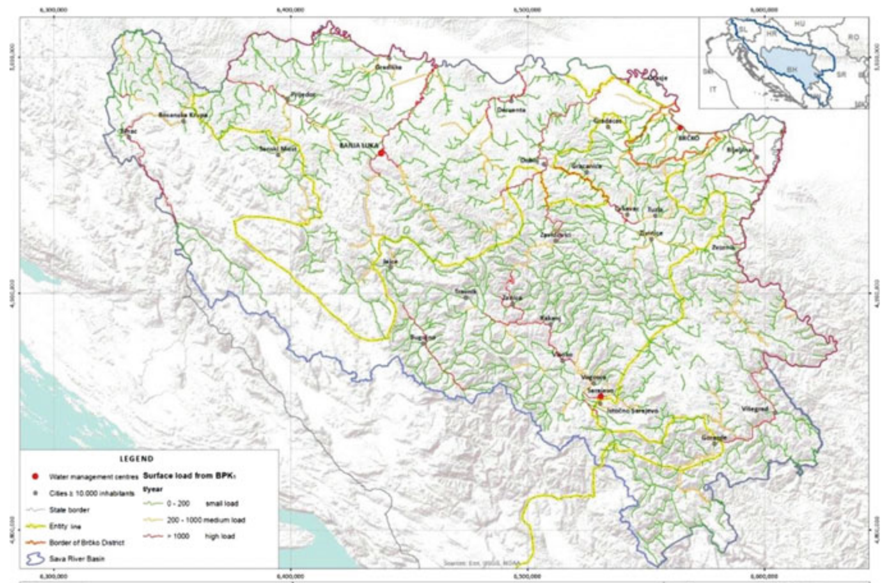

Fig. 8.11 Organic pollution in the Sava River Basin in BiH (DEU BiH 2016)

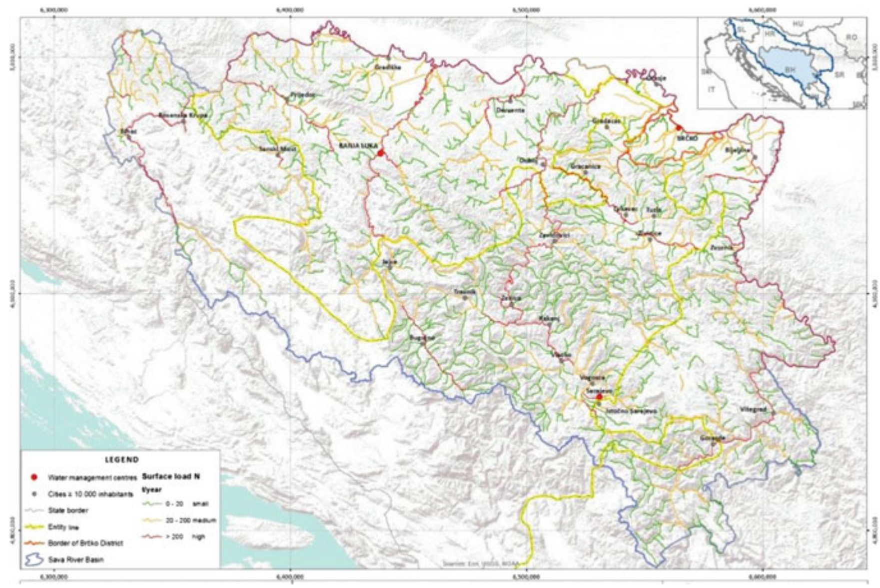

Fig. 8.12 Nitrogen pollution load in the Sava River Basin in BiH (DEU BiH 2016)

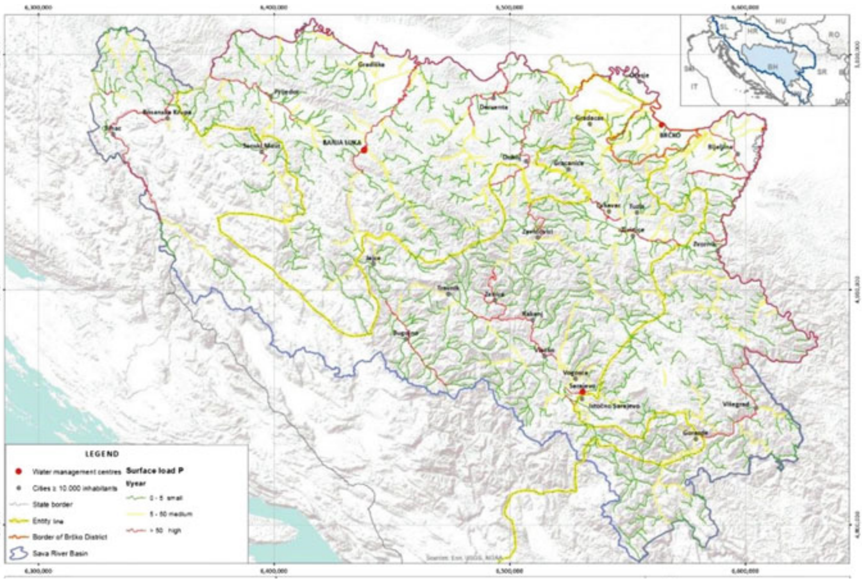

Fig. 8.13 Phosphorus pollution load in the Sava River Basin in BiH (DEU BiH 2016)

8.5 Water Management in Bosnia and Herzegovina

8.5.1 The Legal Framework for Water Management in BH

Bosnia and Herzegovina are the decentralized state with two entities (Federation of Bosnia and Herzegovina and Republic of Srpska) and Brcko District. FBiH consists of 10 cantons (each canton has its Government and Constitution). There are 16 administrative cities, 71 municipalities in FBiH and 57 municipalities in RS as the local administrative units. Brcko District is formed in 2000 as a separate administrative unit administratively under direct sovereignty of Bosnia and Herzegovina.

According to the Constitution of Bosnia and Herzegovina, the competences of water management (development, water protection, water use, water management and flood protection) are within the competence of entity units, i.e. within the competence of the Federation of Bosnia and Herzegovina, Republika Srpska and Brcko District. Foreign policy in the water sector are the responsibility of the institutions of BiH. Such a constitutional solution must be treated in two ways. On the one hand, it gives a lot of rights, because responsibility in water management—as the most vital national resource—is entrusted to the entities, giving them the highest level of state-legal legitimacy and significance. On the other hand, it is also a significant obligation, (Vodoprivreda 1994) because it implies great responsibility to ensure that in very complex management conditions, as the entity boundaries do not match hydrographic units, they find the best forms of management

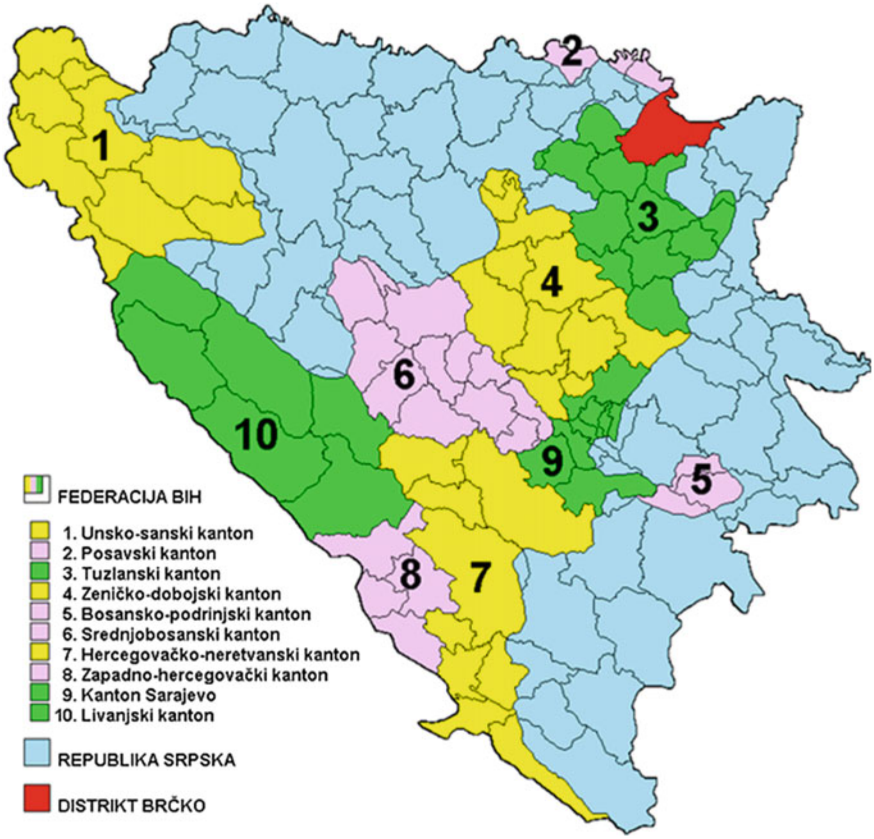

Fig. 8.14 Administrative structure of BiH, (DEU BiH 2011)

coordination, which will ensure optimum water management in conditions of very complex structure in the basins.

The boundary of the entities, as well as the cantonal boundaries (Fig. 8.14), disintegrated river basins. It has a negative impact on the integral and sustainable water resources management across the entire territory of the state (Spahić and Jahić 2014).

The Dayton Peace Agreement does not contain specific and clear provisions that would apply to the national water resources management in BH, that is, to the principles that the Entities and Brčko District should manage in the management of common water resources (resources crossed by the Entity or the district borderline). Therefore, BiH authorities do not have the legitimate to regulate these inter-entity relations. Also, there is no reliable institutional and process system within possible misunderstandings and disputes in the management of common water resources could be resolved. Some efforts have been made by the establishment of the

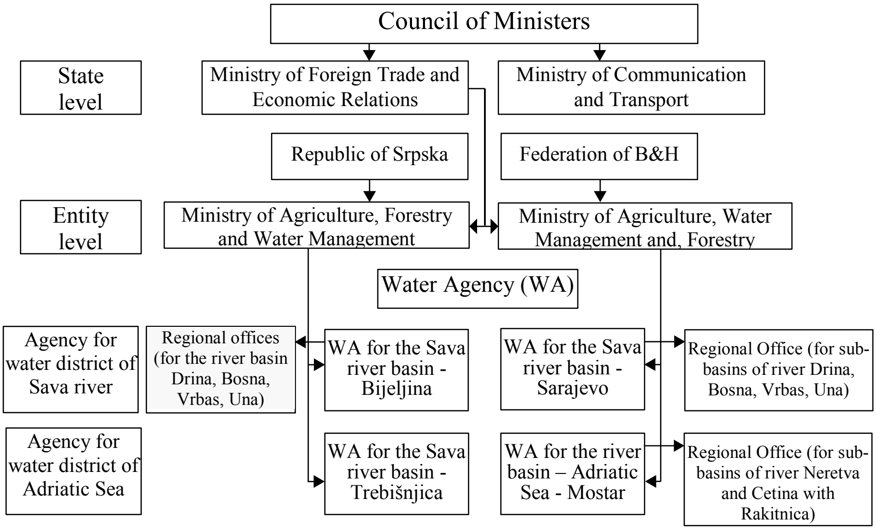

Fig. 8.15 Institutional framework for water management in Bosnia and Herzegovina (according to DEU BiH 2011 and Sparavalo 1999)

inter-cities body the coordination issues in the environmental sector. The representatives of the water management sector are included in this body because water management has a big impact is placed in the environmental division by the EU legislation.

As already indicated, foreign policy in the water management sector is under the jurisdiction of the BiH Institutions, while the Entities have the right to establish special relations with the neighboring countries, aligned with the sovereignty and territorial integrity of the State (DEU BiH 2011). Entities may conclude agreements with states and international organizations with the consent of the Parliamentary Assembly of BiH. Only the state is competent to negotiate and sign international agreements and conventions, which also applies to water management. However, the Entities and the Brčko District are responsible for their implementation.

Figure 8.15 shows the key institutions of Bosnia and Herzegovina that, in addition to several other activities they perform, participate in processes essential for water resources management. Such a complex structure certainly leads to the inefficiency of the water management system, both in the territory of the state and in some parts of it.

Water, due to its importance for the development of other sectors of the economy, is also the subject of legislation that defines the scope of activities at all levels, from the State, Entity, Cantonal and local.

In January 2008, two water agencies were established in the FBiH: The Water Resources Agency of the Sava River and the Adriatic Sea Water Agency. In January 2013, the Public Institution “Voda Srpske”, responsible for water management in the Republic of Srpska, was established in the RS instead of water agencies of the Sava river basin district and Trebišnjica river basin districtt. Within the Entity Ministries of Agriculture, Water Management and Forestry, there is a Sector for Water Management, which is responsible for the entity water management strategies and policies, the adoption of standards and regulations; ensuring compliance with laws and regulation through the granting of permits and licenses, etc., but also for supervision of the work of the Public Institutions (Water Agency).

8.5.2 Legislation and Water Sector Policies

The basic legal act in the field of water is the Water Law, which regulates the water management within the territory of the Federation of Bosnia and Herzegovina (FBiH)[3] and Republic of Srpska (RS).[4]

Water management, according to the Water Law, includes water protection, water use, protection against harmful effects of water, and the regulation of watercourses and other waters. The laws regulate the financing of activities, water property and public water property, water facilities, legal entities and other institutions responsible for particular issues in water management and other issues related to water in the FBiH and RS. The purpose of the Water Law is to ensure integrated water management with the aim of achieving good water status and preventing its degradation, achieving sustainable water use, ensuring fair access to water, promoting social and economic development, ensuring protection from harmful effects of waters, public participation in decision-making, fulfillment of the undertaken international obligations, etc.

Water management issues in the FBiH are also regulated through the cantonal legislation. In accordance with the Water Law of FBiH from 2006, the cantons are obliged to harmonize the provisions of the cantonal water laws with the provisions of the Water Law FBiH. This law also established the scope of the canton's powers to regulate water management issues with its regulations (Sparavalo 1999). Namely, the cantonal water laws regulate issues assigned to the cantons by the Water Law of FBiH.

Under the Government of the Brčko District of BiH, there is the Department of Agriculture, Forestry and Water Management—Forestry and Water Management Subdivision, responsible for water management in the district.

A very significant change made by Water Laws is related to the public participation[5] u processes of preparation and adoption of the Water Management Plans for the water districts. This, as well as a number of other changes that have adopted

[3]Water Law FBiH ("Official Gazette FBiH", 70/06).

[4]Water Law RS ("Official Gazerre RS", 50/06).

[5]Decree on rules for participation of interested public in the procedure of preparation of federal legal regulations and other acts, Official Gazette FBiH 51/12. Regulation on the manner of public participation in water management Sl.gl.RS 35/07.

through the water laws, are accepted changes in order to harmonize the existing water management system with the requirements of policy and legislation of the European Union. The Water Framework Directive (2000/60/EC), as well as a number of other EU regulations,[6] are the backbone in relation to which the water resources management system in Bosnia and Herzegovina is developing.

The Water Law of 2006 defined the basic territorial unit for water management, watershed (district). On the territory of the FBiH, two watershed are defined: the watershed of the Sava River and the watershed of the Adriatic Sea.

In order to carry out the water management tasks, two Water Agencies have been established, the Agency for Sava River Basin Watershed (AVP Sava) and the Agency for Adriatic Sea Watershed (AVP Adriatic Sea), with its headquarters in Sarajevo and Mostar. For the more efficiently performing, it was planned to establish regional offices for the sub-basin of the Bosna river in Zenica, the Una River in Bihać, the sub-basin of the Vrbas River in Jajce and the sub-basin of the Drina river in Goražde.

In accordance with the Water Law of the RS, for the purpose of water management, two regional river basins (water areas, districts) are defined: the Sava River Basin regional Agency and the Trebišnjica River Basin regional Agency, with its headquarters in Bijeljina and Trebinje. These agencies were abolished in 2013 and a unique public institution “Vode Srpske” has been formed.

For the more efficiently performing, it was planned to establish regional offices for the sub-basin of the Una River (Sana) in Prijedor, the sub-basin of the Vrbas River in Banja Luka, the sub-basin of the Bosna River in Doboj and the sub-basin of the Drina River in Visegrad.

The most important planning documents for long-term water management in BiH are the Water Management Strategy of the FBiH 2010–2020 and the Integrated Water Management Strategy of RS 2015–2024. The fact that two strategic documents have been prepared in BH for a different period indicates the difficulties that can be derived for the water resources management sector.

8.5.3 *Basic Characteristics of Water Management and Goals*

Today’s state of the water legislation of Bosnia and Herzegovina has distinct specifics that distinguish it from national water systems of neighboring countries or the countries of Southeastern Europe. These specificities arise, above all, from the

[6]Directive on the Protection of Groundwater against Pollution and Degradation (2006/118/EC); Directive on Treatment of Municipal Waste Water (91/271/EEC); Directive on protection of waters against pollution caused by nitrates (91/676/EEC); Drinking Water Directive (98/83/EC); Water quality management directive lease (2006/7/EC); Directive on the assessment and management of flood risks (2007/60EC); Directive on Strategic Environmental Assessment (2001/42/EC); The Environmental Impact Assessment Directive (85/337/EC); The Habitats Directive (92/43/EEC) and a number of other important EU documents.

constitutional character of Bosnia and Herzegovina, which consists of the entities: The Federation of Bosnia and Herzegovina and the Republika Srpska, and the Brčko District. The Peace Agreement for Bosnia and Herzegovina (Dayton), specifically Annex 4, defines the responsibilities of BiH institutions and institutions of its constituent Entities in Article III. Water sector does not appear explicitly in the Constitution, nor in the competencies of the state of BiH, nor in the responsibilities of the Entity. However, according to the provisions of Article III.-3a, to which "All government functions and powers not conferred by this Constitution are explicitly entrusted to the institutions of BiH belong to the Entities"—it follows that the water sector belongs to the Entities.

According to existing legislation, the key competencies for water resources management in BiH are distributed at the following levels:

- level of Bosnia and Herzegovina;
- level of Entities and Brčko District;
- level of cantons (only in FBiH);
- level of local administration (cities and municipalities).

Although complicated and complex due to the political system, water resources management planning in Bosnia and Herzegovina can be called flexible and interactive at Entity levels. This planning directs development towards potential resources but leaves enough space for the implementation of adaptive solutions. First, water resources are analyzed, the scope of needs is roughly considered, defining possible conflicts of interest of stakeholders, protection and regulation of waters; define potential conflicts of interest in the water using activities, use of space; define priorities in conflict situations. The results are adaptive solutions that are not unequivocal, and that can be adjusted to certain changes in development processes. However, it should also be emphasized that such solutions are often not the most optimal from the aspect of sustainable integrated water resources management, because due to the political organization of the state, they are brought at the entity levels, which is not the area of a certain catchment within the borders of BiH.

One can say that this type of planning is characteristic for the countries of regulated market economies, due to the wide range of ownership relations. This type of planning has to be elastic, oriented to the development and allocation of capital towards resources, while not imposing unnecessary rigid restrictions, proved to be the only possible in a country like BiH. A different concept of planning would not be possible even if deterministic planning would be desirable, due to a number of uncertainties. A different planning concept would not be possible even if deterministic planning would be desirable, due to numerous uncertainties. Specifics and uncertainties that determine this kind of planning are among others: No projections of demographic development, because in this respect the situation in Bosnia and Herzegovina is not yet clear; There are no valid projections of long-term economic development, and there is a very uncertain projected need for water; There are uncertainties in the world market, especially in the capital market, which have an impact on B&H. (Vodoprivreda 1994; UNEP BiH 2004).

Water management solutions are basic and provide all the necessary data on which other economic systems can adapt their development according to realistic resource possibilities and limitations in the field of water. Therefore, the efficiency of water management would be much better if respected solutions were adopted at the level of the catchment areas, and not administrative units. Water resources management planning treated in this way is inseparable from physical planning, i.e. water management plans precede the preparation of physical plans, and they are part of the environmental plans. It is necessary to include an interdisciplinary approach in decision making and to ensue continuous activity that is dynamically adjusted to the economy, society and its needs.

Also, it should be noted that water management solutions for the transboundary river basins (Sava, Drina, Una, Neretva) should be negotiated and harmonized with the neighboring countries and with the international obligations defined by relevant documents. BiH is a signatory of the Danube Convention and members of the ICPDR. Beside Danube Convention two very important treaties for BH transboundary river basins management are enforced: Framework Agreement on the Sava River Basin (FASRB) and Bilateral Agreement with Republic of Croatia (among the other issue concerning water management of Adriatic Sea river basins Neretva-Trebišnjica, Krka and Cetina)—signed 1996. Also, two Bilateral Agreements are in preparation: the Agreement with Republic of Serbia, with the aim to deal with Management of Drina River Basin (Sava's tributary) dominantly regarding flood protection and hydropower generation and the Agreement with Republic of Crna Gora (Šeperović and Imamović 2011; DEU BiH 2016).

Having in mind all above mentioned, it is concluded that one of the obstacles to water resources management in BiH is the lack of a state-level body that would be responsible for overall water management and coordination of activities between entities as well as between neighboring countries. There are initiatives to create an inter-entity water management agency in order to overcome the problem. This could certainly be a satisfactory solution in the field of water resources management in BiH.

8.5.4 Conclusions and Recommendations

In Bosnia and Herzegovina, since the Dayton Agreement, there is no clear, organized structure for water management at the state level. This is certainly a major challenge since the FBiH, RS and BD have their separate constitutions and governments, separate legislation, including water management and environmental legislation. It is obvious that differences in entity water management structures make it impossible to effectively manage water resources.

In Bosnia and Herzegovina, itself, given the fact that six of the seven rivers flow through both entities and pass through at least two cantons, there is a clear need for co-ordination and co-operation on the inter-cantonal and inter-entity basis.

Another significant obstacle for the water sector is the lack of a national-level organization, responsible for overall water management and coordination. This leads to numerous problems and obstacles to effective international cooperation in the field of water resources. For example, although Bosnia and Herzegovina is a signatory to numerous international water conventions (including: the International Convention for the Protection of Birds, the Convention on the Conservation of Life Resources at Sea, the Ramsar Convention on Wetlands and the Convention on Biological Diversity, the Convention on Cooperation in the Field of sustainable use of the Danube River), due to the lack of a systemic solution to the competencies in water management at the state and entity level, there is still a significant number of multilateral water and environmental agreements that Bosnia and Herzegovina has not yet signed. Also, participation in important regional initiatives is often restricted to Bosnia and Herzegovina for observer status due to the lack of a state-level body that would take over and coordinate BiH's active participation in resolving international issues. Therefore, Bosnia and Herzegovina misses significant financial support and technical assistance provided by these agreements to support the implementation and monitoring of international procedures and standards.

Generally, it could be said that Bosnia and Herzegovina still faces the problems with inadequate (DEU BiH 2011): (i) urban and industrial water supply; (ii) infrastructure (water and sewage-treatment plants and outdated water pipelines and sewage systems); (iii) protection of the drinking water resources; (iv) collection, treatment and disposal of urban and industrial wastewater; (v) flood risk control; (vi) protection of the water ecosystems; (vii) capacities and expertise in the institutions and utility companies; etc. Besides those problems, very significant issue is the development of the institutional framework for water management sector. These problems exist due to the lack of Integrated water resources management strategy and institutional arrangement at the state level, insufficient financial support and incompatible legislation.

Due to the complexity of governance in Bosnia and Herzegovina, the management capacities of the responsible authorities in the water resources management are limited, especially the capacities of public authorities at the state level. This brings attention to the fact that local and national authorities sometimes have different priorities (e.g. local tourism versus. national energy strategy; or local agricultural interests versus. national biodiversity strategy). This is nowhere more apparent than in Bosnia and Herzegovina where good cooperation across entity lines in the field of monitoring may be contrasted with a lack of inter-entity cooperation on permitting. "Authorities in both entities have complained about a lack of inter-entity cooperation on permitting. A lack of cooperation in permitting has been described in the case of large hydropower facilities, in which Republic of Srpska unilaterally changed permit conditions regarding the return of flow to the main channel that had been agreed with the Federation of Bosnia and Herzegovina. This resulted in a situation where minimum flow was not guaranteed to the downstream Federation of Bosnia and Herzegovina users.

The water permit is still separate from other aspects of integrated permitting, which presents a level of difficulty in coordination. The water sector also tends towards a larger number of permits for the various aspects of water use, including the manner, conditions and scope of water use and wastewater discharge, the storage and release of hazardous and other substances that might pollute water, and the conditions for other works influencing the water regime.

In order to improve the state of governance in the water sector, authorities in BiH should be focused on: (i) strengthening the institutional framework, preparation of strategic, planning and legal documents at the state level; (ii) Improving cross-sectoral cooperation and coordination at all levels of government; (iii) harmonization of water legislation and planning documents with EU policies and legislation; (iv) Improving water management infrastructure; (v) Develop adequate economic and financial instruments in the management of water resources. The fact is that for the fulfilment of the set goals, take a long time to respond to the challenges, but well water resource management should be a priority in the development plans of each country, as well as Bosnia and Herzegovina.

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Part V
Water Resource Management in Serbia

Chapter 9
Water Resources of Serbia and Its Utilization

Borislava Blagojević, M. Langović, I. Novković, S. Dragićević and N. Živković

Abstract Serbia is landlocked country with territory of 88,361 km^2 primarily draining through the Danube River/Black Sea Basin. The rivers Tisa, Sava and Velika Morava are three significant tributaries flowing into the Danube River on the territory of Serbia. The dominant natural conditions influencing water resources in the country include characteristics of moderately continental climate, with average monthly air temperature ranging from 0 °C in the winter to 23 °C in the summer, and average annual precipitation sum of 720 mm. The relief changes from mountaneous forms in the south, east and west, over hilly-mountaneous in the central part surrounding the Morava River valleys, to the plain in the north of the country. Geological structure of Serbia is distinctively complex, predominant automorphic soils quickly drain excess water, and forest land is present on one third of the territory with deciduous trees as prevailing forest type. Such natural conditions provide for the average river network density of 747 m/km^2, a few natural lakes from the most famous Palić (5.6 km^2) to a tiny karstic lake Vrmdža, and groundwater accumulation estimated to potentially utilizable 67 m^3/s. The primary water resources utilization sectors in the country are water supply and hydro-power production. Water supply for population and industry is currently distributed from numerous local groundwater and surface water sources, together with 18 regional water supply systems. Hydropower provides for almost one third of the total electricity production in Serbia, with lead hydropower plant being Djerdap I on the Danube River. Irrigation in agriculture holds great, yet insufficiently utilized potential, because the soil and climatic conditions favour many cereals, industrial and fodder plants, fruits and vegetables. In this sector, with present water consumption of 1,600 m^3/ha per year Serbia is behind its neighbouring countries. The same stands for water transport, present up to 5% in the total load transport in Serbia nowadays. However, the traffic of passengers and the number of cruise ships

B. Blagojević
Faculty of Civil Engineering and Architecture, University of Niš,
Aleksandra Medvedeva 14, Niš, Serbia

M. Langović · I. Novković · S. Dragićević · N. Živković (✉)
Faculty of Geography, University of Belgrade, Studentski Trg 3/III, Belgrade, Serbia
e-mail: jatepo3@gmail.com

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have been steadily increasing in the last two decades. Tourism, sports and recreation on rivers and lakes, together with spa tourism play an important role in the overall tourist offer of the country. Also, a promising sector in water utilization in Serbia is fish farming, which together with catch in fishing waters satisfy almost 1/2 of the domestic needs. The chapter describes legislation, regulatory and institutional framework for water utilization, and provides the detailed data and information about natural conditions, as well as the latest monitoring data on water resources quantity and quality significant for water utilization in Serbia. The data and information are mapped and many indicators crucial for understanding commercial, economic and other activities related to water utilization are presented.

Keywords Natural conditions · Water resources utilization · Integrated water management approach

Abbreviations

amsl	Above mean sea level
Bill	Billion
DTD	Danube-Tisa-Danube Hydrosystem
SEPA	Environmental Protection Agency
HPP	Hydroelectric power plant
HS	Hydrologic station
ILI	Infrastructure Leakage Index
Mill	Million
RL	Real Losses
RHMSS	Republic Hydrometeorological Service of Serbia
RS	Republic of Serbia
SHPP	Small Hydroelectric Power Plant
SPRS	Spatial Plan of the Republic of Serbia
UNCLOS	UN Convention on the Law of the Sea

9.1 Introduction

Water resources of Serbia comprise all its surface water and groundwater. Surface water features include rivers, natural lakes and reservoirs. These waters drain through three sea basins: The Black Sea Basin, the Adriatic Sea Basin, and the Aegean Sea Basin. Groundwaters that participate in the feeding of rivers and other hydrological objects are represented in several forms: accumulated in Neogene sediments, as sub-artesian and artesian aquifers, and as a special type of aquifers in karst formations. Water resources, characterized by their quantity, quality, and location, represent an important natural condition and factor for the survival and life of the population in Serbia, its commercial and economic activities.

Therefore, numerous water resources utilization options are systematically studied, planned, organized, implemented and monitored.

9.1.1 Legislation, Regulatory and Institutional Framework

The first Water Law in Serbia was adopted in 1878. This Law foresaw the procedure for seeking and obtaining a license for the use of waters with respect to the prescribed rights and conditions. Other significant laws include the Water Regulation and Use Law (1905), and the Law from 1965 that introduced a novelty—social property over water as a good of general interest (RWD 2018). The current Water Law was adopted in 2010 (Water Law 2010a). It was followed by the changes (Law on Changes to the Water Law 2012) and amendments (Law on Changes and Amendments to the Water Law 2016). The current Law is also followed by a series of by-laws including regulations, decrees and acts that regulate specific areas and activities closely concerning water. The Law is based on an integrated water management approach, and the EU Water Framework Directive, while by-laws consider the relevant EU Directives derived from the main one—The Water Framework Directive (2000).

Water resources management in Serbia takes place through the development and implementation of the key planning documents: Water Management Strategy on the Territory of the Republic of Serbia (hereinafter: the Strategy) (Water Management Strategy on the Territory of the Republic of Serbia until 2034 2017), the Danube River Basin Management Plan, and Water Management Plans for Water Areas. There are also plans for the protection against harmful effects of water, such as: Flood Risk Management Plan, General and Operational Plan for Flood Protection, as well as Plans for Water Protection (Pollution Protection Plan and Monitoring Program 2010b). The Strategy is a planning document that sets out long-term water management guidelines for implementation of water sector reforms aimed at achieving the necessary standards in water management, including organizational adjustment and systematic strengthening of professional and institutional capacities at national, regional and local levels. In 2016, the Government of the Republic of Serbia adopted the Strategy for the period 2016–2034. Analysis and research for the development of the Strategy were done according to the Law on Waters. The Strategy holder is the Ministry of Agriculture, Forestry and Water Management. The main strategic goal is to achieve integrated water management, i.e., harmonized water regime throughout the territory of the Republic of Serbia, and to ensure such water management maximizes economic and social effects in a fair and sustainable manner, and with respect to the international agreements. The Strategy contains projections of the necessary means for functioning and development. The projected development and efficient management of the water sector requires funds of about 21.7 bill. EUR in the next twenty years (Water Management Strategy on the Territory of the Republic of Serbia until 2034 2017).

Due to the complexity of the water issues, the Government of the Republic of Serbia includes 10 out of 18 Ministries in the drafting and/or implementation of water-related planning documents. The Government also relies on numerous bodies and organizations, including the Republic Hydrometeorological Service; Republic Water Directorate; Public Water Management Companies; Environmental Protection Agency; Institute for the Development of Water Resources "Jaroslav Černi"; Academia; Institute for Nature Conservation of Serbia; The Office for European Integration.

According to the Water Law (2010a) the Republic Water Directorate, as an administrative authority within the Ministry of Agriculture, Forestry and Water Management, carries out tasks related to: water management policy; multipurpose water use; water supply excluding water distribution; protection against water; implementation of measures for water conservation and planned rationalization of water consumption; regulation of water regimes; monitoring and maintaining the water regimes that make and cross the border of the Republic of Serbia; inspection supervision in the field of water management; performs other tasks in this field.

Public Water Management Companies "Srbijavode", "Vojvodinavode" and "Beogradvode" are the companies of general interest, covering engineering activities and technical consulting in the following areas: (1) watercourse regulation and protection against harmful effects of water; (2) water management and use; (3) water protection from pollution. The companies operate under both the Water Law and the Law on Public Enterprises (Law on Public Enterprises 2012).

The Republic Hydrometeorological Service of Serbia (RHMSS) provides support in water management. It is a state administration body—a unique organization with the status of a legal entity, performing meteorological and hydrological tasks according to the Law on Meteorological and Hydrological Activities, adopted in 2010 (Law on Meteorological and Hydrological Activities 2010). The history of RHMSS dates to 1848 with regular meteorological measurements in Belgrade, while the first hydrologic stations were installed on the Sava River near the capital Belgrade in 1920, and at the Danube River close by the city of Smederevo (RHMSS 2018).

In 2011, the Environmental Protection Agency (SEPA) was established as a body within the Ministry of Environmental Protection. This agency, inter alia, performs monitoring the quality of water sampled by RHMSS, including the implementation of prescribed and agreed programmes for the water quality control of the aquifer with free groundwater table level (the first, phreatic, artesian aquifer) and pressurized groundwater (deep, sub-artesian).

The RHMSS monitoring networks comprise meteorological, hydrological surface and groundwater stations, nowadays excluding the territory of Kosovo and Metohija. The monitoring data is processed and published in Yearbooks, available on RHMSS website. Climatological observations that include 51 meteorological events and measurements of 12 meteorological elements were performed at 85 stations in the year 2016 (RHMSS 2017a). The network of surface hydrological stations has 184 stations, 69 reporting in real time. The water level is monitored at all stations, the water temperature at 74, water flow at 148, the ice phenomena at

172, and 29 stations are in the system for estimating the suspended sediment transport (RHMSS 2017b). The groundwater hydrological stations cover the regions with intergranular porosity by 355 piezometers located individually or in clusters. The water table level is monitored at all piezometers, and temperature at 149 (RHMSS 2017c).

9.2 Key Facts About Water Resources

9.2.1 Natural Conditions

9.2.1.1 Climate Characteristics

The climate of Serbia is moderately continental with more or less pronounced characteristics. The most significant geographical features, characterizing and affecting climate characteristics in the region of Serbia, are the Alps, Mediterranean Sea, Pannonian Plain and the Morava River valley, Carpathian and Dinaric Alps, as well as inland hilly—mountainous area with its landforms. The southwest part of Serbia (Metohija, Beli (White) Drim river basin) is under the influence of modified Mediterranean climate.

Air temperature. The influence of continental climate is manifested in the Pannonian plain and its surrounding, the valleys of Velika (Great) and Zapadna (West) Morava rivers and the eastern part of Serbia. Therefore, warm summers and cold winters are characteristic for the north and central lowland of the country with average temperature difference from over 22 °C (January–July). The average annual air temperature in these parts of Serbia is between 11 and 12 °C. The average annual air temperatures increase from the north (Palić 10.5 °C) to the south (Belgrade 12.5 °C), also from the west (Sremska Mitrovica 10.8 °C) to the east (Jaša Tomić 11.2 °C). The effects of a changed continental and mountain climate (Sjenica 6.7 °C) are felt 800 m above the sea level, while mountain climate is dominant 1400 m above the sea level (Kopaonik 3.7 °C). The average annual temperatures are linearly decreasing with altitude rise, at an average vertical gradient of—0.6 °C/100 m. Changed effects of a mild Mediterranean climate are felt in the Metohija area (Prizren 11.8 °C).

All seasons are manifested on the territory of Serbia. The warmest is the summer with the average seasonal temperatures from 21 to 22 °C. The average winter air temperature is lower than 0 °C in higher areas (the lowest at Kopaonik—4.4 °C) while at other meteorological stations it ranges from 0 to 2 °C, except for Belgrade with 2.4 °C because of the emphasized urbanization effect. At the half of the meteorological stations, during the spring and the autumn, the average seasonal temperature reaches values between 11 and 12 °C. The average seasonal air temperatures show the coldest spring is on Kopaonik (2.4 °C), the warmest in Belgrade (12.9 °C), and the same holds in autumn—the warmest is Belgrade (12.7 °C) and the coldest Kopaonik (4.6 °C). Temperature in July is the highest (20–23 °C, in the mountains 13–17 °C), and January the coldest, with average monthly air temperature in the most of the stations from 0 to 1 °C, and on the mountains down to -4.5 °C.

Precipitation. Annual precipitation sums vary from about 550 mm in the north up to 2000 mm on some mountain peaks, while average precipitation in Serbia is approximately 720 mm (Fig. 9.1).

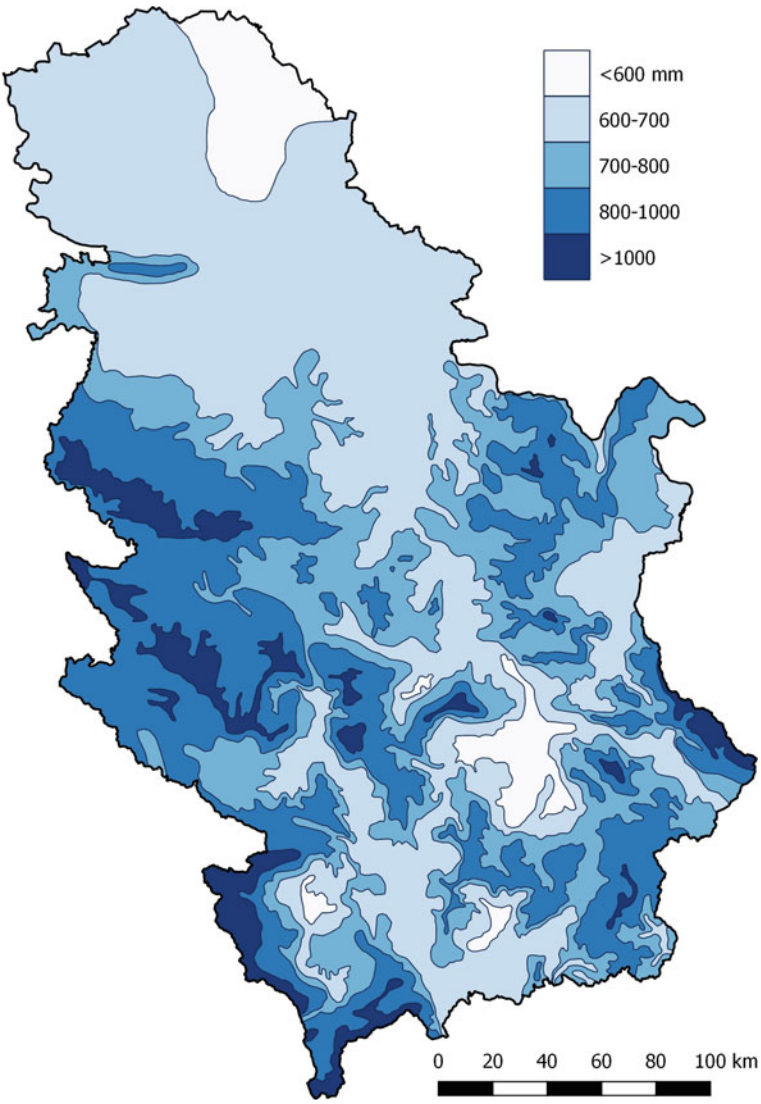

Fig. 9.1 Isohyet map of Serbia for the period 1961–2014

The vertical gradient of precipitation is not constant; it ranges from 25 mm/100 m to 40 mm/100 m (Water Management Strategy on the Territory of the Republic of Serbia 2015). Higher precipitation sums are recorded in the mountains Zlatibor (1018 mm) and Kopaonik (985 mm), while the Prokletije mountain range receives over 2000 mm of precipitation a year (on mountain ridges over 2500 mm). On average, there is a declining tendency of rainfall from the west to the east.

The largest area of Serbia, laying in the Danube river basin, has a continental precipitation regime with the highest amount of precipitation in the warm period of year (May–June), and the lowest in the cold period January–March. Besides, Mediterranean precipitation regime is present south from the line Prokletije—Besna Kobila, where the highest precipitation amount occurs from October to December, and the lowest in July and August.

The extreme precipitation at different time scale (annual, monthly, daily, hourly) cause extreme hydrological events—droughts and floods. The annual extreme precipitation sums recorded so far include the minima at Rakov Dol 220 mm (SE Serbia), Negotin 211 mm (E Serbia), Vršac 189 mm (Vojvodina), and the maxima at Krnjača 1,884 mm (SW Serbia), Pleš 1,614 mm (Kopaonik area), Breždje 1,585 mm (W Serbia), Lukovo 1,569 mm (Kopaonik area). Frequently, the extreme short-term precipitation events trigger flash floods in hilly parts of Serbia, especially dangerous due to a large amount of sediment load set in motion (torrential floods) (Dragićević and Filipović 2016).

9.2.1.2 Other Characteristics

Relief. There is a variety of relief forms on the territory of Serbia, from plains to 31 mountain peaks above 2,000 m above sea level (amsl) (Fig. 9.2). The highest point in Serbia is Djeravica peak, 2,656 m amsl on the mountain Prokletije, while the lowest point is the confluence of the Timok River to Danube River at 28 m amsl The average altitude of Serbia is 473 m amsl Plains (up to 200 m amsl) cover 35.5% of the territory: the Pannonian plain and its southern rim, and valleys of large rivers.

Hilly—mountainous region (200–500 m amsl) covers 31% of the territory and annually receives an average between 600 and 800 mm of precipitation. It includes broad valleys located in the Zapadna Morava River basin and its tributaries, in the Južna Morava River basin, a part of Šumadija region, a large part of Metohija region, and low mountains of Vojvodina. Mountainous areas (above 500 m amsl) cover 33% of Serbia's surface and receive 800–2000 mm of precipitation per year. They spread across the most considerable part of Southeast Serbia, on the rim of Kosovo and Metohija region (Prokletije and Šara mountains). Around 50% of a total amount of precipitation in a mountainous area of Serbia runs off (Dragićević and Filipović 2016).

Geological composition. Geological structure of Serbia is characterized by distinctive complexity. There are magmatic, sediment and metamorphic rocks in the structure of terrain. The complexity of geological and tectonic structure is also reflected in the complexity of hydro-geological characteristics of Serbia. The oldest

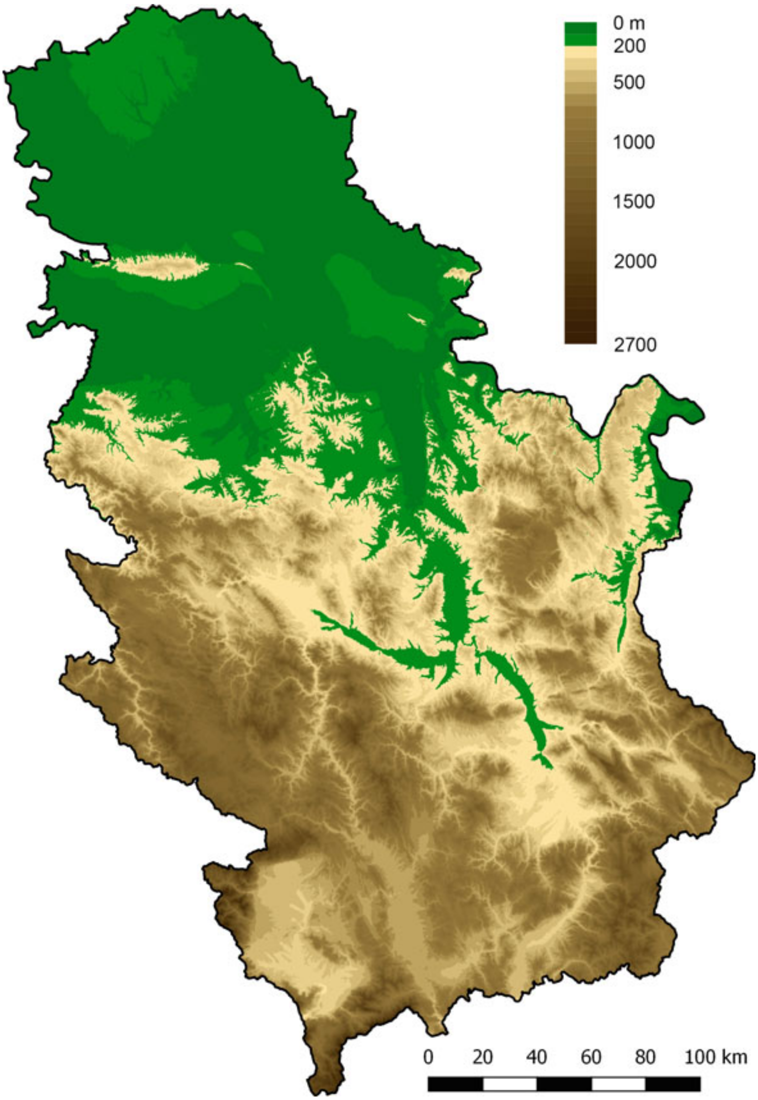

Fig. 9.2 Hypsometric map of Serbia

rocks on the territory of Serbia are related to Precambrian, present in a series of crystalline schists. These formations are found in the East and West Serbia, the Vršac mountains and in the Pannonian Basin, in the underlying stratum of Cenozoic and Mesozoic sediments.

The creations of Paleozoic age have a wide spread. Older periods (Cambrian, Ordovician, Silurian and Devonian) are less present than younger (Carboniferous and Permian). They are spread in the eastern and central Serbia, and Carboniferous and Permian sediments are particularly found in the area of western Serbia (Drina River basin). These creations are mostly present in a metamorphic rock complex. Basins built from the rocks mentioned above are characterized by high surface runoff. Mesozoic sediments are also significantly present, especially in the eastern and western Serbia, in the sediments of Triassic, Jurassic and Cretaceous age. Carboniferous creations mostly deposited during the Middle and Upper Triassic and Upper Carboniferous, are of the greatest importance. Karst terrains in Serbia cover the area of 8,414 km^2, distributed mostly among the Eastern Serbia (49%), and Western Serbia (37%), less represented in Kosovo and Metohija (11%), the least in Šumadija (3%), Southeast Serbia (0.5%) and Vojvodina (0.05%). Predominant characteristics of karst terrains are karst springs and natural lakes due to percolation, in the basins of karst landforms: dolina and uvala. Apart from carboniferous sediments, powerful flysch creations of Cretaceous age are related to the Mesozoic period, as well as the diabase-chert formation of Jurassic age.

Sediments of the Cenozoic period are significantly spread on the territory of Serbia. They are present as Tertiary and Quaternary sediments. The span of tertiary sediments is mostly related to Pannonian basin and smaller basins in the south and east Serbia, where sea and lake sediments are deposited. In lithological point of view, these sediments are present in a wide sediment spectrum, and they take up around 20% territory of Serbia. Quaternary sediments are mostly present in the area of Vojvodina where they appear from the surface to the depth of 200 m, except for Fruška Gora and The Vršac mountain range area. Southward from Sava and Danube, quaternary sediments are connected to the lowest basin parts, most frequently alluvial plain and alluvial river terraces. High water permeability of these sediments causes the existence of a powerful aquifer, quite significant in the runoff process (Water Management Strategy of the Republic of Serbia 2015).

Soil. General soil classification in Serbia is based on the characteristics of its natural moistening, i.e. on the hydro—physical properties of soil. The classification presents not only convenient but also the purposeful approach to managing water regime from the aspect of applying agro-meliorative measures, as well as the assessment of soil suitability for irrigation. The soil of Serbia can be classified into three broad groups: automorphic, hydromorphic and halomorphic soils.

Automorphic soils cover over 80% of the Republic of Serbia, and they are characterized by exclusive rainfall moistening, without long-lasting retention of excess water. The agricultural soil of the highest quality, chernozem, is the most widely spread on the territory of Vojvodina, Mačva, Stig and Braničevo. Hydromorphic soils are characterized by occasional or permanent over moistening under the influence of individual and/or combined action of surface and groundwater, and additional moistening is caused by flooding. This soil type is located on the lower terrain level, in the terrace depressions of loess, lakes and rivers, especially in valleys of large rivers (Danube, Tisa, Sava, Morava and their tributaries). Halomorphic soils include defective soils (saline soils) formed under a dominant influence of easily soluble salt. This soil group is relatively less present but quite crucial for water of Bačka and Banat areas, the Lower Danube and Srem area, and for drainage and irrigation (Water Management Strategy of the Republic of Serbia 2015).

Vegetation. Serbia is considered medium-scaled forest land. On its territory, forests take up 2,452,000 ha (around 30%) out of which 60.5% belongs to deciduous forests, 8.5% to coniferous forests, and 31% to mixed forests. The dominant deciduous types of trees include beech, Turkey oak forest, sessile oak, Hungarian oak, and European hornbeam. The coniferous types include spruce, black and white pine and fir (Branković et al. 2009). The least areas under the forests are located in Vojvodina (around 7%), in the central part of Serbia 32%, and in the area of Kosovo and Metohija around 39.5%.

9.2.2 *Spatial Distribution of Water Resources*

9.2.2.1 Surface Water Resources

Waters of Serbia gravitate to three seas: Black Sea, Adriatic Sea and the Aegean Sea (Table 9.1) (Fig. 9.3). All three sea drainage catchments meet at one point—the peak of Drmanska glava (1,359 m amsl) located on the Jezerska mountain in Kosovo and Metohija. The favorable natural conditions and factors contributed to the development of the hydrographic network consisting of thousands of river flows and a few hundreds of natural and artificial lakes.

The total length of all river flows in Serbia is around 65,980 km, while the average river network density is 747 m/km^2. The density is quite uneven and varies from 50 m/km^2 in the karst areas, and 75 m/km^2 in plain terrains, to 3,500 m/km^2 in the basins comprising of serpentinite. There are 11 rivers and international river sections longer than 200 km flowing in Serbia, and nine river basins with an area greater than 5,000 km^2.

Black Sea basin covers 81,703 km^2 (92.46%) of the total area of Serbia. The average altitude of the basin is 470 m amsl, the highest point in the basin is the Midzor peak (2,169 m amsl) of the Balkan mountain range in the Nišava River basin, and the lowest point is at the confluence of Timok River and the Danube, 28 m amsl The most significant rivers in the Black Sea basin are Danube, Tisa, Sava, Velika Morava, Južna Morava, Zapadna Morava, Ibar, Drina, Mlava, Pek, and Timok river, with numerous tributaries.

Table 9.1 Basic characteristic of sea basins in Serbia

Sea basin	Area		Average altitude (m)	The highest point (m)	The lowest point (m)
	km^2	%			
Black Sea basin	81,703	92,46	470	2,169	28
Adriatic Sea basin	4,732	5,36	820	2,656	270
Aegean Sea basin	1,926	2,18	825	2,651	315
Republic of Serbia	88,361	100	473	2,656	28

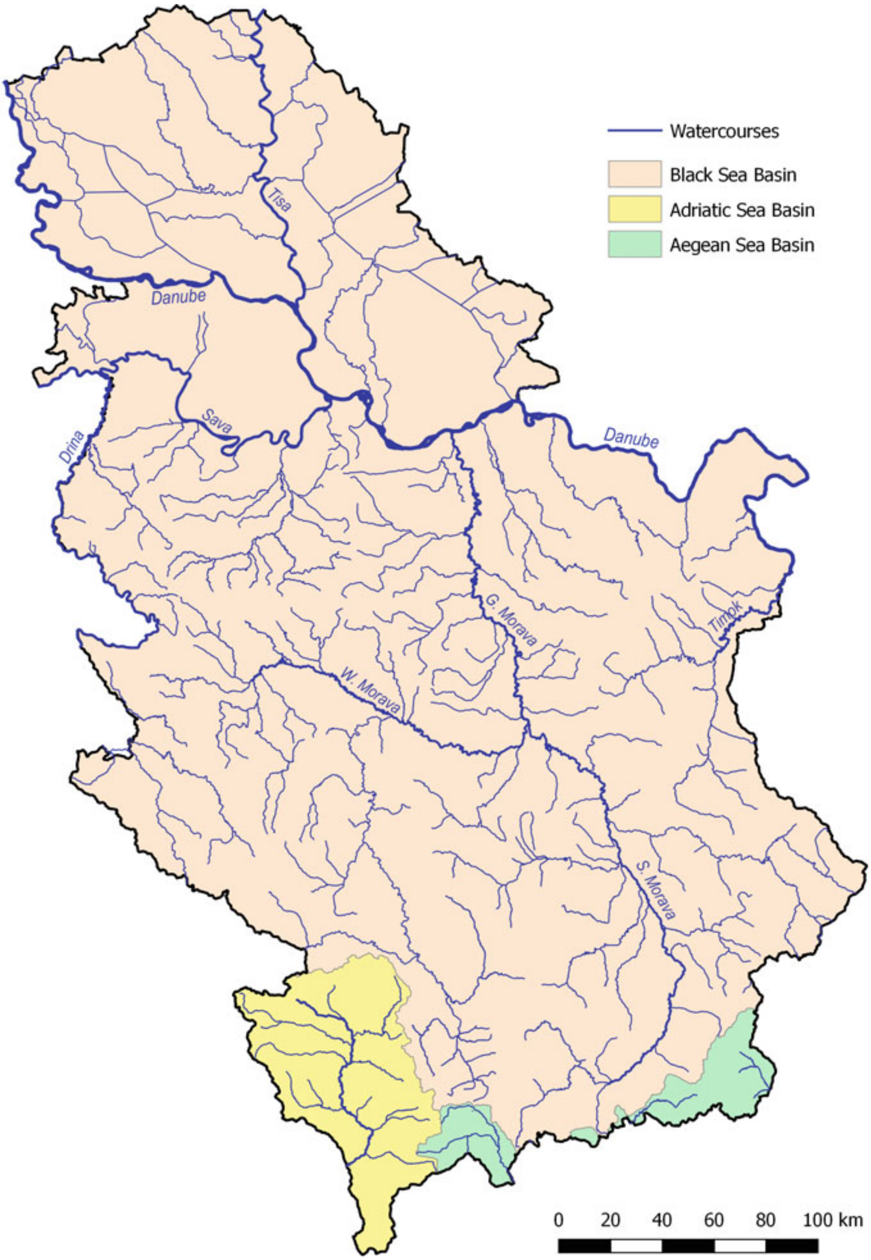

Fig. 9.3 Hydrographic map of Serbia

The Danube River. Danube flows into the territory of Serbia from Hungary, and out after the confluence of river Timok, at the tripoint between Serbia, Romania and Bulgaria. The total length of the Danube river is 2,850 km, in Serbia the flow length is 588 km. There are three sectors of the Danube flow through Serbia: Pannonian, Djerdap, and Pontian. The average annual water flow in the Pannonian sector is 2,268 m^3/s (HS Bezdan), and after it receives the largest tributaries, its flow is 5,413 m^3/s at HS Veliko Gradište. On the territory of Serbia, a few significant tributaries flow into the Danube—rivers Tisa, Sava and Velika Morava, as well as smaller ones. The Danube is navigable all along its flow in Serbia.

The largest tributary of the Danube River according to its basin area is Tisa River (basin area 157,186 km^2, in Serbia 10,856 km^2). It flows into the territory of Serbia from Hungary at the village Djale in Banat and flows into the Danube at Slankamen. The total length of the Tisa River is 966 km, while 168 km is in Serbia. Its average flow is 804 m^3/s at HS Senta. Tisa River is important for water management in Serbia because its water is used for irrigation and navigation. The largest tributary of the Tisa in Serbia is Begej River, 244 km long (75 km in Serbia).

Sava River, the most significant right tributary of the Danube (according to the length and water quantity), flows into the Danube in Belgrade. The basin area of Sava River is 97,713 km^2 (in Serbia 15,147 km^2), and its total length is 945 km (in Serbia, 206 km). Along the flow through Serbia, Sava River is in its lower course, with many meanders and oxbow lakes. Sava River is the richest with water of the Danube tributaries, the average water flow being 1,534 m^3/s (HS S. Mitrovica). It is navigable all along its flow, and the most important tributaries in Serbia are Bosut River on the left and Drina River and Kolubara River on the right (Gavrilović and Dukić 2014).

The largest tributary of the Sava River is Drina River (basin area 20,320 km^2) at the same time a border line between Bosnia and Herzegovina and Serbia along 220 km of its flow. The average flow of Drina River near the confluence with Sava River is around 400 m^3/s. Drina River holds the greatest hydropower potential, and several big hydropower plants are built in its basin in the territory of Serbia. The largest right-side tributaries of Drina River in Serbia are Lim River and Jadar River. The most downstream tributary of Sava River is the Kolubara River, flowing into Sava River in Obrenovac, near Belgrade.

The second largest tributary of the Danube in Serbia according to its basin area is the Velika Morava River (38,207 km^2). It is considered the largest river of Serbia, 185 km long, although small parts of its basin are located in Montenegro, North Macedonia and Bulgaria. The Velika Morava River begins in Stalać, where the rivers Južna Morava (basin area 15,696 km^2) and Zapadna Morava (basin area 15,754 km^2) meet. More water Velika Morava receives on average from the Zapadna Morava River (106 m^3/s at HS Jasika) than Južna Morava River (94 m^3/s at HS Mojsinje). An average discharge close to the Velika Morava River confluence with the Danube is 234 m^3/s (HS Ljubičevski most). Downstream from the confluence, another significant right-side tributary flows into the Danube River, Timok River. It is also known as Veliki (Great) Timok River, due to its origin from the

Beli (White) and Crni (Black) Timok in Zaječar. From the village Bregovo to the confluence into the Danube (in the length of around 15.5 km), it is a border river between Serbia and Bulgaria. Its total length (with Beli and Trgoviški Timok) is 202 km.

The Adriatic Sea basin share in the Republic of Serbia territory is 5.36% (4,732 km^2). It is located in the area of Metohija with a hydrographic system of the Beli (White) Drim River of the average discharge of 57 m^3/s. The highest point in the basin is the peak of Djeravica (2,656 m), and the lowest point is at the exit of Beli Drim River from Serbia (270 m amsl). The average basin altitude is 820 m amsl

The least of the Republic of Serbia territory, 2.18% (1,926 km^2) belongs to the Aegean Sea basin. The average basin altitude is 825 m amsl, with the highest peak of Peskovi on the Šarplanina (2,651 m amsl) and the lowest point near the exit of Lepenac River from Serbia (315 m amsl). The largest rivers in this basin on the territory of Serbia are Lepenac, Pčinja and Dragovištica rivers (Gavrilović and Dukić 2014).

The phenomenon of sinking rivers (ponornica) is frequent in Serbia because karst terrains comprise 9.5% of the total territory. The most of them is found in Eastern Serbia, where 70 such flows exist (one at 60 km^2 on average). The most of subterranean rivers are found on the mountain Kučaj, and they are also present in the west and southwest Serbia, where the largest sinking river is located, Boroštica River in Pešter karst polje. Its flow appears after 13 km of subterranean flow in the gorge of Bistrica at 680 m amsl

The integral part of a hydrographic network of the Republic of Serbia and its water potential are natural and artificial (human-made) lakes. The number of natural lakes in Serbia is relatively small. Based on the genetic classification of natural lakes in Serbia there are aeolian, fluvial, glacial, karst and landslide lakes, as shown in Table 9.2.

Table 9.2 The largest natural lakes in Serbia (Statistical office of the RS 2016)

Name	Genetic type of lake	Area (km^2)	Elev. (m amsl)	Max depth (m)
Palić	Aeolian	5.6	101	3.5
Belo (White)	Fluvial	5.4	75	2.5
Obedska bara	Fluvial	5.3	70	7
Rusanda	Fluvial	3	82	1.5
Ludaško	Aeolian	3.2	94	1.7
Oblačina	Landslide	0,14	280	4.7
Zasavica	Fluvial	1	74	10
Jovac	Landslide	0.05	421	10
Velika Djeravica	Glacial	0.03	2,320	3.8
Livadica	Glacial	0.02	2,200	7.3
Vrmdža	Karst	0.007	613	3

Table 9.3 The largest reservoirs in Serbia (Water Management Strategy of the Republic of Serbia 2015)

Name	River	Year of creation	Area (km^2)	Max depth (m)	Elevation (m)	Volume (10^6 m^3)	Purpose
Djerdap	Danube	1972	253	92	70	5000	E
Bečej	Tisa	1978	18	10	85	160	I, N
Vlasina	Vlasina	1949	16	22	1213	176	W, E
Perućac	Drina	1966	12.4	70	270	340	E
Gazivode	Ibar	1977	11.9	105	693	370	E, N, I, W
Gruža	Gruža	1984	9.2	35	273	65	W, N
Zvornik	Drina	1955	8.1	28	140	89	E
Zlatar	Uvac	1962	7.25	75	880	273	E
Potpeć	Lim	1967	7	40	437	44	E
Radonjić	Prue	1980	5.62	30	455	113	I, W
Zavoj	Visočica	1989	5.5	60	612	170	E
Sjenica	Uvac	1979	5	35	985	212	E

Key: E—energy production; I—irrigation; N—navigation; W—water supply

There are 28 large water reservoirs in Serbia (volumes greater than 10 mill. m^3) (Table 9.3). They were created in the 20th century to serve one or more purposes, primary energy production, water supply, and irrigation; secondarily navigation, tourism and recreational activities on water.

9.2.2.2 Groundwater Resources

A substantial segment of total water resources in Serbia is groundwater. The total capacity of the present sources of groundwater in Serbia, as the most important water resources for the residential water supply, is 678 mill. m^3 per year or 21.5 m^3/s (out of which 6.25 m^3/s in Vojvodina and 15 m^3/s in Central Serbia). Groundwater accumulation in Serbia is present within rock mass with a different kind of porosity: intergranular porosity (Quaternary and Neogene sediment), karst porosity and crack porosity.

Serbia's geological classification relies on geotectonic forms, meaning the characteristics of water change according to the conditions in the Dinarides, Vardar zone, Serbian—North Macedonian mass, the Balkan—Carpathians as well as in the youngest depressions, Pannonian and Dacian basin (Fig. 9.4). Therefore, in the Dinarides and the Balkan—Carpathians, limestones are dominant (Mesozoic with the first mentioned and Jurassic and Cretaceous with the former), crack porosity is developed with the system of the karst canals from which strong karst springs come out. Such water contains carbonate, domineering with calcium and magnesium, increased mineralization and water hardness. Compared to them, Vardar zone is characterized by lacking in groundwater because its rocks belong to

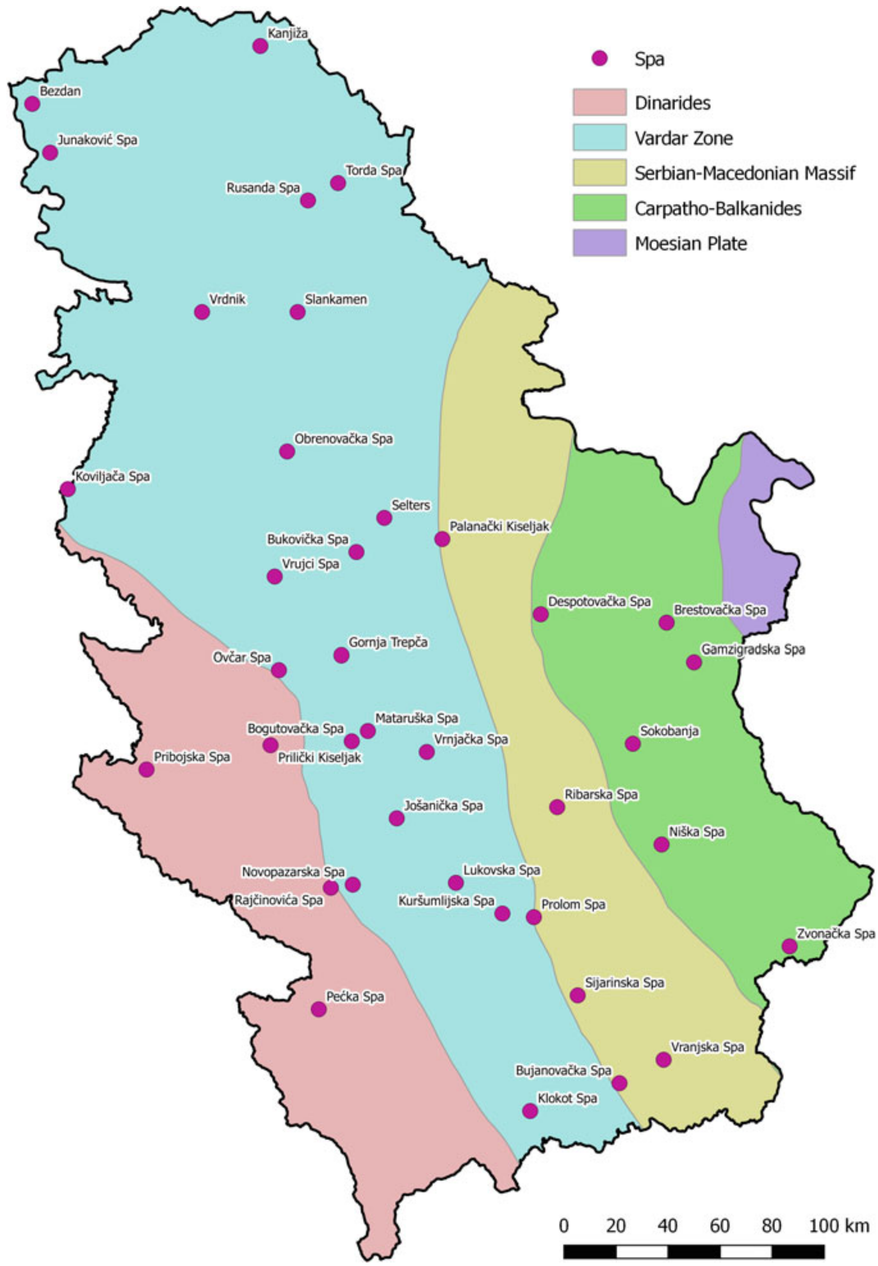

Fig. 9.4 Geotectonic map of Serbia and spa sites

semi-permeable and impermeable environment. Serbian—North Macedonian mass has a simple structure with crystalline schists in its core. In the southern part, a shallow, poor aquifer is formed but with numerous thermo-mineral sources, while in the northern part there is a more powerful aquatic environment in the Neogene sediments and Quaternary deposits of the Velika Morava River. In the north of the country, Pannonian basin is clearly distinguished by geomorphological and hydrogeological features, filled with thick series of Cenozoic sediments. Its lower part consists of Miocene and Pliocene sediments within which huge aquatic environment refer to Lajtovac limestone and the Sarmatian limestone with highly mineralized thermal waters. The upper part consists of permeable Pliocene and Pleistocene sand and gravel where numerous artesian horizons are formed.

On the very surface, there are the youngest alluvial creations of the Danube, Sava and Tisa rivers where phreatic aquifer is developed. Although the Pannonian basin is the richest in quantity of groundwater, its use is limited considering that the shallow and deep waters are very much polluted. The latter, because of the long period of contact with sediments and increased content of heavy metal, and the former because of the pollution from the surface (Geological atlas of Serbia 2004).

9.2.2.3 Annual Pattern of Runoff

Rivers of Serbia mostly belong to rainfall—snow regime of runoff. As shown on the hydrographs (Fig. 9.5), the prevailing runoff pattern is simple, with one high flow and one low flow period. In the Velika Morava River basin, high flow period occurs

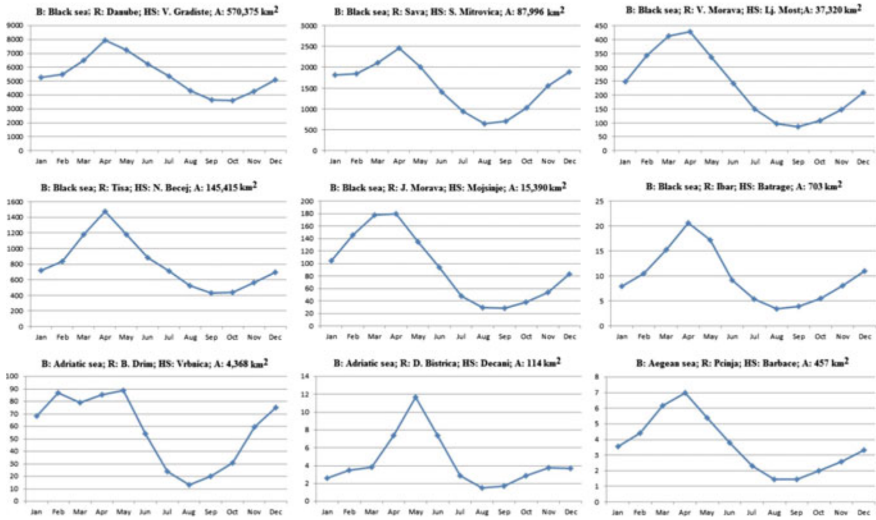

Fig. 9.5 Average annual pattern of runoff at selected hydrological stations (HS) in the period 1961–2014

in March-April, caused by combined snowmelt in contributing lower altitude basins and low mountains, and the abundant spring rains. In April, high flows occur on the largest rivers (the Danube, Sava and Tisa), while they exibit elements of the combined regime, flowing through different climate regions. The exception are the rivers in the Metohija region where the influence is felt from both the Mediterranean and the high mountains, Prokletije and Šara. Thus, the maximum on the Beli Drim occurs in February from rain and melted snow in the lower basin areas, and it retains until May when the snow melts from the highest parts of the mountains. In the Beli Drim River basin, as well as in the upper Ibar River basin, there is a secondary high flow period caused by autumn rains. Low flow period for the rivers in Serbia is at the end of summer and the beginning of autumn, because of low precipitation, large-scale evaporation and exhausted aquifers.

9.2.2.4 The Main Elements of Water Balance

A view on water balance in respect to water quantity generated in the territory of Serbia (domicile waters) and the quantity flowing in from the neighbouring countries (transitional waters), shows high disproportion. The share of domicile waters in the total water quantity available is smaller than 10%.

As shown in Table 9.4, the least domicile water quantity is available in the north part of the country, i.e. Vojvodina, due to low precipitation and high evapotranspiration. At the same time, this is the country area where almost all transitional waters flow in (5,100 m^3/s on average), improving hydrological situation by filling in the aquifers and providing water for numerous water utilization activities. The most water-abundant areas of the country are border and mountain areas, where the mountains of Prokletije, Šarplanina, the Western Serbia mountains, and Stara planina precede, with the runoff coefficient exceeding 0.5. The discrepancy in available water is also shown through the specific runoff (runoff per basin area unit —runoff yield) which in Serbia ranges from 1 $L/s/km^2$ in the north to more than 40 $L/s/km^2$ in the southwest basins of the country. The central and largest part of Serbia belongs to the Velika Morava River basin, where 7.3 bill. m^3 of water is generated. That is almost half of the total domicile water quantity, but the specific

Table 9.4 Annual water balance elements of domicile waters in the main administrative units (Water Management Strategy of the RS 2015)

	A	P	Q	q	h	ET	C	W
	(km^2)	(mm)	(m^3/s)	($L/s/km^2$)	(mm)	(mm)	(–)	(10^9 m^3)
Vojvodina	21,588	605	32	1.48	47	558	0.08	1.0
Central Serbia	55,880	759	365	6.53	206	553	0.27	11.5
K&M	10,939	750	101	9.23	291	459	0.39	3.2
Serbia	88,407	720	498	5.63	178	542	0.25	15.7

Key: A (area), P (average precipitation), Q (discharge), q (specific runoff), h (runoff depth), ET (evapotranspiration), C (runoff coefficient), W (runoff volume) runoff of 6 L/s/km^2 and runoff coefficient of 0.25 point out to bad runoff conditions and resulting water shortage.

Including the transitional waters in the water balance analysis, the situation significantly improves. The approximate average annual inflows of international rivers to Serbia are the following: Danube River 2,800 m^3/s, Sava River 1,160 m^3/s, Tisa River 800 m^3/s and Drina River 300 m^3/s. The average runoff from the territory of Serbia is around 5,650 m^3/s, leading to 20,000 m^3 of water annually available per capita. That is the very top in Europe, and it considers both domicile and transitional waters. Quite a different light is shed on water availability when the total water quantity is assessed from the average precipitation of 720 mm for the entire territory of Serbia. It is around 63.7 km^3 of water volume annually, and considering that only one quarter transforms to runoff, it means that domicile waters produce the flow of 500 m^3/s or 9% of total runoff. Annually, that is 1,800 m^3 of domicile water per capita, and it is closer to water stress limit (1,500 m^3) than the minimum required for stable water supply of 2,500 m^3 per capita.

9.3 Water Resources Utilization

9.3.1 Water Supply and Demand

The remaining of structures used for water supply in Serbia belong to the Roman period. Water was supplied to the military compounds, public baths and palaces from the far distance by complex systems and aqueducts. The best-preserved aqueducts are in Sremska Mitrovica (Sirmium), Belgrade (Singidunum) and Stari Kostolac (Viminacium), as well as in Brzi Brod (Mediana), Gamzigrad (Felix Romuliana), Niš (Naissus) and Caričin grad (Iustiniana Prima) (Mrđić 2007). After the fall of the Roman Empire and destruction of castra, a millennium long period of stagnation in water supply began. Water supply networks were built in Serbia at the end of 19th century, although very slowly, while the sudden development happened during the 1970s. The water needs suddenly increased due to the intensive urbanization and industrial development. The water consumption in most of the cities of Serbia went over 400 L per inhabitant a day, and such state continued to the 1990s when water demand decreased because of the political-economic crisis and the shutting down of factories.

9.3.1.1 Sources of Water Supply

Local sources of groundwater and surface waters present a strategic orientation for water supply in Serbia. Besides, there are 18 regional water supply systems in Serbia, built to provide water in water-scarce areas.

The total exploitation of groundwater is 23 m^3/s. The most present are those from the first aquifer (Phreatic, alluvial sediments) with around 13 m^3/s. Groundwater from the basic water complex (60–200 m deep) is taken in Vojvodina in the total amount of around 4 m^3/s. The deepest groundwater, artesian and sub-artesian, is used across Serbia, mostly in Šumadija and Vojvodina and its exploitation is 2 m^3/s. Groundwater in the karst environment is very important due to its quality. The water supply of 4 m^3/s comes from karst springheads, the most important present in the Eastern and Southwest Serbia (up to 1.6 m^3/s) (Dokmanović and Nikić 2015).

The estimated quantity of groundwater potential is 67 m^3/s, but only 1/3 is used. The largest unused reserves are found in the first aquifer, about 30 m^3/s in the plains, i.e. in the alluvions of large rivers. Significant amounts can be taken from karst springheads where there is a potential to exploit additional 10 m^3/s. The importance of this resource generates ideas for its enrichment by methods of artificial feeding of aquifers by infiltration (rainwater harvesting and storage), and it is estimated an additional 40 m^3/s is achievable (Polomčić et al. 2012). In this way, groundwater reserves could be doubled.

Water reservoirs have been intensively built after the World War II as an integral solution of water management problems. The main purpose of the most of reservoirs was water supply for the population, e.g. Ćelije, Vrutci, Gruža, Prvonek, while it was secondary purpose in the reservoirs built for hydropower production (Gazivode, Kokin Brod, Vlasina). There are 30 large reservoirs with volume over 10 mill. m^3 of water, where 6 km^3 of water is stored. In the water management plans, 26 more reservoirs are planned with the primary purpose of population water supplying. The cities and their surroundings, nowadays dependent on water supply from the existing reservoirs include Arandjelovac, Zaječar, Aleksinac, Kruševac, Vranje, Leskovac, Užice, Kragujevac, Kosovska Mitrovica and Priština.

The direct water intake from rivers for domestic water supply is rarely considered. However, in the absence of other solutions, and with the treatment of raw water, the capital of Serbia, Belgrade, supplies from the Sava River in the amount of 3.2 m^3/s, combined with almost the same amount of groundwater. The Rzav River exploitation of 500 L/s supplies water to the population of Arilje, Lučani, Čačak, Požega and Gornji Milanovac. There are also plans for regional water supply systems with water intake from the Drina River lower flow, Danube River in Bačka and Tisa River in Banat.

9.3.1.2 Residential Water Supply

There are a lot of factors causing big differences in the residential water supply in Serbia. Starting with the natural conditions describing availability (location, quantity and quality of water), over historical heritage (uneven infrastructural conditions before the industrial boost in the last century), to the absence of sanitary culture and lack of financial resources (Djordjević 2014).

Table 9.5 Connectivity of Serbia's population to public water supply systems, water withdrawals and sources of public water supply (2012) (Water Management Strategy of the RS 2015)

	No of inhab. (mill.)	No of users (mill.)	Conn. coeff.	Spec. water consumption	Water withdrawal		Source type (%)	
				L/inh./day	L/s	10^6 (m^3/year)	Surf.	Undergr.
Vojvodina	1.93	1.75	0.91	207	4,618	145.63	0	100
Belgrade	1.66	1.52	0.92	422	7,146	225.5	45	55
Central Serbia	3.60	2.56	0.71	236	9,839	310.27	35	65
Serbia (without K&M)	7.19	5.83	0.81	260	21,602	681.25	31	69

According to the Table 9.5, almost 1/5 or 1,352,000 inhabitants of Serbia is not connected to a public water supply. The worst situation is in the south of Serbia where for example in Nišava and Toplica administrative districts with 50 and 60% population connected to public water supply systems.

In 2012, 680 mill. m^3 of water, or 21.6 m^3/s, was used for the public water supply in urban areas. That is a mild consumption fall compared to the beginning of the century, but it could be changed with time, depending on the needs (mostly industrial) and the climate (temperature change, rainfall and humidity). More water was taken from the underground (69%), less from surface waters (31%). The picture of water supply in Serbia is complete with rural population water supply data (Fig. 9.6). The population in rural areas uses local, small water supply systems, and individual water intakes—wells. In the administrative districts, the number of inhabitants connected to the rural water supply systems reaches 1/3 in Zapadna Bačka, Morava, Zlatibor and Toplica district, while a quarter of population is supplied with water from the wells in Mačva, Kolubara, Podunavlje and Pomoravlje district (districts in Peripannonian area) (Implementation of the Protocol on Water and Health in the Republic of Serbia—analysis of the condition 2014).

9.3.1.3 Industrial Water Supply

Compared to the end of the 1980s, nowadays modern industrial production reaches only half of the volume at the time. This is reflected in the water consumption of the industrial sector. There are also industries that do not need a supply with high-quality water, such as mining with annual use of about 10 mill. m^3 of water, processing industry for cooling (about 50 mill. m^3), irrigation (total 160 mill. m^3), and electrical energy production plants for cooling (3 bill. m^3).

From the drinking water supply in 2016, households received 77%, industry 10% and agriculture 13%. The major problem of existing water supply systems are water losses (Real Losses—RL) including the annual volumes lost through all types

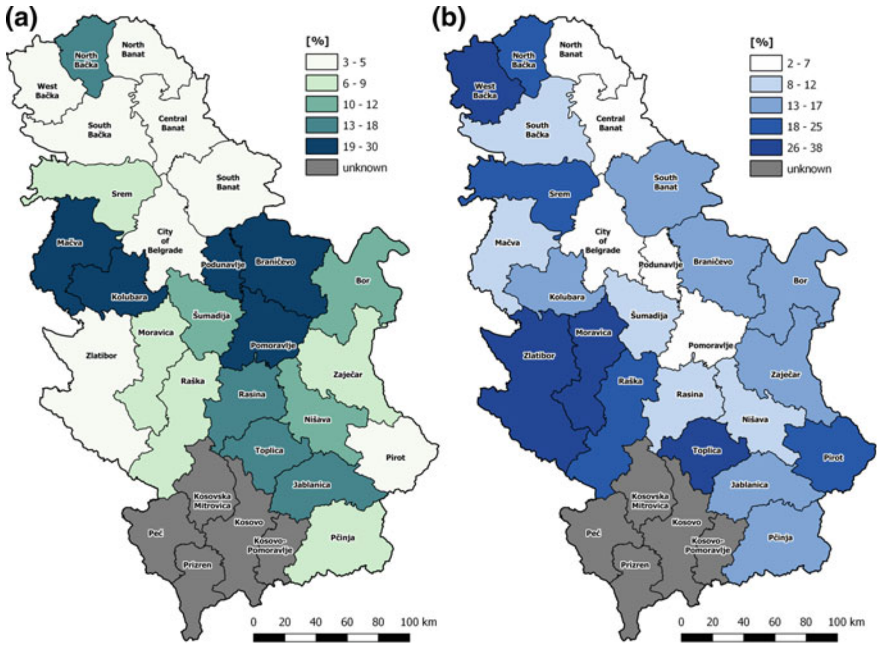

Fig. 9.6 Population connected to **a** rural water supply systems **b** individual water intakes, shown for Serbian administrative districts

of leaks, bursts and overflows on mains, service reservoirs and service connections, up to the point of customer metering). At the annual level, 226 mill. m^3 of water is lost, which is about 7 m^3/s of clean, processed water or 36% of the total system input volume. The highest RL are found in the water supply and distribution systems in Golubac (72%), Soko Banja (66%), Novi Pazar (65%), Obrenovac and Raška (60%). In Belgrade, a third of the prepared drinking water does not reach the consumers. Regionally, the best situation is in Vojvodina where water losses are 22%. It is found that an average Infrastructure Leakage Index (ILI), a measure of how well a distribution network is maintained for the control of RL at the current operating pressure, is at an average of 10.8 for Serbia (Radivojević et al. 2007). This is the indication of a poor condition of water mains, with high potential for significant RL reduction.

9.3.2 *Agricultural Irrigation*

The most important agricultural region of Serbia is Vojvodina, followed by the peri-Pannonian border area, and the basins of central Serbia. The land and climatic conditions favour a large number of cereals, industrial and fodder plants, fruits and vegetables. However, it often happens that during the vegetation period plants lack water, and therefore yields are much lower than possible. The fact is that the consequences of agricultural drought in Serbia are much higher than flood damages. The average annual precipitation in Vojvodina is between 550 and 650 mm, while in the southern flatland areas it is about 700 mm. Although the precipitation pattern is such that May and June are the wettest months, autumn crops are regularly missing from 100 to 300 mm of water, since July and August are very dry. By applying irrigation, such a situation should be overcome. This sector in Serbia is significantly behind neighbouring countries with climate conditions as ours, acheiving higher yields.

The first designed irrigation systems were built in the 1930s, while significant development was experienced after the World War II, especially after the construction of the Danube-Tisa-Danube Hydrosystem (DTD). The economic problems that our country has encountered in the past, have caused stagnation in almost all sectors of the economy, consequently agriculture and irrigation. Despite the relatively good conditions for the development of irrigation, it does not develop in accordance with the needs of the society. This is reflected in a relatively small area where irrigation is used, as well as in the insignificant use of available water resources, especially in northern flatland agricultural regions (Savić et al. 2013). In Serbia, there is a total of 4.7 mill. ha of arable land, of which 3.6 mill. ha is suitable for irrigation. Official data indicate that its utilization for irrigation systems is almost negligible. Irrigation equipment that is socially owned is used on an area of 41,000 ha, although it could cover 106,000 ha. The reason is its poor condition and out-of-date systems whose replacement is costly. It is estimated that about 45,000 ha of irrigated areas are privately owned, then there are 2,000 ha within the experimental properties of agricultural schools, as well as about 10,000 ha with gardens irrigated around houses. All this together makes about 100,000 ha of irrigated areas (excluding Kosovo and Metohija) or 2.8% of total area suitable for irrigation (Živković 2017).

Water resources that could be used for irrigation are rivers, built channels and reservoirs. Their potential is large, especially of the transit river Danube and its tributaries: Sava, Tisa, and Morava river. The total length of the main channel network in Hydro-system Danube-Tisa-Danube is about 930 km. Counting in all channels, it is about 20,000 km long, intended for both irrigation and drainage.

In Serbia, about 160 mill. m^3 of water is used annually for irrigation. When this quantity is divided by irrigated area, water consumption of 1,600 m^3/ha per year is obtained. Considering that over 3,000 m^3/ha per year are used in our neighbouring countries, it is clear irrigation cannot be understood as an additional measure in food production, but it has to be a backbone to the entire food sector.

9.3.3 River Navigation

Until 2006, Serbia was a maritime state (as a Kingdom, a Federal Union or the Federal Republic of Yugoslavia) having access to the Adriatic Sea. The disintegration of the state (Yugoslavia) has caused gradual disbanding of its fleet, while about 2,000 of our citizens are nowadays considered to have the status of professional seafarers working in foreign companies. In order to provide smooth transition from maritime to landlocked state, two laws concerning maritime navigation and nationality of ships came into force in 2011 and 2013 respectively. This way, the advantage could be taken from the UN Convention on the Law of the Sea (UNCLOS) from 1982 that recognized the right to freedom of transit to the sea, the right to the flag of the naval merchant navy, free access to and use of services in seaports.

The internal network of Serbia's waterways consists of rivers and channels (Fig. 9.7). They are concentrated in the northern part of the country, although, by their hydrological characteristics, some other rivers could be navigable as well. This refers to the Velika Morava River and the Drina River, which are not navigable due to unfavourable morphological conditions, both extremely meander and create shallows. Modern navigation criteria are such that they allow vessels to navigate throughout the year, which also means a significant width and depth of the waterway that these rivers cannot provide.

The length of the waterways in Serbia is 1,680 km, and those with the international category are about 1,000 km long. Although there are favourable conditions for the development of this type of traffic, it is not sufficiently utilized. In relation to total traffic, transport by waterways is only 4–5%. In comparison to the neighbouring countries, Serbia is far behind Romania, Bulgaria and Hungary, and in the ranking with the inland transport by waterways of Croatia. According to some estimates, the trade transport in waterways in Serbia will continue to grow, and from the 2 mill. t transported in 2016, it is expected to reach 8.5 mill. t in 2025. The bulky load would be dominant (89%), while the manufactured goods would be in the background (Strategy for the Development of Water Transport of the Republic of Serbia from 2015 to 2025 2014).

This situation in our water transport is due to poor infrastructure, primarily the state of the river ports. Their handling capabilities are insufficient and excessively long lasting, which increases total transport costs and service to both the providers and the users. In Serbia, there is not a single terminal for the RO-RO traffic, and only a few ports have conditions for modest container reload. The traffic of goods in the Port of Belgrade, as the largest port in the country, is between 200,000 and 400,000 t per year, and the general cargo is dominant. Unlike it, the cereals, artificial fertilizers and ferrous metallurgy products are most often transshipped in the Port of Novi Sad. The goods supplied to Pančevo and Bačka Palanka are similar, while the Port of Smederevo is carrying out the transfer of iron ore, coke, and products made of rolled steel. In addition to these ports, the ports in Apatin,

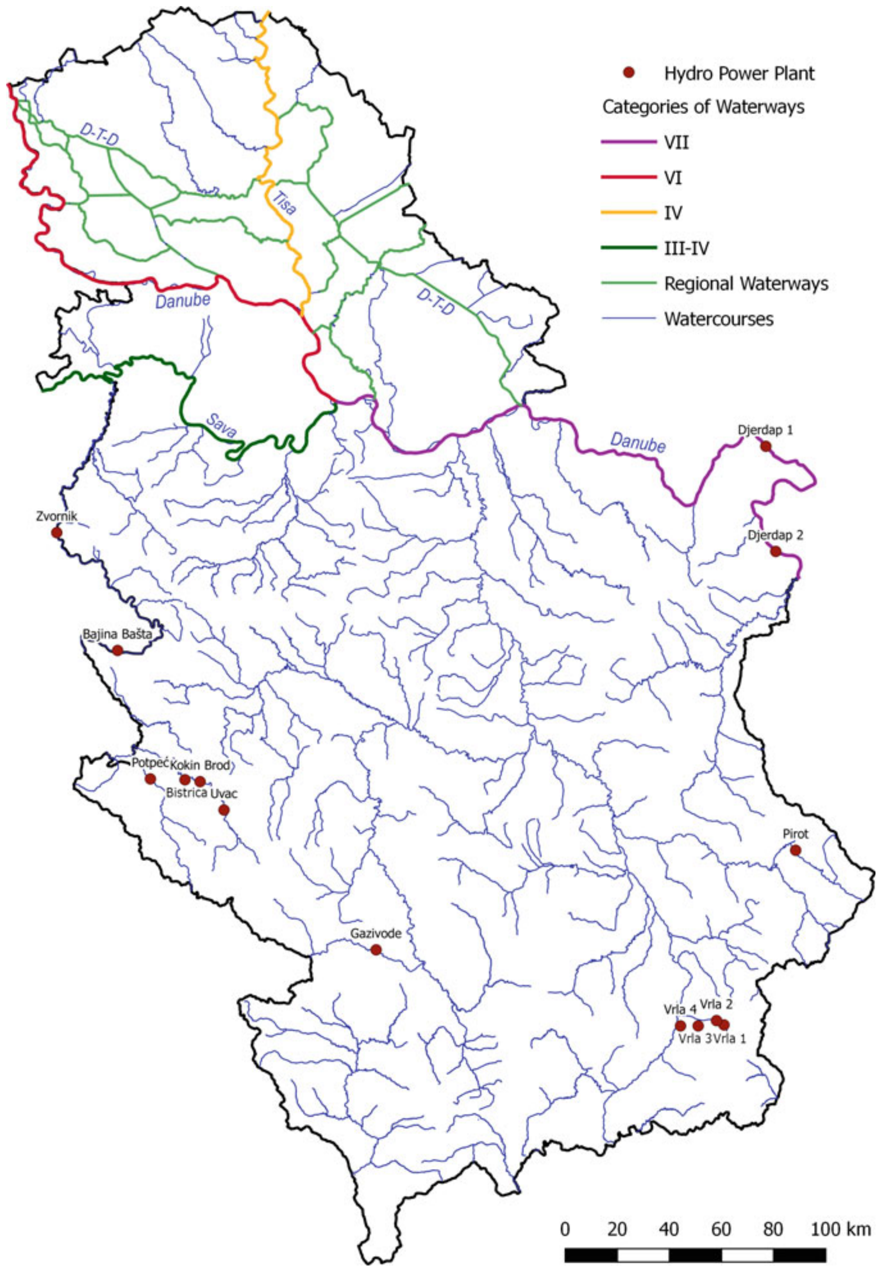

Fig. 9.7 Combined map of waterways and hydropower plants in Serbia

Bogojevo, Senta, Beočin, as well as the ports on the Sava River in Sremska Mitrovica and Šabac are significant.

There is no organized regular passenger river transport in Serbia. However, there has long been an initiative to strengthen the nautical sector due to exceptional conditions, as well as the interests of foreign operators. So far, the nautical clubs organize annual events that include cruising along the following rivers: Danube, Sava, Tisa, Tamiš, by the channel network, as well as rafting by the Drina, Ibar, and Morava rivers. The nautical infrastructure is missing, especially the construction and equipment of marinas that would serve all types of vessels.

More than 96% of passenger traffic in water transport in Serbia refers to international multi-day cruises performed by specialized cruise ships. The traffic of passengers and the number of ships that landed in domestic ports have been steadily increasing since the beginning of 2000. Thus, from the symbolic two berthing of ships with 190 passengers in 2001, the traffic on the Belgrade passenger terminal on the Sava River in 2013 reached 65,285 passengers and 510 berths. According to the structure of passengers, the most numerous are those from Germany, the USA, Austria and France. The estimate is that the number of berths will be about 650 boats in 2025, and the number of passengers about 93,000 (Živković 2017).

9.3.4 Hydropower

The production of electricity in Serbia using water power has a long tradition. After the launch of the first turbines in England and the USA, Serbia quickly built the first hydroelectric power plant (HPP) on the Rasina River in the central part of the country in 1891. It had three turbines of 18.6 KW. Ten years later, in Užice, on the Djetinja River, the first HPP was commissioned according to Tesla's principle of alternating current, named "Pod gradom" (Under the City). At that time, it was one of the most modern in the world, and now it is a cultural monument, although still in function. In the next ten years, three significant HPPs in Eastern and Southeastern Serbia were put into operation: HPP Vučje (1903), HPP Sveta Petka (1908) and HPP Gamzigrad (1909). During the process of rapid industrialization after the World War II, the energy system of Serbia has been significantly developing in former Yugoslavia. The first major HPP was Zvornik on the Drina River (1955), and the last of the larger ones was built in Pirot (1990), which used the water of Zavoj Reservoir on the Visočica River (Table 9.6).

The largest water potential of Serbia is located in the border zone. It includes the following rivers: Danube, Drina, Beli Drim, Ibar, Timok, and Dragovištica. The total hydroelectric potential of the rivers in Serbia is 21.7 TWh per year, although 19.2 TWh is technically usable. According to the data from the year 2015, the electricity production was 10.8 TWh. In the total electricity production in Serbia, this is 28%, while the rest is from the thermal power plants (72%).

The total installed capacity of all HPP in Serbia is 2,993 MW, of which 2,940 MW is in large HPP and 53 MW in small—SHPP. There are 31 SHPP in

Table 9.6 Hydroelectric power plants in Serbia with an installed power greater than 10 MW (Water Management Strategy of the Republic of Serbia 2015)

Hydroelectric power plant	River	Power (MW)	Type	Beg. of work
Djerdap I	Danube	1,058	R	1972
Bajina Bašta II	(Drina)	614	PS	1982
Bajina Bašta I	Drina	420	R	1968
Djerdap II	Danube	270	R	1988
Vrla I-IV	Vrla	129	R, D	1954
Bistrica	Uvac	102	R, D	1960
Zvornik	Drina	96	R	1958
Pirot	Visočica	80	R, D	1990
Potpeć	Lim	51	R	1970
Uvac	Uvac	36	R, D	1979
Gazivode	Ibar	35	R	1981
Kokin Brod	Uvac	22	R, D	1962

Key: Djerdap I—a total of 2,116 MW, Djerdap II—a total of 540 MW, R—Reservoir/Impoundment, PS—Pumped Storage, D—Diversion

operation, while 38 do not work, although they could be activated with few resources. The unused potential is about 7 TWh per year, concentrated in Djerdap (Danube) and the Drina River Basin. Although most of the HPP (7 in Serbia, 1 in Montenegro and 1 in Bosnia and Herzegovina) were built in this latter basin, only a third of the capacity was used. The plans imply both large and expensive projects and numerous SHPP. A priority is the modernization of the existing system and the installation of new generators wherever possible. This would generate an additional 178 MW, and these plans include the HPPs of Djerdap I, Bajina Bašta, and Zvornik.

A Small Hydroelectric Power Plant Cadastre for the Republic of Serbia was made thirty years ago (1987). The document identified 856 locations on the rivers suitable for the production of electricity either as a single purpose or within the multipurpose water management solutions. After the pause due to social, economic and political crises that immediately followed, some SHPPs have been constructed since the 2000s by private investors. Currently, the innovation project of the Cadastre is being funded from the EU IPA Fund, focusing on the SHPPs with estimated power between 100 kW and 10 MW.

By ratifying the Treaty on Establishment of the Energy Community, the Republic of Serbia has also assumed obligations under the Directive 2009/28/EC, which, inter alia, deals with the promotion of electricity produced from renewable energy sources. To increase the use of renewable energy sources, the Republic of Serbia has joined the countries that subsidize the production of electricity from renewable sources and introduced the most widespread model—the incentive fixed purchase price ("feed-in" tariff), with a guaranteed 12-year power takeover period. This has caused great interest in the construction of SHPPs (< 10 MW), so that the number of allocated locations for them has been significantly increased lately, and the number of constructed facilities increases as well. The allocation of locations for the construction of SHPPs is not in line with the needs of the water management sector and environmental protection, which must be corrected as soon as possible (Water Management Strategy of the Republic of Serbia 2015).

9.3.5 Fishing and Aquaculture

Fishing waters in Serbia comprise 66,000 km of the river network, floodplains, river gulls, oxbow lakes, then about 50 natural lakes and 150 reservoirs and about 30,000 km of channels. They are divided into 6 water districts. Fishing in Serbia takes place on rivers and channels. Catch in reservoirs is not shown separately, but along with the rivers where the reservoirs are located, while this activity is not performed in natural lakes. This is the reason why commercial fishing takes place only on the following rivers: Danube, Tisa, Sava and the lower course of the Velika Morava. According to official data, the catch of fish in Serbia is between 2,000 and 3,000 t per year, and taking into account unreported and illegal catch, this number is probably between 5,000 and 10,000 t. In Serbia, sports fishing is practiced throughout the country, but the catch data are not officially reported (Gavrilović and Dukić 2014).

Most fish are annually caught in the Danube River, about 2,500 t, although in the past this amount was higher. The construction of the dams (Djerdap I and Djerdap II) completely disrupted the natural migration of fish (moruna, herring, sturgeon), of which there was a great benefit, especially due to the production of caviar. Before 1970, their participation in the catch of fish was as high as 43%. Nowadays, the Danube River is home to 58 species of fish.

Fishponds are much more economically valuable. Their construction started at the end of the 19th century, and the first of them was the Ečka fishpond, today the largest in the country and one of the largest in Europe. It belongs to a group of warm water or carp fishponds. In our conditions, carp fish (80%), tolstolobik, amur, cat fish, slut and pike are usually grown. The total area of about 70 fishponds in Serbia is 14,000 ha, and most of them are in the northern part of the country, in Vojvodina. In the present conditions, the production of fish in carp fishponds is around 13,000 t per year.

Another type of fishponds is coldwater or trout fishponds located in the mountainous region. They are of small areas, up to several hundred square meters, and they cultivate a noble species of fish, a trout (Californian and flowering) that requires intensive farming (flour, industrial nutrients). The yield of trout per m^3 of water is about 50 kg, and the total production in Serbia is about 2,000 t. The largest fishponds of this species are Resava, Sisevac, Ljubovija, Žagubica, and there are about 150 of them with a total area of 14 ha (Živković 2017).

Fish farming in Serbia has been growing steadily in recent years, but it only satisfies a third of domestic needs. Imports (about 35,000 t) are much more dominant than exports (several hundred tons), and its structure is dominated by sea fish. It is interesting that the areas under fishponds (carp) have used only a tenth of the potential territories suitable for this purpose and are predominantly in Vojvodina.

9.3.6 Tourism and Recreation

In Serbia, there are 57 registered public bathing sites on rivers and lakes under the control of competent authorities. Apart from them, there is a much greater number of those which are out of control and used for their account, so it is also necessary to ensure their monitoring and reporting the water quality. The most well-known and most essential resorts in Serbia are Ada Ciganlija in Belgrade, Štrand in Novi Sad, Jugovo near Smederevo, Lido on Veliko Ratno Ostrvo in Zemun, City Beach in Užice, Srebrno jezero (Silver Lake) near Veliko Gradište, Bela Crkva lakes. Some of the mentioned lakes are also nice examples of complex, multipurpose use of water, which is achieved by good water management design and maintenance of the system.

It happened many times that Sava Lake and the complex of Ada Ciganlija in Belgrade visited even 300,000 people per day. This river beach is one of the largest and best-preserved in Europe, and there are numerous sports fields and catering facilities in its immediate vicinity. Nevertheless, the water quality is most often in the first class, due to the sake of bathers, and because the lake with its 4,000,000 m^3 is a vital drinking water reservoir. This is achieved by a strict regime of protection and technical solutions for maintaining the artificial flow of the lake.

Apart from the bathing function, the rivers in Serbia are used for numerous sports and recreation, such as sailing, kayaking, rowing, water skiing, rafting. However, the most famous is rafting, which takes place in some calm waters and for recreational purposes, the so-called tourist rafting (Drina, Lim, Uvac, Ibar, Južna Morava rivers), which is different from rafting competition (wild water rafting). Regattas on different vessels are traditionally held on these rivers, and on the Danube River, they are of international character.

9.3.6.1 Spa Tourism in Serbia

In the territory of Serbia, there is a long tradition of using thermo-mineral wells that date back to the Neolithic period. However, only in the time of the Roman Empire, they were gaining a more significant role, and facilities for rest, recreation and treatment have been built near them. According to the written traces and remains of the sites, pools and the hot water pools, it is known that the waters of Sokobanja, Gamzigradska Banja, Niška Banja, Vranjska Banja, Zvonačka Banja, Vrnjačka Banja and other spas in Serbia were in use at the time. Later, this practice was continued in the Ottoman period by the construction of baths (hamams). According to the number of thermo-mineral wells per area, Serbia is at the very top of Europe. There are over 300 of them, around 40 are already well-established spa resorts, and there are about 30 spas of local importance and somewhat less equipped. At the lowest altitude of 80 m amsl, Rusanda Spa is situated near the Tisa River, and the highest, Lukovska Banja Spa on Kopaonik (681 m amsl). According to the water temperature and chemical composition, these sources are quite different.

In the Spatial Plan of the Republic of Serbia (SPRS 2010), spas are divided into those of a ***Prospective International Significance, National, and Regional Significance***. This was done according to their affirmation (realized turnover, valorized natural conditions, resources and values, as well as created conditions) and criteria of prospects in relation to tourist destinations, transit routes and city centers. The highest category is given to seven spas: Vrnjačka Banja, Niška Banja, Sokobanja, Mataruška Banja, Bukovička Banja, Banja Koviljača and Vranjska Banja. Among those of national significance are Prolom Banja, Gornja Trepča, Ribarska Banja, Kanjiža and Junaković spas.

Wells in the Vranjska Banja Spa are among the hottest in Europe. They occur along the faults in volcanic rocks at every 60 m, and they are all hyperthermal, the temperature ranges from 61 to 96 °C. Particular importance to the chemical composition of water is given by the increased presence of iron, aluminium, strontium, lithium, manganese, rubidium, and anion sulfate. The gas composition is dominated by nitrogen. These waters have been proven in the treatment of diseases of the locomotor apparatus, dyspnea, sciatica, lumbago, muscle atrophy, degenerative rheumatism, neurological disorders, anemia, gynecological and digestive organs diseases. In addition to therapeutic purposes, the industry of the city of Vranje uses a 12 km long hot water pipeline for heating many facilities in the spa itself, for growing flowers, etc.

According to the number of tourists in 2015 (Statistical calendar of the year 2015 2016), Vrnjačka Banja Spa is the most visited one with 175,000 guests of which 29,000 are foreigners. Spa tourism is recognized as one of our tourist supports with a total of 430,000 tourists and 1,9 mill. overnight stays per year.

9.4 Assessment of Water Resources Quality

9.4.1 Pollution of Surface Waters

There are four surface water quality classes in quite long use in Serbia. Each of them is given by the values of basic physical, chemical and biological parameters. The cleanest waters are in the first, and the most polluted in the fourth class. All rivers are classified in a class by the Decree on the Classification of Watercourses issued in 1968, which denotes the required water quality class with regard to their natural state and anthropogenic impacts upstream from the sampling site. Therefore, water quality analyzes performed so far, systematically included sampling points downstream of the settlement. Given that very few settlements have waste water treatment plants, according to these analyzes results, the general picture of the water quality condition in Serbia is quite poor (Marković 2011). However, the largest number of watercourses in the mountainous region beyond the reach of everyday human activities has water of the highest, first class. Due to their remoteness and low water flow, their economic significance is low. The middle-sized rivers that have the highest water class upstream from the larger settlements include the rivers Rzav, Studenica, Nošnica, Ljubovija, Gradac, and Dojkinačka.

In general, prevailing water quality Class in rivers is III, meaning water should not be used for the supply of the population, in the food and pharmaceutical industry, as well as for swimming. The most often found were the excessive amount of suspended sediments, the number of coliform cells of fecal origin and the high value of BOD_5. Alarming is the long-standing excessive presence of hazardous pollutants in certain rivers, which gave them the status of environmental black spots. Such are the watercourses Borska, Veliki Bački Canal, Bosut, Topčiderska, Begej, Veliki Lug (downstream from Mladenovac), Lugomir and Belica (downstream of Jagodina), Lepenica (downstream of Kragujevac), Prištevka (downstream of Priština), Nišava (downstream from Niš). In addition to the mentioned parameters in some of these rivers, there is a constant presence of heavy metals, mineral oils, high content of organic matter, phenol, ammonium and nitrite nitrogen etc. (SEPA 2017).

One of the actions to understand the status of surface waters is derived from the EU Water Framework Directive. The new methodology is oriented to aquatic ecosystems and consists of ecological and chemical status. It includes an analysis of a number of elements, each of which has a quantitative and qualitative definition of five different levels of status: high, good, medium, weak and poor status. By summarizing all individual categories, a general assessment of the status of each water body with the same names is achieved. According to the analyzes carried out by the Environmental Protection Agency (2012–2014), poor and bad ecological status has been shown by those rivers (water bodies) that were labeled as problematic in the previous years: Veliki Timok with Borska, Crni Timok, Svrljiški Timok and Trgoviški Timok rivers, Tamiš, Begej, Krivaja, Hydrosystem DTD, Turija, Velika Morava, Crnica, Djetinja, Blatašnica, Jablanica, Nišava, etc. Of the hundreds of sampling points, there were none with a high ecological status, and only Uvac River and Lužnica River had a good ecological status. Medium or moderate status was found in the rivers: Visočica, Jerma, Vlasina, Raška, Ibar (Batrage), Južna Morava (Mojsinje), Moravica (Gradina), Djetinja (Užice), Lim (Prijepolje). As for the chemical status of the water, its estimates are descriptive: "good" and "not achieved good status". In 2012, good status was found at 65% of sampling points, and at others, the problem was in dissolved nickel, lead and cadmium. In the following, 2013 year, at 97% of the sampling points status was good, while in 2014 the number fell to 59%, the listed metals being again cause for not achieving good status (SEPA 2015).

Serbia does not have many natural lakes. The largest ones are in Vojvodina, and except for the lakes Palićko and Ludaš, others originate from the meandering process in river flows—oxbows, either left to natural aging or converted into fish ponds. If not used, the oxbows have a large production of organic matter and sedimentation, poor oxygen regime and accelerated eutrophication, so their water quality is in class II or III. Other natural lakes are in the mountains, mostly of glacial origin (at the Prokletije Mountain, Šarplanina). They are small, but unpolluted and clean.

Reservoirs are mostly of the same water quality status as the rivers feeding them. For their quality, water temperature is especially important, indirectly meaning altitude, depth and quantity of flowing water. The higher the altitude, depth and quantity of flowing water, the better the water quality. The analyzes of water in the reservoirs show there is inadequate pH, the oxygen regime, and the presence of manganese (SEPA 2015).

9.4.2 Groundwater Pollution

The monitoring of groundwater quality is systematically performed in the monitoring network at 60–70 locations in alluvial soil of larger rivers, combining activities of the RHMSS and SEPA. The rest of Serbia is under the jurisdiction of the regional Public Health Institutes. Their groundwater sample analyzes are service, provided upon request from individuals, organizations or companies, as well as during an emergency. Therefore, the picture about the quality of these waters is not entirely conclusive.

During the period 2005–2013 in the groundwater monitoring network, four parameters of water quality were examined: nitrates, chlorides, ammonium ion and nitrites as chemical indicators of organic pollution. According to the SEPA, it has been shown that the content of nitrates was lowering year by year, i.e. the number of samples with excessive quantity decreased. In most samples, chlorides showed mean values (20–40 mg/L), while the presence of ammonium ions in about 10% of the samples was above high (>1.5 mg/L). The worst condition was with nitrites. According to the Rules on the Quality of Drinking Water in Serbia (SEPA 2017), their limit value is 0.03 mg/L. In water samples analyzed during the final years of the period, exceeding the limit value was recorded in 60% of them. According to the microbiological analyses of samples from urban and rural water supply systems, school and public water facilities (wells, sealed sources, springs), the worst situation is in the north of the country, in Vojvodina, and the Districts of Rasina and Moravica. In the Central Banat District of Vojvodina, 60% of the water samples have shown poor groundwater quality, due to the presence of Escherichia coli, Streptococcus of faecal origin, and coliform bacteria. In the same District, there was an excessive content of iron, manganese and arsenic in all samples. On the other hand, the best quality of groundwater is in the basin of the river Nišava and the western parts of the country.

9.5 Concluding Remarks

Water resources in Serbia are diversified both in water quality and quantity and characterized by an uneven temporal and areal distribution. The most industrially developed and populated, northern part of the country is scarce in domicile waters, while all transit waters are concentrated in it. The transit waters account for 90% of the total water volume in the territory of Serbia. In the southern, mountainous part of the country, water comes from the border regions either scarcely populated or in the process of severe depopulation. All this has a major impact on both the way and volume of water consumption and utilization.

The needs for municipal water supply outgrew the capacity of local water supply sources a long time ago. The country is well into finding solutions in the regional water supply systems to enable more reliable water supply for the population. It is assessed a stable water supply in the future would require about 4 bill. m^3 of water annually. This is several times more than the current drinking water delivery. Along with water supply, wastewater treatment is in focus. Although there are rare examples of small-scale wastewater treatment plants (e.g. Bela Palanka and Blace), the larger ones are being built lately, including the plants for the cities of Šabac, Subotica, Leskovac, and Valjevo. Wastewater treatment is also closely linked to water quality protection for irrigation. For quite some time, the growth in the agricultural food production sector is expected from improvements in the irrigation, given the favourable natural conditions. There is an announcement for an incentive from the relevant ministry to cover an area of one million hectares of irrigated areas by 2021. It is 3.5 times less than estimated potential, but also 10 times more than current irrigated areas.

There are several significant opportunities for water resources utilization in Serbia, including the navigation in rivers and canal network, spa tourism, and hydropower production. An intensive transformation is expected in the existing harbours both for the reception and supply of passenger ships to improve conditions for nautical tourism because it shows a constant positive trend worldwide. The transhipment of goods, repairing vessels and ships, are also seen as the significant economic activities in the near future. At present, the recreational and healing water use are in the rapid increase, spa tourism being at the top of the touristic offer in the country, due to the number and quality of thermo-mineral resources. By adopting the practice of combining healthcare and recreational function through wellness and spa centres, the capacities of most of the spas are full throughout the year, with an increasing number of foreign guests.

An important motion sector for the country is the hydropower production. Nowadays, its share in electricity production in Serbia is close to 1/3. Therefore, it is a significant segment of the country's energy sector. According to the current plans, the priority is given to SHPPs, mostly to increase the use of renewable energy sources, although professionals call for a revision of such plans, warning it is not in line with the needs of the water management sector and environmental protection. There are also capital hydropower production projects, such as the construction of Djerdap 3 on the Danube River. This would be a pumped storage plant in the Djerdap sector, the largest of its kind in Europe. It would produce 2400 MW at the end of the last stage of construction, more than the total capacity of the existing Djerdap 1 HPP. The cost estimate for the project is nearly 6.0 bill. € ($8.6 bill.).

While legal, regulatory and institutional framework for further development and progress in the water resources utilization sector is laid out within the integral water resources management approach, it is estimated that time, investments, and human resources are the key factors in achieving long term strategic goal (Water Management Strategy in the Territory of the Republic of Serbia until 2034 2017). According to the Strategy, twenty years of smooth progress in the water sector is needed, along with the following investments for operation and development, shown for the main sectors: 48%—Water resources utilization (Drinking Water Supply, Regional Water Supply Systems, and Irrigation); 42%—Water resources quality protection; 10%—Protection from harmful water effects. Anticipated financial sources comprise: the Republic of Serbia Budget—22%; EU and other Funds—21%; Local Self-government Funds—16%; Investors own Funds—15%, Public Utility Companies, water price—7%; and other assets (credits, donations)—19%. The last, but not the least is human resources. To support current operation and development, the present capacity of highly educated professionals is not sufficient. The proposed structure of engineers only is 35% Civil-Hydraulic Engineers and 65% of others (Civil, Mechanical, Forestry, Agronomy, Geology-Hydrogeology, etc.). The demand for engineers would grow from 1,600 to 3,200 by the end of twenty years period, gradually shifting the focus in expertise from planning and design to construction.

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Chapter 10
Microbial Quality of Irrigation Water in Serbia: Risks to Food Safety

Željka Rudić, Igor Kljujev, Bojana Vujović, Mile Božić and Vera Raičević

Abstract The human pathogen bacteria can colonize and contaminate fresh vegetables and fruits in any part of production chain. Water for irrigation is recognized as a potential source of pathogens that can cause foodborne illnesses. Water is a very effective vector of the transmission of human pathogen to plants, so microbiologically safe water has a unique role in a safe food production. Due to expected water scarcity, the availability of good-quality water for irrigation will be affected, and irrigated agriculture will be challenged. Therefore, a sufficient resource of quality water for irrigation is crucial for sustainable agricultural production. Generally, in Serbia, all surface water resources (canals and rivers) are polluted to some extent, which becomes obvious particularly during the growing season. Even the quality of shallow groundwater occasionally exhibits the levels of faecal indicator bacteria that exceed the limits proposed by international standards for irrigation water quality. The presence of *Escherichia coli*, *E. coli O157:H7*, *L. monocytogenes*, *Salmonella spp*. on different kind of fresh vegetables has been confirmed, using different methods, i.e. PCR, *green fluorescent protein* (Gfp) for transformation bacteria, *fluorescence* in situ *hybridization* (FISH) and confocal laser scanning microscopy (CLSM). This research shows the ability of the human pathogens to surface, and

Ž. Rudić (✉) · M. Božić
Jaroslav Černi Water Institute, Jaroslava Černog 80, Belgrade, Serbia
e-mail: zeljka.rudic@jcerni.rs

M. Božić
e-mail: mile.bozic@jcerni.rs

I. Kljujev · B. Vujović · V. Raičević
Faculty of Agriculture, Department for Microbial Ecology, University of Belgrade, Nemanjina 6, 11080 Zemun-Belgrade, Serbia
e-mail: ikljujev@agrif.bg.ac.rs

B. Vujović
e-mail: vujo.bojana@gmail.com

V. Raičević
e-mail: verar@agrif.bg.ac.rs

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endophytic colonize root, stem and leaf of different vegetables. This chapter deals with the detected water quality of sources used for irrigation in agricultural areas of Serbia, and the potential risks if water of poor quality is used for irrigation.

Keywords Irrigation · Water quality · Plant contamination, Human pathogenic bacteria · Health risks

10.1 Introduction

Water scarcity is a major constraint for sustainable development, not just of the arid and semi-arid, but also temperate climate regions (Rey et al. 2016). Droughts occurred many times and will continue, still, due to growing water needs their adverse effects are expected to increase in the future (Panu and Sharma 2002). Agriculture is a significant user of water resources in Europe accounting for 30% withdrawal (Massarutto 2003; FAO 1997), and reaches 70% of global water withdrawal (FAO 2004; Calzadilla et al. 2010; Rey et al. 2016). Due to expected water scarcity, even in temperate regions, irrigation will be obligatory to support agricultural production, not just to mitigate drought effects. The irrigation system (or irrigation development plan) is acceptable only if it is economically sustainable, i.e. it can close the supply-demand balance and reduce environmental and social problems. Therefore, the issues with respect to water supply and irrigation include both quality and quantity. The water of poor quality may impact the operation of an irrigation system, can affect the soil quality and may also affect food safety.

Water for irrigation is recognized as a potential source of pathogens (Gemmell and Schmidt 2010; Steele and Odumeru 2004; Uyttendaele et al. 2015). Research in South Africa (Gemmell and Schmidt 2010) confirmed the transfer of microbial pathogens to irrigated fruits and vegetables since the population uses surface water for irrigation due to water shortage. According to US FDA (2009), reducing contamination of fresh vegetables before harvesting is crucial in reducing the risk of foodborne illness and outbreaks. In cases when the quality water for irrigation is limited, there is alternative to use this water for irrigating crops that are not used raw and avoid irrigating crops such as leafy greens or tomatoes (Steele and Odumeru 2004). In agricultural areas of Chile, the problem of poor water for irrigation taken from a very polluted river was solved so that only certain crops were irrigated, which led to a significant reduction in hepatitis, typhoid and other gastrointestinal diseases (Steele and Odumeru 2004).

In food production, wastewater must not be used for irrigation of crops that are eaten raw or minimally processed. Water that doesn't satisfy certain quality, especially considering microbial indicators, should never be used for sprinkling fruits in integral fruit production. This is especially important since fresh produce has an increasing role in human diet, due to health-promoting nutritional properties (Maffei et al. 2013) therefore pathogen contamination may represent a serious health risk (Cardamone et al. 2015). "Pathogen contamination in minimally processed vegetables suggests failures in risk assessment and management systems in processing facilities, where contamination sources may be very heterogeneous: soil, irrigation waters and processing environment" (Cardamone et al. 2015). The transmission of human pathogenic bacteria from irrigation water to vegetable plants is a crucial point in plant microbial ecology and the basis for the occurrence of the foodborne disease (Mandrell 2011).

Water quality control, particularly from the microbiological point of view is vital for irrigation planning, intended for ensuring food safety. To achieve sustainable management of water resources in agriculture, the irrigation water could be used after the application of phytoremediation (Radić et al. 2013) and other ecoremediation technologies (Božić et al. 2013). Having in mind the expectation that water shortages will become an increasing problem in the future in the world and getting poor water quality, it is imperative to pay attention to the microbiological quality of irrigation water. This chapter covers several issues regarding the water for irrigation. It begins with the current use of water resources for irrigation in Serbia and the existing regulations concerning the quality of applied water. The quality of water from different sources including large watercourses, canal network, and shallow groundwater is considered. The potential risks when consuming raw food (fruits and vegetables) that was irrigated with water of inadequate quality are highlighted.

10.2 Current Irrigation Practice in Serbia

Moisture is the main agricultural limitation in most areas of Serbia, which makes irrigation development very appealing. Nevertheless, only 3% of the utilized agricultural land is irrigated. The important issue concerning irrigated agriculture is the absence of functional irrigation infrastructure, which would deliver water from reliable sources. The other issue is the poor microbiological quality of water used for irrigation. In Serbia, there is no national regulation targeting particularly the irrigation water criteria, which will encompass microbial indicators among the other parameters. Adequate guidelines or regulations for irrigation water quality should contain criteria designed to protect the ultimate consumers of the crop, grazing animals, farm workers, and in the case of non-farm irrigation, the general public.

10.2.1 Available Water Resources

Irrigation development in Serbia is best described by the Census of Agriculture that was organised and implemented by the Statistical Office of the Republic of Serbia in 2012 (RZS 2013). It was concluded that in the agricultural year 2011/2012, around 12% of agricultural holdings irrigated 3% of the utilized agricultural land. The farmers who grow vegetables, melons and strawberries are most concerned with irrigation, namely 64% of total area under these cops is irrigated. As the main source of water for irrigation, 61% agricultural holdings declared groundwater at holdings, 6,5% public water supply network, and the rest declared surface water at or outside the holding. Further, 60,6% holdings apply surface irrigation, while 12,2% holdings apply sprinkler irrigation, and 27,2% holdings apply drip irrigation. The census results indicate irrational water usage. Surface irrigation is unacceptable in terms of development and expansion of irrigated areas because it consumes huge amounts of water due to high water losses. Use of groundwater (of high quality) and water from the public water supply network is also unacceptable because in that manner our valuable, high-quality resources are spent. Impacts of water abstraction can occur after several hours of pumping and lead to a lowering of groundwater levels in a wide area. Continuous reduction in the groundwater, and thus changes of the water balance can affect other water management activities and water users. With increasing water consumption, current sources are becoming unreliable and insufficient. To preserve current resources and make them reliable and sufficient for priority groups, i.e. domestic use, it is necessary to provide other, alternative water resources for irrigation, which is the largest consumer of water.

Census results confirm that the farmers exploit water sources that are most accessible, i.e. owners of land adjacent to a river or a canal use surface water, but if the land is located away from the surface water bodies, they drill wells in search for water. Currently, the interest in irrigation is growing, particularly in parts where water is less available, but the conditions are suitable for the cultivation of higher-value crops, e.g. vegetables, fruits, aromatic plants. In water-scarce regions, the abundance of available water resources determines the size of the irrigated area. Consequently, it is necessary to apply the interdisciplinary approach to selecting and prioritizing infrastructure, by differentiating water sources for irrigation (Rudić et al. 2019). Development of large irrigation schemes requests both the analyses of the water source abundance and the water quality.

Previous irrigation development plans in Serbia anticipated water use from the Hydrosystem Danube-Tisa-Danube (complex open canal network in Vojvodina province), natural watercourses and impoundments (Petković 2003). The advantage of using surface water for irrigation is adequate water temperature. The roots of crops are very sensitive to significant temperature differences between irrigation water and the environment. Irrigation water temperature affects the metabolic activity of plants, so using water that is too cold can put plants under stress. The downside is dynamic water quality, particularly regarding the microbial quality. Therefore, the available water for irrigation in Serbia is reduced due to significant water quality degradation, which is as mainly a consequence of the wastewater discharge (Belić et al. 2003). In many places, the availability of good-quality water for irrigation is threatened. Also, irrigated agriculture faces the challenge of using less water for irrigation, which is in many cases of poorer quality (Alobaidy et al. 2010).

10.2.2 Regulations

In Serbia, there is a lack of regulations formulated to define the quality of irrigation water from all necessary aspects. According to the Regulation on limit values of pollutants in surface water, groundwater and sediment, and the deadlines for their achievement (Uredba o graničnim vrednostima zagađujućih materija u površinskim i podzemnim vodama i sedimentu i rokovima za njihovo dostizanje 2012), the water used for the irrigation of agricultural land in the most unfavourable case, has to correspond to a fourth class (low ecological status; Table 10.1). This regulation is basically focused on the quality and ecological status of surface water and lists the possibilities of using water of a certain class. In the absence of guidelines or comprehensive regulations that deal with this topic, guidelines proposed by Ayers and Westcot back in 1976, and revised in 1985, are mostly used for the irrigation water quality assessment. Guidelines (Ayers and Westcot 1985) assess the general constituents in water, evaluating and identifying potential problems related to water quality.

According to widely used standards (Ayers and Westcot 1985) water used for irrigation from watercourses and impoundments in Vojvodina (Nešić et al. 2003; Vranešević et al. 2016; Belić et al. 2003) and central Serbia (Trajković 2004; Belić et al. 2003) is estimated to be of acceptable quality. However, taking into account the concentration of heavy metals, bacterial content and enzymatic activity, the water quality often becomes unsatisfactory (Belić et al. 2003). The researchers were not occupied as much with the microbial quality of irrigation water sources, although the water is an important material in the fresh produce chain.

When it comes to the microbiological quality, it is recommended to use the regulations that had been developed specifically to assess the quality of irrigation water, such as the Canadian guidelines or guidelines of the World Health Organization, or other suitable regulations (Table 10.2). The microbiological quality is often overlooked, but we should keep in mind that improper microbiological quality of irrigation water should not be used for sprinkling fruits and vegetables that will be consumed raw because it represents a potential health risk (Uyttendaele et al. 2015).

Table 10.1 Limits for surface water of poor ecological status (IV class). Microbial parameters from the Regulation on limit values of pollutants in surface water, groundwater and sediments, and the deadlines for their achievement (Uredba o graničnim vrednostima zagađujućih materija u površinskim i podzemnim vodama i sedimentu i rokovima za njihovo dostizanje 2012)

Parameter	Unit	Limit
Faecal coliforms	CFU/100 mL	100.000
Total coliforms	CFU/100 mL	1.000.000
Intestinal enterococci	CFU/100 mL	40.000
Aerobic heterotrophic bacteria (Kohl method)	CFU/100 mL	750.000

Table 10.2 Microbial quality limits of irrigation water

Parameter	Unit	WHO (Uyttendaele et al. 2015)	Canadian water quality guidelines (Anonymous 1999)	German standard (DIN 1999; Stauffer et al. 2001)	British Columbia guidelines (Anonymous 1988)
		Wastewater	Surface water		All
Faecal coliforms	CFU/100 mL	1,000	100	–	1,000/200[b]
Total coliforms	CFU/100 mL		1,000	–	–
E. coli	CFU/100 mL			200/2000[a]	
Entero-cocci	CFU/100 mL		–	100/400[a]	250/20[b]

[a]Outdoor and greenhouse crop for raw consumption/vegetables up to 2 weeks prior to harvest outdoor crop for raw consumption until time of fructification
[b]Irrigation general/crops eaten raw; geometric means are calculated from at least 5 samples in a 30-day period

The complex water-plant-soil relationship, in addition to human-induced changes, explains the difficulties in producing one universal classification of irrigation water quality. The required irrigation water quality may vary for some parameters, and it depends on the chosen irrigation method, soil quality, crop needs and the use of grown crops. The latter is important since the growth of crops for raw consumption need more stringent microbiological water quality standards. To avoid the use of different classifications, comprehensive guidelines that should encompass understandable, competent and internationally comparable indicators are needed.

10.3 Evaluation of Irrigation Water Quality from Different Water Sources

For the research purposes, the laboratory of Department of Ecological Microbiology (Faculty of Agriculture, University of Belgrade), performed numerous investigations of the microbiological quality of surface and groundwater during the period from 2005 to 2017. Water sampling was conducted in nine areas with established agricultural activities in the Republic of Serbia (Fig. 10.1). The part of these investigations was realized during the WATERWEB (Water Resource Strategies and Drought Alleviation in Western Balkan Agriculture) project No. 509163, funded by the EU FP6, INCO-West Balkans (2004–2008). These investigations were carried out at the experimental school estate “Radmilovac” of the Faculty of Agriculture (Belgrade) and assessment of the irrigation water quality was done using coliform bacteria, zooplankton and zoobenthos as bioindicators (Dulic et al. 2008).

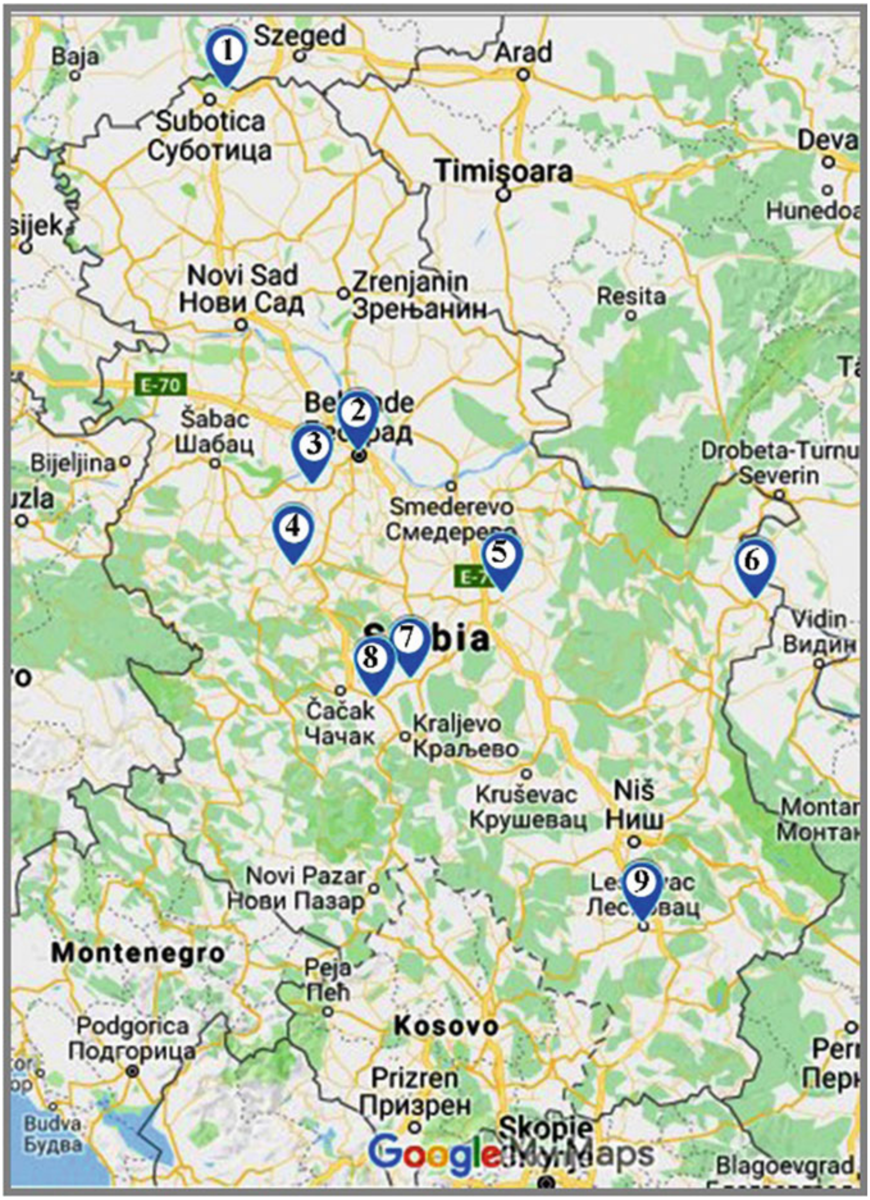

Fig. 10.1 Sampling areas: 1-The Palic-Ludas canal, 2-Belgrade, 3-Obrenovac, 4-Western Serbia, 5-Svilajnac, 6-Negotin, 7-Knic, 8-Mrcajevci, and 9-Leskovac

Examined water bodies are grouped per location and type. The far north of Vojvodina is represented by the Palic-Ludas canal, which is not intensively used for irrigation, but flows through rural parts and is easily accessible for farmers.

Table 10.3 List of examined locations and water resources

	Sampling area	W*	C*	R*
1	The Palić-Ludaš canal	–	10	–
2	Belgrade area	2	5	–
3	Obrenovac	3	7	2
4	Western Serbia	6	–	–
5	Svilajnac	5	–	1
6	Leskovac	7	–	–
7	Negotin	–	3	–
8	Knić	–	–	4
9	Mrčajevci	1	–	1
	No. samples	24	25	8

*Sampling sites: *W*-wells; *C*-canal; *R*-river

The high concentrations of nutrients, along with significantly high values of faecal indicators in water samples, indicate that the Palic-Ludas canal, contributes to the pollution of the recipient Lake Ludas (Rudic et al. 2018). Area of Belgrade encompasses two agricultural parts: the experimental field "Radmilovac", which is irrigated with water from the open canal Sugavac, two open and one closed well; the canal network in Surčin that drains the floodplain of the Sava river but is also used for irrigation of neighbouring plots. The investigations about the irrigation water quality of the canal network in Surčin have been realized within the EU SAFIR (Safe and High Quality Food Production using Low Quality Waters and Improved Irrigation Systems and Management) Project No. 023168, funded by the EU FP6 ONCO (2005–2009). Water for irrigation in agricultural parts of Obrenovac is mainly used from the Sava and Kolubara rivers, the canal network of Krtinska, and water wells. At the other locations, designated as Western Serbia, Svilajnac and Leskovac, water samples are taken mainly from groundwater, while in Negotin and Knić examined water sources are natural and artificial watercourses (Table 10.3).

In order to compare and verify our findings, we also performed the statistical analysis of monitoring records for a few large rivers in Serbia, the Danube, Sava, Drina and Velika Morava. For that purpose, we used monitoring records of the Republic Hydrometeorological Service of Serbia (RHMZ 2005–2010), and Serbian Environmental Protection Agency, which has continued the monitoring process from 2011 (SEPA 2011–2014).

10.3.1 Methods for Microbiological Analysis

The microbiological analysis included the following parameters: a total number of aerobic heterotrophic bacteria, both mesophiles and psychrophiles, total and faecal coliforms, *E. coli*, enterococci, *Salmonella* sp. and *Pseudomonas aeruginosa*. All parameters were determined following the standard microbiological procedures. Samples were taken from watercourses and existing wells that were mainly used for irrigation. Bottled samples were stored inside the travel cooler for up to 6 h before reaching the laboratory. The total number of aerobic heterotrophic bacteria was done by heterotrophic plate count method using the Meso-peptone agar (MPA); incubation of mesophilic bacteria was ensured at 37 °C for 48 h and psychrophilic bacteria at 22 °C during 3 to 5 days. Detection of faecal contamination indicators (total coliforms, faecal coliforms and *Escherichia coli*) was done by different methods, since the time span of all conducted research is rather long: (1) the most probable number (MPN) method using the Mac Conkey (lactose) broth, using three tubes in each dilution for surface water and five tubes with 10 mL of well water; (2) the Coliform-Count-Plate (EC) petrifilm (3 M, USA) method; and (3) the Selective-E.coli/coliform-chromogenic-medium (CM1046) (Oxoid, Hampshire, UK). Following the MPN method, detection of *Escherichia coli* and other faecal coliform strains, as well as confirmation of the presence of total coliforms, were done by inoculation eosin-methylene blue (EMB) agar from positive presumptive test tubes and incubation at 44 °C/24 h, and at 37 °C/24 h for faecal and total coliforms, respectively. The results are recorded as MPN per 100 mL of water. The presence of *Salmonella* sp. and *Pseudomonas aeruginosa* was confirmed by using tubes of presumptive MPN test and separate inoculation of the one drop of suspension to Salmonella-Shigella (SS) agar and Cetrimide agar, ensuring the incubation at 37 °C and 42 °C for 24 h. Presence of typical colonies was confirmation of the presence of these groups of bacteria. Subsequently, the isolated Enterobacteriaceae were identified based on morphological characteristics of cells (gram stain reaction, shape, size) and biochemical reactions tested with API 20 NE and API 20 E (BioMereiux, France).

10.3.2 Microbiological Indicators in Water for Irrigation

According to results of monitoring performed by Republic Hydrometeorological Service of Serbia (RHMZ) and Serbian Environmental Protection Agency (SEPA), water quality of several main watercourses (the Danube, Sava, Drina and Velika Morava rivers) is mostly satisfactory considering chemical quality (salinity, the content of nitrogen, chlorides and bicarbonates). Nevertheless, microbial quality of water is changeable, and during the growing season, it is in general unsatisfactory. During summer the water level drops, therefore the concentrations of pollutants in water are higher than during the rest of the year. Median for total coliforms in water of the Drina, Sava and Danube were 2,100 CFU/100 mL for the monitoring period 2005–2014. The same parameter in the same period for the Velika Morava was lower, 1,350 CFU/100 mL, although the water quality varied in a broader range

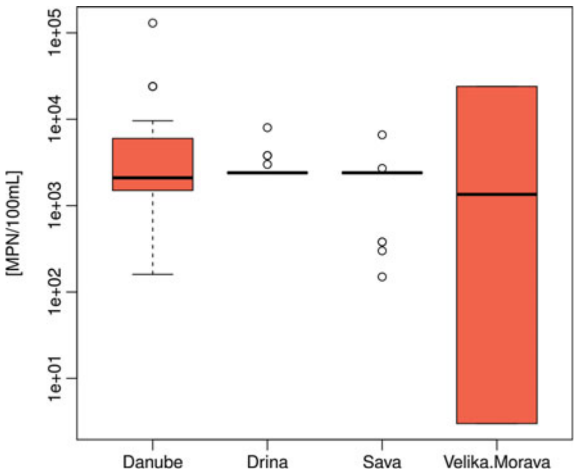

Fig. 10.2 Total coliforms in the Danube, Drina, Sava and Velika Morava rivers. Analysis of monitoring results (2005–2014)

when comparing to other analysed rivers (Fig. 10.2). A couple of valuable parameters (faecal coliforms and enterococci) could not be appropriately evaluated since they have been included in monitoring plan recently.

When considering the microbial quality of surface water, the quality is satisfactory concerning current Regulation, which is not specifically created for water for irrigation. However, when the monitoring results are compared to Canadian guidelines (maximum allowed content of total coliforms in irrigation water 1,000 CFU/100 mL), the average content of total coliforms is high, and 52% to 100% of samples exceed this limit (Table 10.4). According to international experience and practice, the use of this water for irrigating fruits and vegetables for raw

Table 10.4 Water quality of large rivers: observations that exceed proposed limits

Observations	Faecal coliforms*	Total coliforms*
Velika Morava		
No.	2	12
%	100	52
Sava		
No.	1	19
%	100	83
Drina		
No.	–	26
%	–	100
Danube		
No.	9	23
%	90	79

*According to Canadian standards

consumption is not recommended without prior treatment. Despite the great importance of irrigation water quality in agriculture and food chain, monitoring of irrigation water is globally inadequate (Pachepsky et al. 2011) and research regarding the microbial quality of water has been focused on reclaimed water, drinking and recreational water supplies and the effects of agriculture on the environment (Allende and Monaghan 2015). A legal framework for irrigation water quality and regular monitoring of crop water sources does not exist. Pachepsky et al. (2011) emphasized that no databases on microbial quality of irrigation water had been collected and no uniform legislative about the required water quality exist.

The surface water has been classified as the riskiest irrigation water source by several international agencies because, among other reasons, it may be a recipient of treated or untreated wastewater (Allende and Monaghan 2015; Truchado et al. 2018). Regulations for the microbiological quality of surface waters tend to be milder than those for wastewater because many specific human pathogens that are present in the wastewater are usually not found in unpolluted surface waters (Feachem et al. 1983). When considering the deficiency of wastewater treatment in Serbia, the current regulations are not sufficient for assessing the suitability of surface water for irrigation regarding microbiological quality.

The results of research conducted in listed agricultural areas (Table 10.3) are gathered in two groups according to the type of water body, surface water and groundwater. The highest counts of faecal indicators were detected in the "Palić-Ludaš" canal (faecal coliforms: 1.553.100 MPN/100 mL; enterococci: 98.800 MPN/100 mL; *E. coli*: 727.000 MPN/100 mL). The indicators of faecal contamination were detected in all tested samples. Median, upper and lower quartile of enterococcal counts in surface water indicate the variability of obtained results and changeable water quality (Fig. 10.3).

Numerous *E. coli* was detected in surface water, Kolubara and Krtinska canal network, while the lower number was obtained in the basin of river Morava

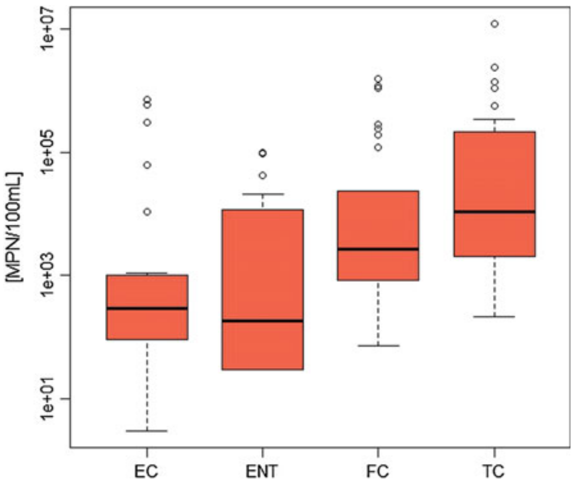

Fig. 10.3 Faecal indicators in surface water of investigated sites (EC—*E. coli*; ENT—enterococci; FC—faecal coliforms; TC—total coliforms)

(Mrcajevci and Knic). EPA declared *E. coli* and *Enterococcus* as the best indicator of faecal contamination of surface water bodies. Moreover, *E. coli* together with faecal coliforms are a better indicator of faecal pollution that the faecal coliforms itself. Anyway, the obtained results indicate that almost none of them met Canadian guidelines for total and faecal coliforms. Seventy-nine per cent and 93% of samples exceed the limit for total and faecal coliforms respectively.

The obtained results are in the agreement with previous conclusions and monitoring results of RHMZ and SEPA. They show that more or less each surface water body is polluted to some extent. The water quality of the Palic-Ludas canal is affected by wastewater discharge at the downstream section, which shows signs of degradation, particularly regarding the content of nutrients and faecal contaminants (Rudić et al. in press). The similar situation is in the canals of Belgrade, Obrenovac and Negotin area. The open canal network, which was initially constructed for drainage of excess water, today is also a recipient of wastewater discharged from households or animal farms. The microbiological water quality is usually unfavourable during the growing season when water levels get lower, and contaminants are more concentrated. Also, the microbiological quality of irrigation water is affected by environmental factors, weather conditions (climate change, rainfall, temperature and seasonality), the presence of domestic animals and irrigation regime (Holvoet et al. 2014; Decol et al. 2017). According to the results of API-WEB tests, numerous pathogenic bacteria including *Escherichia coli 1*, *Klebsiella pneumoniae*, *Citrobacter freundii Aeromonas hydrophila 1, E. coli 2, E. Vulneris, E. Adecarboxylata, Vibrio fluvialis, Yersinia enterocolitica*, *Aeromonas hydrophila 1, Aeromonas spp., E. coli O157:H7, Salmonella spp.*, and *Enterobacter aerogenes* were detected in open-canal network of Belgrade and Negotin, while in the open wells in Belgrade area *Salmonella spp*. and *Shigella spp*. were detected. In the Palic-Ludas canal, Kolubara and Krtinska canal network were detected *Salmonella* sp. and *Pseudomonas aeruginosa*. Water pollution is presumably the consequence of the continual discharge of faecal matter from livestock farms and urban wastewater. *Salmonella spp.* is one of the leading causes of intestinal disease worldwide, usually spread by water (Levantesi et al. 2012). Presence of *Salmonella* was reported in surface waters such as rivers, lakes, and ponds, while groundwater, in general, has better microbial quality. *Salmonella* is frequently present in surface water because it possesses efficient survival mechanisms, including entry into the non-culturable state and residing with free-living protozoa. An increasing detection indicates irrigation water as a source (or a vehicle) for transmission of *Salmonella* (Liu et al. 2018). Another important microbe for the assessment of water quality is *Pseudomonas* which is a genus of a heterogeneous and ecologically important group of bacteria including Gram-negative, motile, aerobic rods and widespread (Vujović et al. 2016). *P. aeruginosa* tolerates a wide range of physical conditions, including temperature. *P. aeruginosa* is commonly present in waters affected by wastewater discharge (Tambekar et al. 2014). It is an opportunistic bacterium with high resistance to many commonly used antibiotics and can cause several diseases (Akrong et al. 2012). The biological hazards that dominate in produce-associated outbreaks include various serotypes of *Salmonella enterica*, *Shigella* spp., verocytotoxin-producing *E. coli* O157, enterotoxigenic *E. coli* and rarely *Campylobacter jejuni*, *Listeria monocytogenes*, human enteric viruses or parasitic protozoa *Cryptosporidium* and *Cyclospora* (Uyttendaele et al. 2015).

Groundwater is often used in agricultural practice and food industry. Generally, groundwater contains a less organic matter (Uyttendaele et al. 2015) and is not usually microbiologically contaminated. Recently, increasing potential for groundwater contamination from surface events is recognized. However, large variations in quality between shallow groundwater and water from deeper aquifers can be expected (Uyttendaele et al. 2015).

Obtained results have shown that poor groundwater quality is becoming a growing concern in Serbia. Groundwater quality degradation is confirmed by high bacterial counts (Table 10.5). The high number of mesophilic and psychrophilic heterotrophic bacteria (Fig. 10.4), as well as total and faecal coliforms (Table 10.5), indicate the anthropogenic impact.

Table 10.5 Groundwater quality—faecal indicators in shallow wells (TC-total coliforms; FC-faecal coliforms, EC-*E.coli*, ENT-enterococci)

[MPN/100 mL]	*TC*	*FC*	*EC*	*ENT*
Mean	2.076,83	5.735,69	51,71	6.869,27
Standard Error	1.239,98	3.118,14	46,31	3.737,69
Median	9	0	0	0
Standard Deviation	5.545,37	13.591,65	207,09	16.292,21
Minimum	0	0	0	0
Maximum	22.853	43.505	930	43.505
Count	20	19	20	19
*No.	5	7		
*%	25	35		

*Observations that exceed limits proposed by Canadian standards

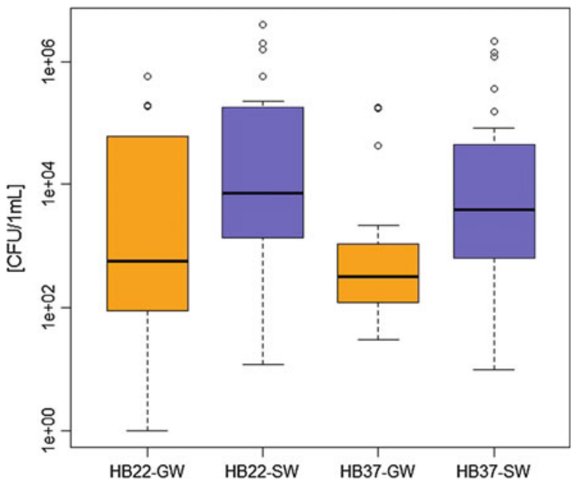

Fig. 10.4 Aerobic heterotrophic bacteria in surface and groundwater (HB22—psychrophilic bacteria; HB37—mesophilic bacteria; GW groundwater samples; SW—surface water samples)

While the highest number of the heterotrophic bacteria was detected in the well close to Krtinska canals (Obrenovac area), the highest counts of faecal indicators were detected in wells of Leskovac (faecal coliforms: 43.505 MPN/100 mL; enterococci: 43.505 MPN/100 mL) and Mrčajevci (*E. coli*: 930 MPN/100 mL). Despite high bacterial counts, median values indicate that the process of groundwater contamination is not steady, i.e. the majority of the samples were free of pathogens (Table 10.5). In the rural settlements, the main cause of faecal contamination is pollution connected with farming, inadequate waste disposal, incomplete sewage system, the absence of watertight cesspits (Yates 1985; Valenzuela et al. 2009) and well shallowness (Rohmah et al. 2018).

Overall, the heterotrophic bacteria are the organisms most abundant in nature. They are commonly present in all types of water, food, soil, and vegetation. This group of bacteria include many genera, like *Proteus, Enterobacter, Aeromonas, Citrobacter, Pseudomonas, Klebsiella, Flavobacterium, Moraxella, Alcaligenese* and *Acinetobacter* which are not indicators of the pathogenic condition (Bartram et al. 2003; Amanidaz et al. 2015). However, some of them, e.g. *Pseudomonas*, are opportunists and can cause infections in the skin and lungs, or they can be linked with other disease aetiology (Bartram et al. 2003). Therefore, the presence of heterotrophic bacteria in water has implications for public health (Davis et al. 2005). A large or increasing number of heterotrophs should be explained with respect to their ecological role in the ecosystem, relating them to concentrations of organic matter and nutrients, and considering them as potential microbiological hazards in primary food production, human and animal environment.

It is well known that coliforms (*Enterobacteriaceae*) are facultatively anaerobic, gram-negative, nonsporogenic bacteria capable to ferment lactose. As it was mentioned above, this group of bacteria is together with enterococci the most commonly used indicator of faecal contamination in microbiological practice. Many guidelines and regulations in the world on appropriate microbial quality specifications for surface water or (treated) wastewater to be used for irrigation are based on testing for faecal coliforms and declare acceptable limits up to 1,000 faecal coliforms and/or 126 *E. coli* per 100 mL (Uyttendaele et al. 2015). However, available literature suggests caution mostly because the levels of *E. coli* can vary significantly depending on several factors including seasonality, geographical location and weather conditions (Forslund et al. 2012). An example from the UK revealed that although the faecal coliform concentrations in water samples were below 1000 CFU/100 mL, the water used for irrigation was contaminated (Tyrrel et al. 2006). On the contrary, Holvoet et al. (2014) found a high prevalence of *E. coli* in the irrigation water sources in Belgium (75% of tested 120 samples), with 65% of the positive samples having *E. coli* levels $\geq$ 1 log cfu/100 mL and 26% counts $\geq$ 2 log cfu/100 mL. Also, 35% of tested samples were positive for at least one pathogen, *Salmonella*, *Campylobacter* or Shiga toxin producing *E. coli*.

10.4 Microbiological Quality of Irrigation Water and Bacterial Colonization of Plants

There are many ways for human pathogens to reach and contaminate vegetables, but the most often way is through irrigation water, especially in fresh vegetable production (Kopper et al. 2014). Coliform bacteria and *E. coli* could be transported from contaminated irrigation water to potato tubers (Forslund et al. 2010; Steele and Odumeru 2004). The highest number of coliforms on potato tubers was 4.20×10^4 CFU/g of potato tuber. The potato is most cultivated plant in Europe. It is important to point out that the potential risk of consuming contaminated potatoes is lower in relation to other vegetables because the potato is not consumed fresh. However, contaminated potato presents a potential risk of cross-contamination in the processing industry and households. Increasing demand for existing and new potato products indicates the importance of its microbiological safety (Doan and Da Vidson 2000).

Also, the high number of coliform bacteria was detected on carrots (1.18×10^6 CFU/g) and spring onions (3.79×10^4 CFU/g), which were irrigated with water contaminated with human pathogenic bacteria. A large number of these bacteria (total and faecal coliforms) were also detected in tomato, peppers, cucumber. The presence of human pathogens *E. coli*, *E. coli* O157:H7, *Salmonella spp*. were determined in the examined vegetables. The *E. coli* was isolated from carrot, spring onion, pepper and tomato and *E. coli* O157:H7 was identified in parsley and carrot roots, as well as tomato fruit. The *Salmonella spp*. was detected in parsley root, spring onion, pepper and tomato fruits (Table 10.6).

Table 10.6 Human pathogenic bacteria isolated from fresh vegetables

Plant	Human pathogenic bacteria		
	E. coli	*E. coli* O157:H7	*Salmonella spp.*
Carrot	+	+	–
Parsley	–	+	+
Celery	–	–	–
Cabbage	–	–	–
Spring onion	+	–	+
Tomato	+	+	+
Pepper	+	–	+
Cucumber	–	–	–

10.4.1 Colonization of Plants by E. Coli PBA28 (Gfp)

Kopper et al. (2014) showed that *E. coli* PBA28 (Gfp) is capable of colonizing surfaces of sweet corn and other leafy vegetable roots. The bacterial counts on the root surface of these plants were above 105 cells/mm^3 of the absolutely dry root (Fig. 10.5). The ability of endophytic colonization of plants by *E. coli* has also been shown by Tyler and Triplett (2008). The endophytic colonization is a result of plant root infection or seed contamination (Cooley et al. 2003), but the degree of colonization is determined by the genetic code of both organisms, bacteria and host plant (Tyler and Triplett 2008). The previous studies revealed the presence of *E. coli* O157:H7 near the stomata or inside the stomata hole on lettuce (Takeuchi and Frank 2001).

The endophytic colonization by *E. coli* PBA28 was more represented in leafy vegetables and sweet corn (>10^4 cells/mm^3 of absolutely dry root) in relation to others (root-carotid) vegetables (Figs. 10.5, 10.6 and 10.7).

Saldana et al. (2011) revealed the presence of STEC bacteria (Shiga toxin-producing *Escherichia coli*) in stomata, intercellular spaces, and in vascular tissue (xylem and phloem), using electron microscopy analysis. The bacteria are protected from the bactericidal effect of different chemical agents. The researchers assume that the expression of the T3S system is responsible for the successful colonization of plant leaves. The evidence that STEC can colonize plant stomata and internal tissues may present a strategy of bacterial survival in a nutrient-rich microenvironment, which is protected from external conditions and could be a potential source for human infection.

The Gfp-transformed *E. coli* O157:H7 is capable of colonizing the interior of lettuce. If this strain is present in irrigation water and soil, it could be transported through plant vascular system (xylem) from root to leaf (Franz et al. 2007). Using

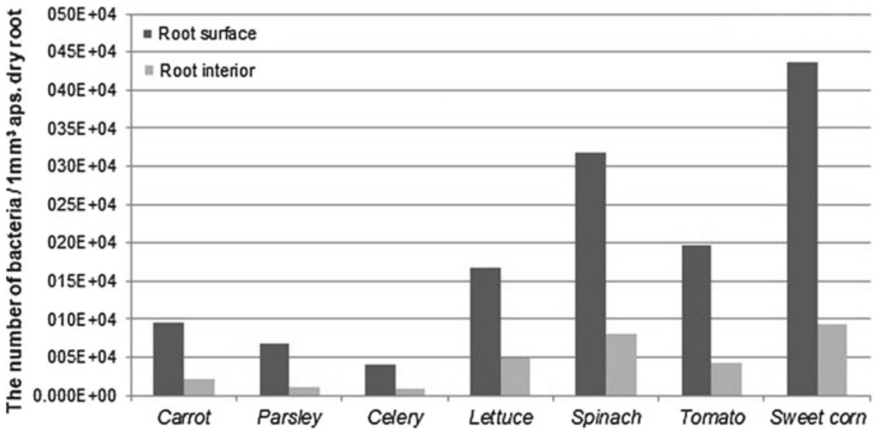

Fig. 10.5 Colonization of plant roots by *Escherichia coli* PBA28 (Gfp)

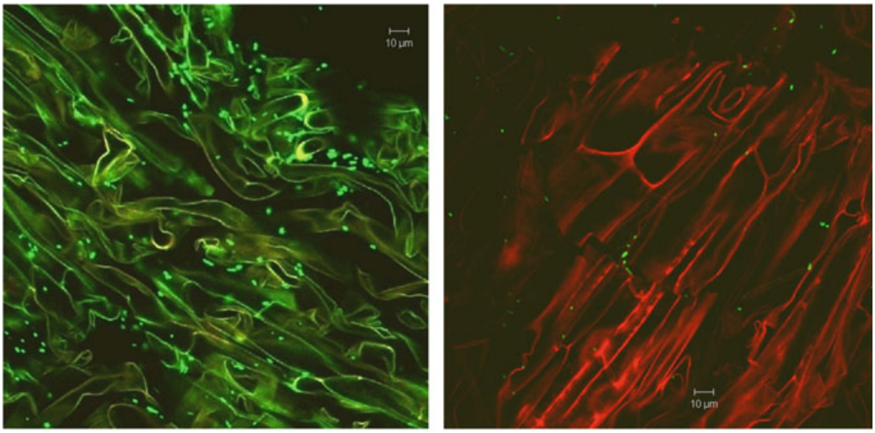

Fig. 10.6 Micrography of surface (left) and endophytic (right) colonization of sweet corn root by *E. coli* pBA28 (Gfp) (green cells)

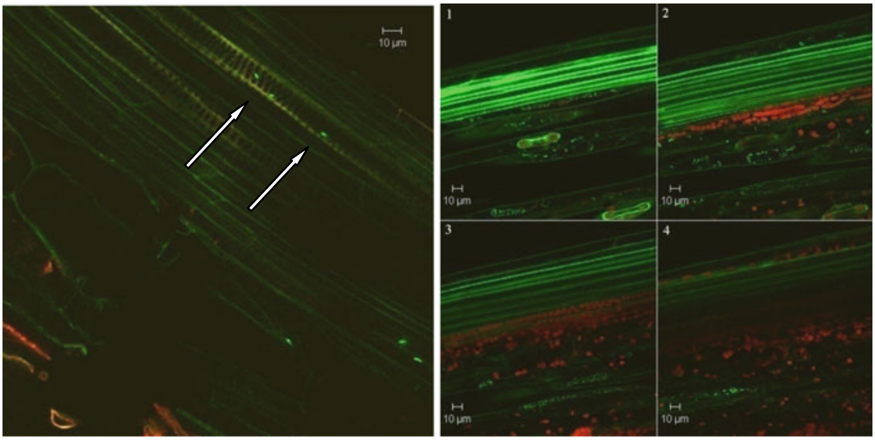

Fig. 10.7 Micrography of endophytic colonization of sweet corn root (left) and leaf (right) by *E. coli* pBA28 (Gfp) (green cells). White arrows show *E. coli* cells inside xylem of sweet corn root

manure and irrigation water contaminated with *E. coli* O157:H7 in growing lettuce, confirmed the presence of this strain on the surface and inside the lettuce leaf approximately 8 weeks after applying manure and irrigation (Oliveira et al. 2012).

By using confocal-laser-scanning microscopy, the presence of *E. coli* was detected inside the lettuce root, very close to the internal vessels and xylem and inside the root, with formed microcolonies of 10–20 cells. Also, obtained micrographs prove the presence of these bacteria in lettuce and parsley leaves. Regarding the sweet corn root, the presence of individual *E. coli* cells is visible in the root vessels (xylem) (Fig. 10.7). Also, *E. coli* cells were visible in the intercellular spaces of the root (Fig. 10.6). A significant concentration of *E. coli* was revealed inside the sweet corn leaves, with bacteria predominantly located around the stomata (Fig. 10.7).

STEC and other *E. coli* can attach to leaf epidermis and inside/around stomata (Xicohtencatl-Cortes et al. 2009; Berger et al. 2009, 2010). The *E. coli* O157:H7 can replicate themselves and survive in a safe, nutrient-rich niche of stomata, internal tissues and intercellular spaces of the plant leaves. The STEC infectious dose is low (10–50 cells) and its ability to colonize the internal plant compartments gives an explanation why bacteria survive decontamination treatments and cause STEC outbreaks linked with consumption of ready-to-eat vegetables.

The infected leafy vegetables may potentially transport the infection to humans. The STEC (human pathogen) uses several pili types, flagella and the T3SS for human intestinal tissue colonization. These bacteria could use these same mechanisms to colonize plant tissue before causing disease (Saldana et al. 2011). The level of attachment of *E. coli* O157:H7 to cabbage and lettuce surfaces is correlated with the number of its curli and their hydrophobicity (Patel et al. 2011).

10.4.2 Colonization of Plants by Salmonella Enterica Serotype Typhimurium (LT2, S1, ATCC14028)

Pre-harvest contamination of the edible plant products occurs through the soil. The transmission of the pathogen from soil to plant tissue is facilitated by the lateral root emerging areas (Karmakar et al. 2018). *Salmonella spp*. strains have different ability to colonize different plant species. The *Salmonella enterica* Typhimurium LT2 has the greatest ability for surface and endophytic colonization of lettuce root and the smallest for carrot root. The obtained results show the ability of human pathogen *Salmonella enterica* serotype Typhimurium (*S*. Typhimurium) for very efficient endophytic colonization of different plant species, active entrance inside the plant tissue and reproduction in intercellular plant root spaces.

Schikora et al. (2008) demonstrated that *Salmonella* Typhimurium could enter *Arabidopsis thaliana* plant and reproduce itself in it. Although the infection of *Arabidopsis thaliana* plants activates the plant immune response, it appears that *S*. Typhimurium can overcome host defence mechanisms and reproduce itself in plants. Hence, *Salmonella* Typhimurium could be typical plant endophyte bacteria (endopathogen) (Kljujev et al. 2018b).

The surface plant root colonization by *Salmonella enterica* serotype Typhimurium S1 was the most expressive on tomato, lettuce and celery (>10^5 cells/mm^3 of absolutely dry root) and endophytic colonization of tomato, celery and spinach (>10^4 cells/mm^3 of absolutely dry root).

The *Salmonella* Typhimurium LT2 cells were single, or they formed microcolonies in the inner layers of the lettuce root. The cells were located in intercellular spaces and close to the vascular vessels of the root (Fig. 10.8). Regarding the tomato and sweet corn root, the confocal laser scanning microscopy showed that

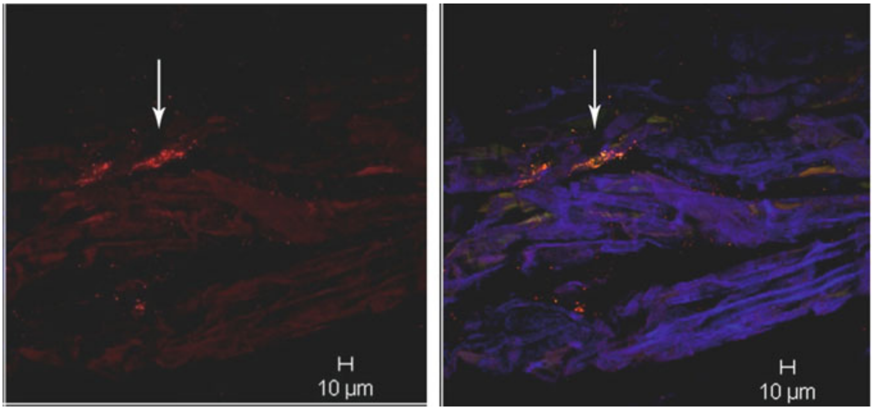

Fig. 10.8 Micrography of colonization of lettuce root by *S*. Typhimurium LT2

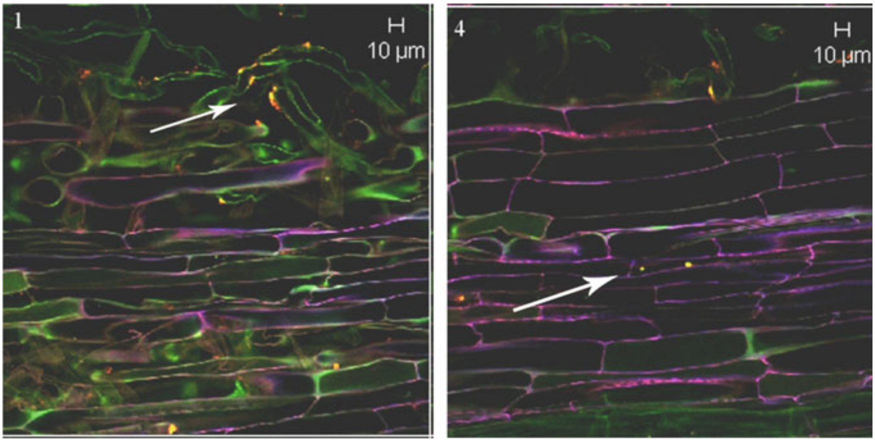

Fig. 10.9 Micrography of colonization of sweet corn root by *Salmonella* Typhimurium ATCC 14028. The white arrow on slide 4 shows yellow *Salmonella* cells inside plant cells

cells might reach very deep inside the root, up to the xylem. The *Salmonella* Typhimurium LT2 cells largely colonize the surface of the root hair as well as the surface of the root itself. Also, the cells were detected in the intercellular spaces of the deeper layers of the plant roots. The *Salmonella* Typhimurium ATCC 14028 intensively colonized the surface of the sweet corn root hairs and formed aggregations or biofilms on their surface. In deeper root layers, cells were single in intercellular spaces (Fig. 10.9). *Salmonella* cells formed microcolonies in intercellular spaces near the xylem vessels of the lettuce root tissue and were firmly attached to the root hairs and formed a biofilm on the spinach root.

The *S.* Typhimurium strains LT2 and DT104 are able to endophytically colonize seedlings and sprouts of barley which were grown in "axenic" conditions. The FISH (Fluorescence In Situ Hybridization) analysis confirmed the presence of *Salmonella* Typhimurium cells in the interior of plant tissue (Kutter et al. 2006). The investigation, related to the "immune response" of lettuce (*Lactuca sativa*) after colonization by *Salmonella enterica* serotype Dublin, showed that 43% of plants were colonized by these bacteria (Klerks et al. 2007).

The model strain *Salmonella enterica* serotype Typhimurium ATCC14028 showed very good ability for colonization of roots of all investigated plant species. The highest bacterial counts were registered in the surface layers of lettuce, sweet corn roots (10^6 cells/mm^3 of absolutely dry root) and spinach, tomato and carrot roots ($>10^5$ cells/mm^3 of absolutely dry root). This bacterial strain colonized also parsley and celery root surface, but to a lesser degree. The endophytic colonization of lettuce, sweet corn roots ($\approx 10^5$ cells/mm^3 of absolutely dry root) and celery root ($\approx 10^4$ cells/mm^3 of absolutely dry root) was also registered. *Salmonella* Typhimurium tends to be very good root colonizer of all examined plants (Figs. 10.8 and 10.9).

Klerks et al. (2007) studied colonization dynamics and found out that the largest number of bacteria was detected on the 12th day after the beginning of inoculation. The early tomato leaf colonization by *S. enterica* causes contamination of all fruit with the concentration of 10^5 CFU per fruit. The tomato plants irrigated with contaminated water have larger *S. enterica* bacterial concentration than the grown plants. However, every way of contamination leads to the presence of *S. enterica* populations in the tomato phyllosphere which represents the risk of fruit contamination and human disease outbreak. The phyllosphere *S. enterica* may cause fruit contamination (Barak et al. 2011).

If human pathogenic bacteria enter leaves, they are capable of replicating, which was shown by our experiments with Gfp-transformed bacterial strains, and consistent with preceding studies (Iniguez et al. 2005). Some studies have shown that *Salmonella spp*. may be present in the plant apoplast (intercellular spaces) and form a biofilm at parsley (Lapidot et al. 2006).

The infection of humans and animals with *S.* Typhimurium depends on various identified factors and the mechanism of penetration this bacterium into the epithelial cells of the hosts. The ability of *Salmonella spp.* for survival in the environment or outside the host organism has not yet been fully clarified, but there is evidence that these bacteria are very adaptable to low pH and high temperature. According to Nicholson et al. (2005), the *Salmonella spp*. could not survive more than 900 days after inoculation in the soil. Nevertheless, many studies show that contaminated soil for growing vegetables, especially those which are consumed fresh, could be the reason for infection by human pathogenic bacteria (Brandl 2006). The *Salmonella spp*. often reaches the soil through manure, wastewater or other organic waste.

The findings of our research show that plants, whose tissue is colonized by *Salmonella enterica* serotype Typhimurium, are a very good model for further studying the mechanisms of colonization and pathogenicity of *Salmonella spp*.—plant interaction.

10.4.3 Colonization of Plants by Listeria Monocytogenes (EGD-E, SV4B)

Listeria monocytogenes, a member of the genus *Listeria*, is widely distributed in the agricultural environment, such as soil, manure and water. The possibility of enteric infections caused by environmental *Listeria spp*. associated with the use of fresh products (vegetables and fruits) is well-known. The main sources of *L. monocytogenes* contamination are humans, animals, manure, compost and irrigation water (Jung et al. 2014). *L. monocytogenes* can be recycled among vegetables, humans and soils contaminated with faeces (Fig. 10.10).

Listeria monocytogenes EGD-E very intensively colonizes the carrot root. Therefore 10^6 cells/mm^3 of absolutely dry root was found on the root surface. This strain was also detected inside of the root (Fig. 10.11). It was noticed that *Listeria*

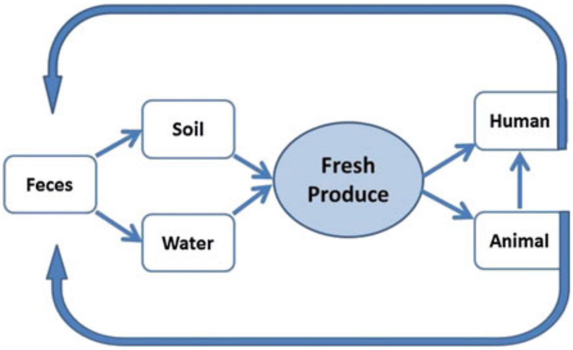

Fig. 10.10 Potential pathways of *L. monocytogenes* transmission to humans via fresh produce (Zhu et al. 2017)

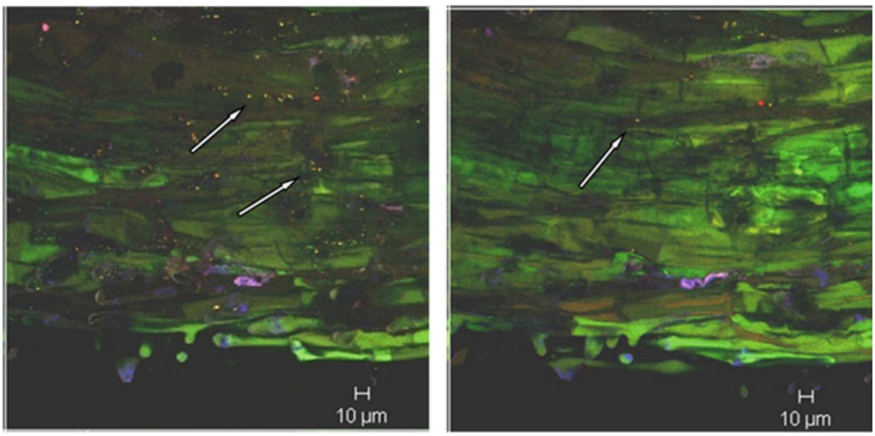

Fig. 10.11 Micrography of colonization of carrot root by *Listeria monocytogenes* EGD-E (yellow cells)

monocytogenes EGD-E cells bind to the carrot root surface and they are less commonly found on the root hairs. In the inner layers of the root, bacterial cells have inhabited intercellular spaces mainly as single cells (Fig. 10.11). At the root of other plant species, celery and parsley, the *Listeria* cells were visible on the root hairs. In deeper root layers, the single cells were detected in the intercellular spaces and very close to the root vessels (xylem). The highest quantity of these bacteria was detected in the interior of the carrot root (10^5 cells/mm^3 of absolutely dry root), and the lowest colonization was noticed at tomato root (Kljujev et al. 2018a).

According to CDC (2016), contamination of lettuce by *L. monocytogenes* was responsible for 19 sick persons and one deceased. This outbreak was in 2015–2016 and included nine different states in the USA. In the past 2 years, there have been more than 40 suspensions of sales of leafy vegetables, fruits due to *L. monocytogenes* in the USA (US FDA 2018). The ability of *L. monocytogenes* to adapt to a wide range of temperatures and survive with or without oxygen conditions leads to its spread to other sources (NicAogain and O'Byrne 2016). This bacterium lives in the soil as a saprophyte but can make the transition into a pathogen after entering the human or animal cells (Zhu et al. 2017; Freitag et al. 2009).

The occurrence of infections and outbreaks caused by *Listeria spp*. happens during processing and manipulation with fresh products. Also, there is evidence of the presence of *Listeria monocytogenes* on fresh cucumber, pepper, potato, radish, leafy vegetables, seedlings and sprouts of bean, broccoli, tomato, cabbage at the point of the sale of these products (point-of-sale). After lettuce contamination by *L. monocytogenes*, the bacteria attach and colonize lettuce leaf surfaces. The washing with clean water or using chemicals for completely removing pathogens from the surfaces of plant leaves is impossible (Luo et al. 2011). The washing parsley leaves with sodium dichloroisocyanurate is not effective in removing pathogens because they can survive it and grow on the surface (Shirron et al. 2009). The *Listeria monocytogenes* may survive on leafy vegetable surfaces in different conditions (Poimenidou et al. 2016).

There is evidence that *L. monocytogenes* is able to reach lettuce leaf surface from a plant growth media which contains partly decomposed organic matter supplemented with contaminated food waste (Murphy et al. 2016). The *Listeria* cellulose binding protein (LCP) has a crucial role in bacterial attachment to lettuce leaf surface (Bae et al. 2013). A mutant without LCP significantly decreased bacterial attaching ability to lettuce leaf surfaces and the percentage of attachment was higher at wild-type strain (mutant with LCP). The pectin and xyloglucan (cell wall structural components) may increase *Listeria* attachment to plant surface (Tan et al. 2016).

In general, plant colonization by *Listeria spp*. is considered the most common in root-carotene vegetable plants and the main reason is the direct contact between plant root and Listeria-contaminated soil. McLauchlin et al. (2004) consider that a large infective dose ($\approx 10^6$ cells of *L. monocytogenes*), different sensitivity of the population to infection, and a long incubation period may explain the lack of evidence about outbreaks caused by the consumption of contaminated fresh products.

The *Listeria monocytogenes* SV4B strain showed the best ability for surface and endophytic colonization of roots of leafy vegetables. The smallest number of this strain was found on the surface and interior niches of the carrot and tomato roots.

Contrary to the findings of our research, Jablasone et al. (2005) state that *Listeria monocytogenes* could only colonize the plant surface and not the plant interior, and that it can survive on the plant surface during the whole growing season. Also, Kutter et al. (2006) did not detect endophytic colonization of barley by *L. monocytogenes*, *L. ivanovii*, *L. innocua.* However, they concluded that the main area of colonization by *Listeria spp*. were the root hairs. According to them, the surface colonization of barley roots by *Listeria spp*. occurs rarely and sporadically with only a few individual bacterial cells.

The mandatory application of good agricultural, hygienic, manufacturing and storage practices are essential in the control of the presence of *L. monocytogenes* on vegetables which are consumed raw (Kyere et al. 2019).

10.5 Summary

This chapter puts the focus on microbial water quality for irrigation and potential hazards to human health. In Serbia, the most used water resource for irrigation is groundwater (61%), and the next is surface water (32%). Investigated canals, rivers and several shallow wells showed degraded water quality to some extent. The content of faecal indicator bacteria makes it unacceptable for irrigating fruits and vegetables for raw consumption. Usage of irrigation water of poor microbiological quality may represent a potential risk to human health. The presence of *Escherichia coli*, *E. coli O157:H7*, *L. monocytogenes*, *Salmonella spp*. on different kind of fresh vegetables has been confirmed, as well as their ability to surface and endophytic colonize root, stem and leaf of different vegetables.

10.6 Recommendation

Increasing levels of irrigation will affect water resources, which will bring out the problems concerning water quality. Therefore, we see the need for developing Serbian irrigation water quality guidelines, which will consider the irrigation method, soil type, crop needs, and also food safety. The outcomes of this research could serve as a guide for setting the general framework for development of irrigation water quality guidelines of the Republic of Serbia, in order to support the sustainability agenda in the field of water and agriculture.

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Chapter 11
Precipitation and Drought Analysis in Serbia for the Period 1946–2017

Milan Gocic, Slavisa Trajkovic and Mladen Milanovic

Abstract Precipitation is one of the most important meteorological variables which can impact on the occurrence of drought. Analysis of precipitation and drought data provides useful information for planning water resources, agricultural production and land use in the region. Monthly precipitation data from 28 synoptic stations in Serbia over the period 1946–2017 were used to analysed precipitation and drought in Serbia. For this purpose, the rainfall variability index was used. Two years (2000 and 2011) were specially analysed as the driest years when most of Serbia were affected by severe droughts. Spatial distribution of annual mean precipitation in Serbia is presented in this study. The north part of Serbia is the area with the least amount of precipitation. The south and the southeast part of Serbia have the moderate precipitation regime, while the west part is the wettest part. According to the applied analysis, it is evident that the stations in the western part of Serbia have the significant increasing trend in annual precipitation. The significant decreasing trend is not identified.

Keywords Precipitation · Drought · Rainfall variability index · Serbia

11.1 Introduction

Analysis of precipitation and drought data produces essential information which can be used to improve water resources management and environmental protection, plan agricultural production or in general, impact on economic development of a certain region (Trajkovic et al. 2016).

Precipitation is one of the most critical meteorological variables and changes in precipitation patterns affect water resources, agricultural production, global biodiversity and life in general. Various studies on the temporal and spatial characteristics

M. Gocic (✉) · S. Trajkovic · M. Milanovic
Faculty of Civil Engineering and Architecture, University of Nis, Aleksandra Medvedeva 14, 18000 Nis, Serbia
e-mail: milan.gocic@gaf.ni.ac.rs

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of precipitation in different parts of the world have been done (Norrant and Douguédroit 2006; Singh 2006; Baigorria et al. 2007; Ngongondo et al. 2011; Martins et al. 2012). For example, it is shown in Greece that the most extended wet periods are observed in Western Greece and Crete, while stations in the Central and South Aegean area had the shortest wet periods (Tolika and Maheras 2005). In Bulgaria, the long-term variations in precipitation were discussed, and it is noted that the last century can be divided into several wet and dry periods with a duration of 10 to 15 years (Koleva and Alexandrov 2008). Niedzwiedz et al. (2009) analyzed the patterns of precipitation variability at seven weather stations in east–central Europe during the period 1857–2007. Also, the temporal variability of precipitation in southern Spain was observed, and the decreasing precipitation trend was noted (Ruiz Sinoga et al. 2011).

There have been a number of precipitation studies and reports regarding different periods and locations in Serbia. Winter and summer precipitation at 30 stations in Serbia and Montenegro during the period 1951–2000 was observed using empirical orthogonal functions and concluded that the large-scale atmospheric circulation was responsible for the precipitation variability (Tosic 2004). Spectral analysis was used to provide information on precipitation variability in Belgrade (Tosic and Unkasevic 2005), while the precipitation trend was studied in Belgrade to provide information on climate variability (Djordjevic 2008). The daily precipitation was statistically analyzed over Serbia during the period 1949–2007 and found that the mean annual precipitation on the wettest day during the 20th century across Serbia increased by nearly 9% (Unkasevic and Tosic 2011). Changes in precipitation were analyzed using Mann–Kendall and Sen's slope estimator statistical tests during the period 1980–2010 and two main drought periods (1987–1994 and 2000–2003) were identified (Gocic and Trajkovic 2013a, b). Gocic and Trajkovic (2014a) analyzed precipitation over Serbia, and identified three distinct sub-regions. Gocic et al. (2016) analyzed three CLINO (Climatological Normals) periods (1961–1990, 1971–2000, and 1981–2010) in three Serbian sub-regions. The CLINO 1981–2010 period had a significant increasing trend. The spatial pattern of the precipitation concentration index (PCI) (Oliver 1980) was also presented. According to the analysis of monthly precipitation from twelve meteorological stations in Serbia during the period 1981–2010, it was observed that the precipitation increased in Serbia during the period from 2001 to 2010 in comparing to previous decades (Milanovic et al. 2015a). Extreme climatic indices in the area of Nis and Belgrade for the period between 1974 and 2003 were analyzed, and the trend line showed a steady decrease in precipitation for the whole observed period (Milanovic et al. 2015b).

Drought is both a complex natural hazard and a disaster which is characterized by the lack of precipitation (Mishra and Singh 2010; Paulo et al. 2012). It can be classified as meteorological, agricultural, hydrological or socio-economic drought (Wilhite and Glantz 1985). Plenty of studies on drought and a variety of indices for describing drought have been developed. Drought indices are used for drought identification and description of its intensity. There have been a number of drought indices such as Standardized Precipitation Index, Standardized Precipitation

Evapotranspiration Index, Palmer Drought Severity Index, and Reconnaissance Drought Index. The Standardized Precipitation Index (SPI) (McKee et al. 1993, 1995) is the most applied index, because of its good characteristics in drought identification. SPI is recommended as a probabilistic drought index, which is simple and spatially consistent in its interpretation (Milanovic et al. 2015b; Guttman 1998). The main characteristic of this index is that it is estimated on the basis of monthly precipitation data which is at the same time its main drawback.

Many scientists in the world have dealt with the analysis of drought (Hayes et al. 1999; Moreira et al. 2008; Khalili et al. 2011; Tabari et al. 2012). The impacts of climate change on meteorological, agricultural and hydrological drought were studied "in the central parts of Illinois, considering the historical data and future scenarios through the following periods: 1991–2000 and 2091–2100, 1990–1999 and 2090–2099, 1980–1989 and 2090–2099" (Wang et al. 2011). It is concluded that the influences of meteorological drought have amplified in agricultural and hydrological droughts due to the increasing in temperature and decreasing in precipitation during the vegetative period. Duan and Mei (2014) compared the meteorological, hydrological and agricultural droughts on the Huai River (China) for the period from 1961 to 2000 and from 2061 to 2100 and concluded that the hydrological and agricultural droughts represent a threat to the water resources management in the future.

In recent years, various studies have analysed drought in Serbia. The temporal and spatial distributions of drought were addressed in the Sumadija region where agriculture is dominant, especially fruit growing, and where drought affects multiple-year yields (Stricevic and Djurovic 2013). Tosic and Unkasevic (2013) analysed wet and dry periods using the SPI on timescales of 1, 3, 6 and 12 months (SPI1, SPI3, SPI6 and SPI12) at ten stations in Serbia during the period 1949–2011. Using the SPI time series, it was found that the frequency of droughts in the southern part of Serbia was higher than in the other parts of the country. Gocic and Trajkovic (2013b) indicated the increasing trends in both annual and seasonal minimum and maximum air temperatures' series in Serbia, while the relative humidity decreased significantly in summer and autumn. These changes have a direct impact on the occurrence of dry periods. Gocic and Trajkovic (2014b) analyzed the drought on the territory of Serbia, and Serbia was divided into three sub-regions on the basis of the identification of drought: northern and north-eastern Serbia; western and south-western Serbia; and the central, eastern, southern and south-eastern Serbia. Milanovic et al. (2014) analyzed impacts of meteorological and agricultural drought across the SPI and the Agricultural Rainfall Index (ARI) on the territory of Serbia for the period from 1980 to 2010. For both types of drought, the year 2000 had the highest drought intensity in most of the observed stations.

In this paper, the precipitation and drought were analyzed in Serbia for the period from 1946 to 2017. The territory of Serbia is observed over 28 meteorological stations. Drought is analyzed with the help of the rainfall variability index. The aim of this chapter is to monitor and analyze precipitation and drought which cover various fields of influence in Serbia in the some detailed and expedient manner.

11.2 Analysed Study Area and Its Characteristics

Serbia is the Western Balkan country located in the southeast part of Europe whose the capital, Belgrade, is a cosmopolitan city at the confluence of the Danube and Sava rivers. The climate of Serbia is moderate-continental precipitation regime affecting by the geographic features and position such as the Mediterranean Sea, the Pannonian Plains, the Morava valley, the Carpathian and the Rhodope mountains. June is the rainiest month, while February and October have the least of precipitation.

In this study, the monthly data from the 28 synoptic stations in Serbia were used. Spatial distribution of synoptic stations in Serbia map is shown in Fig. 11.1. According to Gocic and Trajkovic (2014a), Serbia can be divided into three sub-regions. In Table 11.1 the geographical descriptions and three statistical parameters, i.e. mean, standard deviation and coefficient of variation of precipitation of the synoptic stations analysed in this study are presented. The sub-region R1 includes the north and the northeast part of Serbia, R2 includes the western part of central Serbia and south-western part of Serbia, and R3 includes central, east, south and southeast part of Serbia. The monthly precipitation analysis showed that the sub-region R2 had the values above average, while the sub-regions R1 and R3 had the precipitation values under average.

According to the 28 monthly precipitation series, the variability of mean precipitation in seven observed periods, precipitation regarding climate normal (1961–1990) and the period 1981–2010 are presented in Fig. 11.2. It can be seen that the values of precipitation during the last two periods underestimate the value of climate normal (661.1 mm) by 7.2% and 8.6%, respectively.

Time series of total annual precipitation averaged over whole Serbia, and linear trend are presented in Fig. 11.3. The wettest year was 2014 with the total precipitation of 1014.2 mm, while the two driest years were 2000 (420.0 mm) and 2011 (471.0 mm).

Spatial distribution of annual mean precipitation in Serbia is presented in Fig. 11.4. Annual precipitation sums rise in average with altitude. The north part of Serbia is the area with the least amount of precipitation. The south and the southeast part of Serbia have the moderate precipitation regime, while the west part is the wettest part where the highest mountains in Serbia are located such as Zlatibor and Kopaonik have the precipitation above 1000 mm per year.

The results of applied Mann-Kendall and Spearman's Rho tests showed the significant increasing trends for Palic, Zlatibor, Loznica, Kopaonik and Sjenica stations.

Spatial distribution of observed stations with their trends is shown in Fig. 11.5. It is evident that the stations in the western part of Serbia have the significant increasing trend in annual precipitation. The significant decreasing trend is not identified.

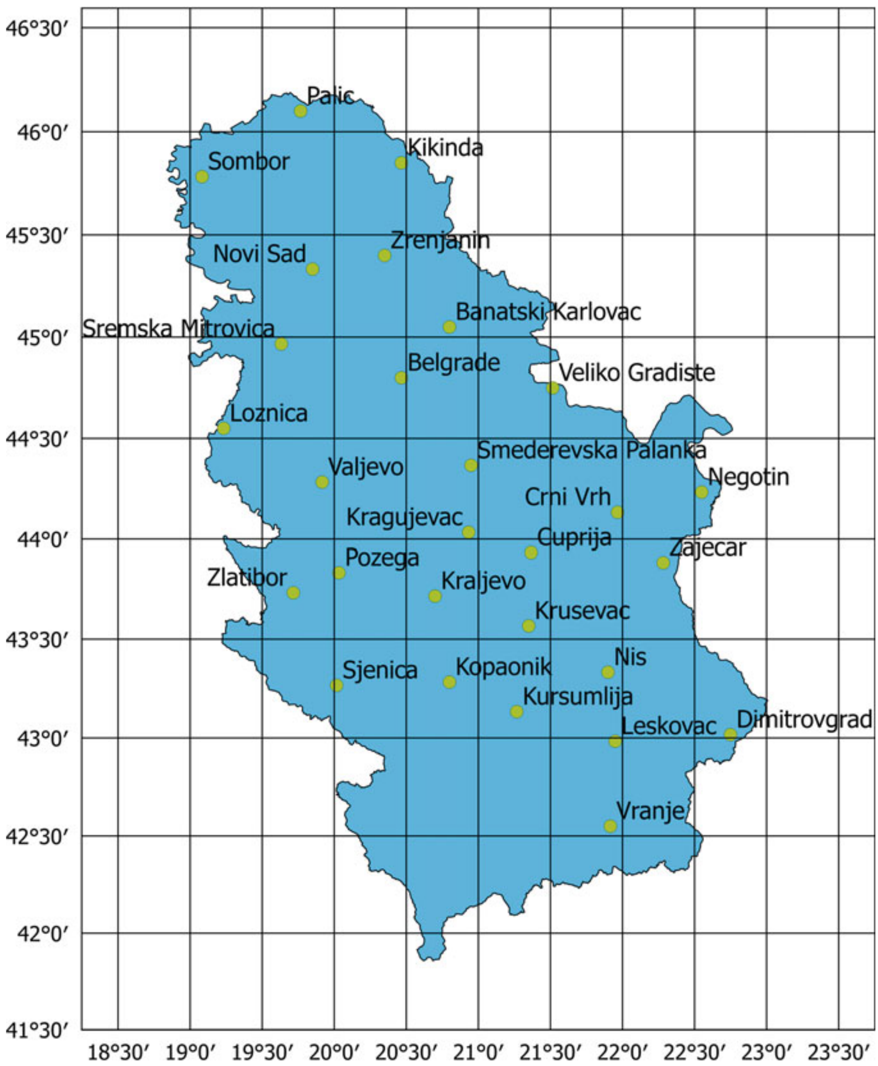


Fig. 11.1 Spatial distribution of the 28 synoptic stations in Serbia map

Figure 11.6 shows the values of autocorrelation and partial autocorrelation functions calculated for the stations with increasing precipitation trends (Palic, Zlatibor, Loznica, Kopaonik and Sjenica). The autocorrelation functions show the presence of significant seasonal dynamics, and the functions have peaks at lags equal to 12 and its multiples. The partial autocorrelation function does not cut off after one peak, which indicates a strong seasonality, especially for the Palic and Kopaonik stations.

Table 11.1 Geographical descriptions and statistical parameters (mean, standard deviation and coefficient of variation i.e. CV) of the precipitation of the synoptic stations used in the study

Region	Station name	Longitude (E)	Latitude (N)	Elevation (m amsl)	Mean (mm)	Standard deviation (mm)	CV (mm)
R1	Banatski Karlovac	20°48′	45°03′	89	630.0	143.5	22.8
	Belgrade	20°28′	44°48′	132	694.7	138.8	20.0
	Crni Vrh	21°58′	44°08′	1027	792.2	157.3	19.9
	Kikinda	20°28′	45°51′	81	550.2	124.0	22.5
	Kragujevac	20°56′	44°02′	185	637.1	118.4	18.6
	Novi Sad	19°51′	45°20′	86	620.2	152.7	24.6
	Palic	19°46′	46°06′	102	555.1	119.4	21.5
	Sombor	19°05′	45°47′	87	594.6	128.9	21.7
	Sremska Mitrovica	19°38′	44°58′	82	618.9	120.8	19.5
	Veliko Gradiste	21°31′	44°45′	80	669.4	143.9	21.5
	Zrenjanin	20°21′	45°24′	80	578.6	121.6	21.0
R2	Kopaonik	20°48′	43°17′	1711	743.8	229.5	30.9
	Kraljevo	20°42′	43°43′	215	753.2	136.7	18.1
	Loznica	19°14′	44°33′	121	828.9	145.8	17.6
	Pozega	20°02′	43°50′	310	750.6	142.2	18.9
	Sjenica	20°01′	43°16′	1038	728.3	137.2	18.8
	Valjevo	19°55′	44°17′	176	784.5	147.6	18.8
	Zlatibor	19°43′	43°44′	1028	964.4	166.6	17.3
R3	Cuprija	21°22′	43°56′	123	660.8	129.2	19.5
	Dimitrovgrad	22°45′	43°01′	450	640.9	123.8	19.3
	Krusevac	21°21′	43°34′	166	650.6	140.2	21.5
	Kursumlija	21°16′	43°08′	383	645.3	135.8	21.1
	Leskovac	21°57′	42°59′	230	623.3	114.0	18.3
	Negotin	22°33′	44°14′	42	648.5	147.4	22.7
	Nis	21°54′	43°20′	204	587.2	117.3	20.0
	Smederevska Palanka	20°57′	44°22′	121	643.1	122.7	19.1
	Vranje	21°55′	42°33′	432	609.7	118.6	19.4
	Zajecar	22°17′	43°53′	144	609.3	126.1	20.7

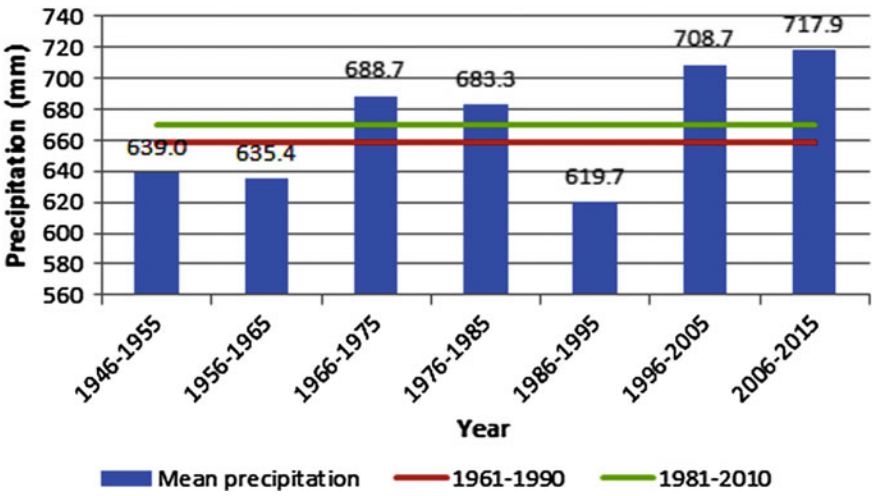


Fig. 11.2 Variability of mean precipitation data in seven observed periods

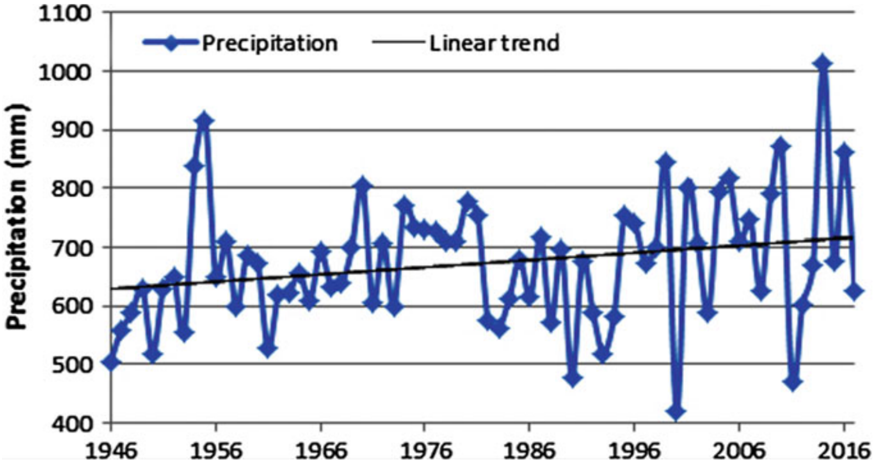


Fig. 11.3 Time series of total annual precipitation averaged over whole Serbia and linear trend

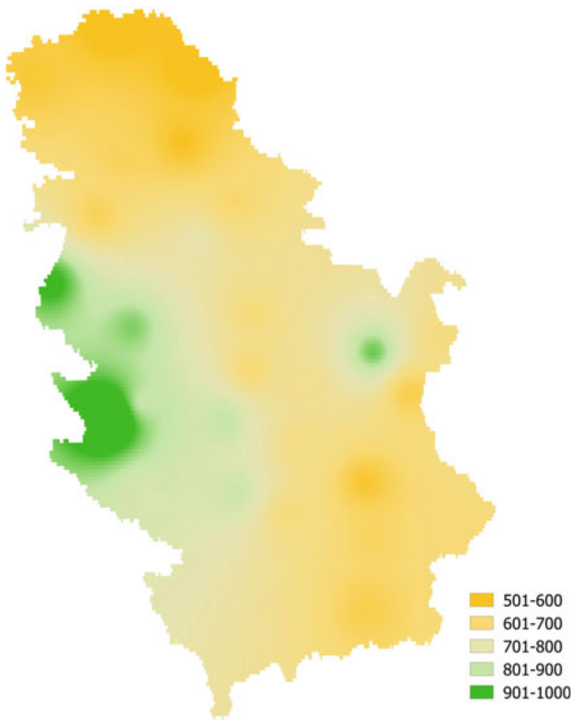
11.3 Rainfall Variability Index

Rainfall variability index (δ) is calculated as:

$$\delta_i = (P_i - \mu)/\sigma \quad (1)$$

where δ_i is rainfall variability index for year i, P_i is annual rainfall for year i, μ and σ are the mean annual rainfall and standard deviation for the period between 1946

Fig. 11.4 Spatial distribution of annual mean precipitation in Serbia



and 2017. A drought year occurs if the δ is negative. According to the World Meteorological Organization (1975), rainfall time series can be classified into different climatic regimes:

$$\begin{aligned} P < \mu - 2 \cdot \sigma - &\ \text{extreme dry} \\ \mu - 2 \cdot \sigma < P < \mu - \sigma - &\ \text{dry} \\ \mu - \sigma < P < \mu + \sigma - &\ \text{normal} \\ P > \mu + \sigma - &\ \text{wet} \end{aligned} \tag{2}$$

Annual rainfall variability indices for Serbia are presented in Fig. 11.7.

11.4 Drought Analysis

Percentage of Serbia affected by drought during the period 2000–2017 is presented in Fig. 11.8. It is shown that the extremely dry periods occurred only during the years 2000 and 2011 in percentage 53.57% and 14.29%, respectively. Dry periods occurred approximately in 45% of the observed years in the XXI century. The

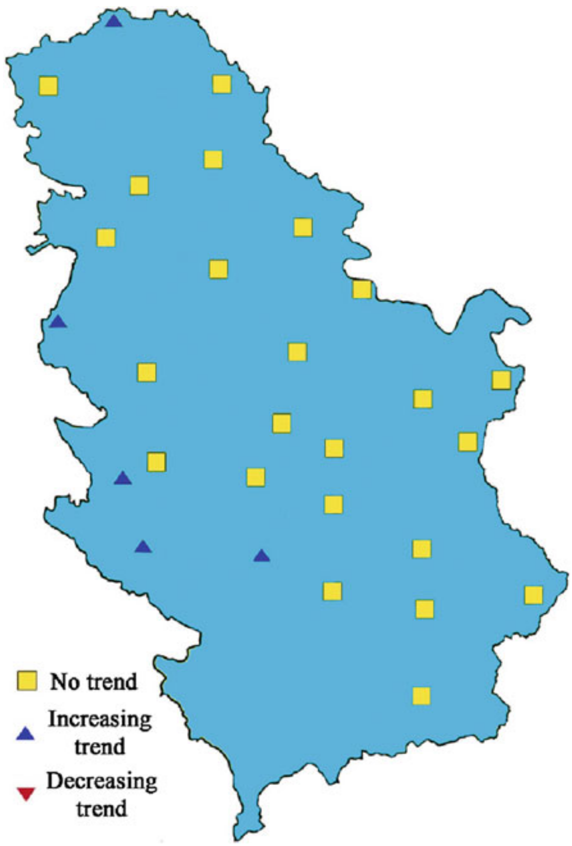


Fig. 11.5 Spatial distribution of observed stations with their trends, according to Mann-Kendall and Spearman's Rho tests

achieved results are in line with the results presented in Gocic and Trajkovic (2014a, b).

Percentage of years affected by four drought severity levels during the period 2000–2017 is shown in Fig. 11.9. It can be seen that 58.61% of the frequency of drought belongs to the normal drought category. The results showed that 15.84% of years belongs to the dry period i.e. periods with drought. Extreme dry periods are recognized in 3.76% of analysed years. Most of years belong to the normal climate regime.

Percentage of years affected by four drought severity levels presented in three sub-regions in Serbia during the period 2000–2017 is presented in Fig. 11.10. It can be seen that the great number of extremely dry and dry years belong to the sub-region R1, while the wettest part is sub-region R2.

Spatial distribution of drought severity levels throughout 2000 and 2011 year is presented in Fig. 11.11. The majority of the country had the extreme drought during the 2000 year, while the dry periods are presented throughout 2011.

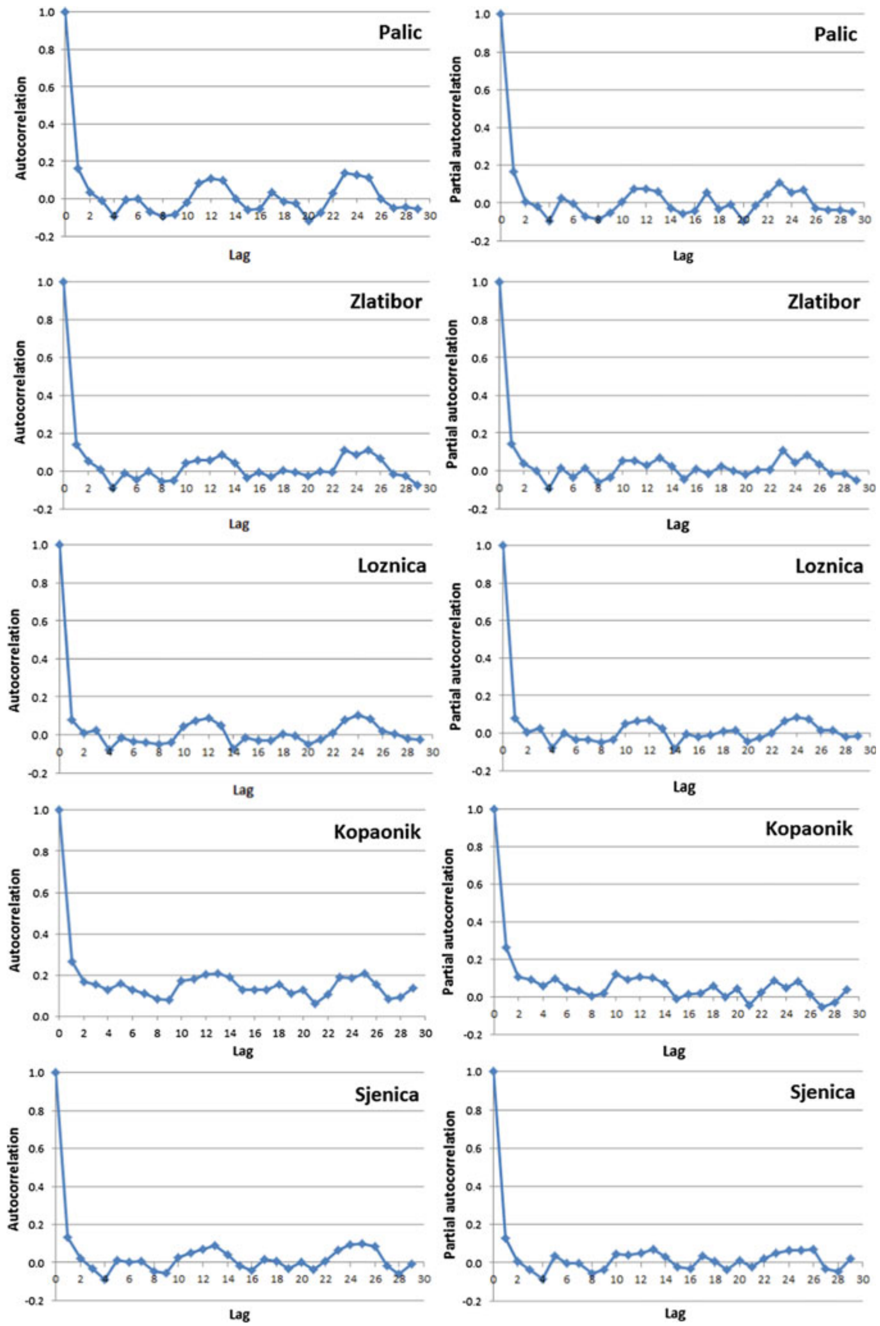


Fig. 11.6 Autocorrelation and partial autocorrelation of the precipitation time series for the stations with increasing precipitation trends on the territory of Serbia

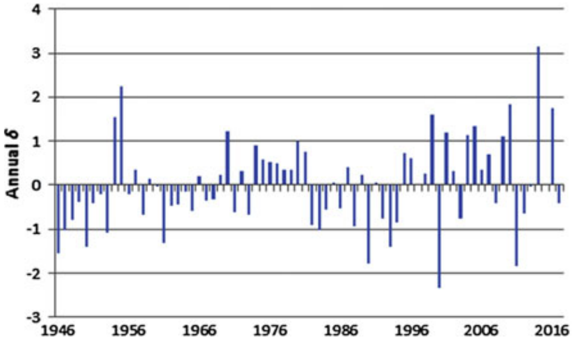


Fig. 11.7 Annual rainfall variability indices for Serbia

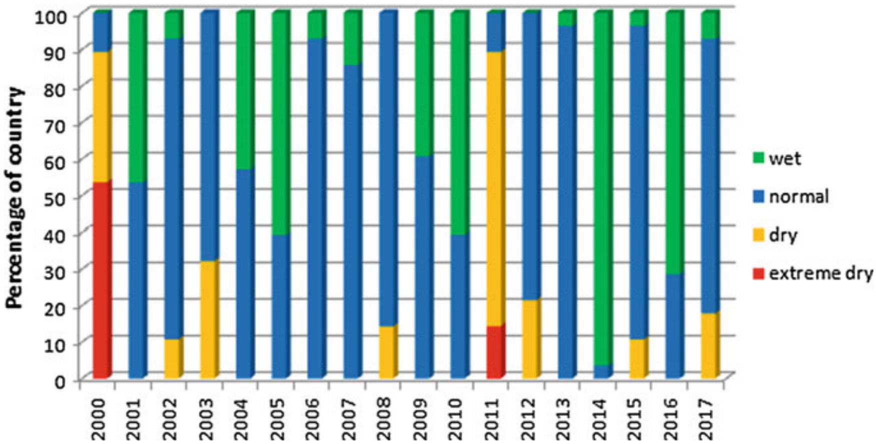
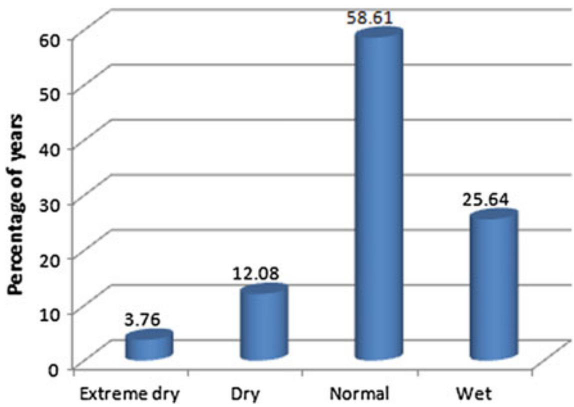


Fig. 11.8 Percentage of Serbia affected by drought, 2000–2017

Fig. 11.9 Percentage of years affected by four drought severity levels, 2000–2017



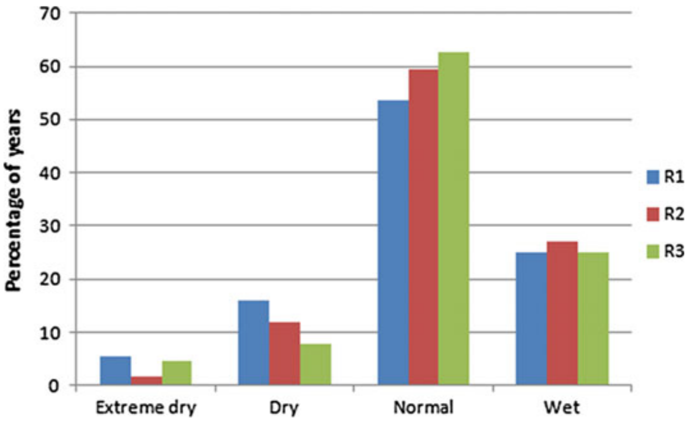


Fig. 11.10 Percentage of years affected by four drought severity levels presented in three sub-regions, 2000–2017

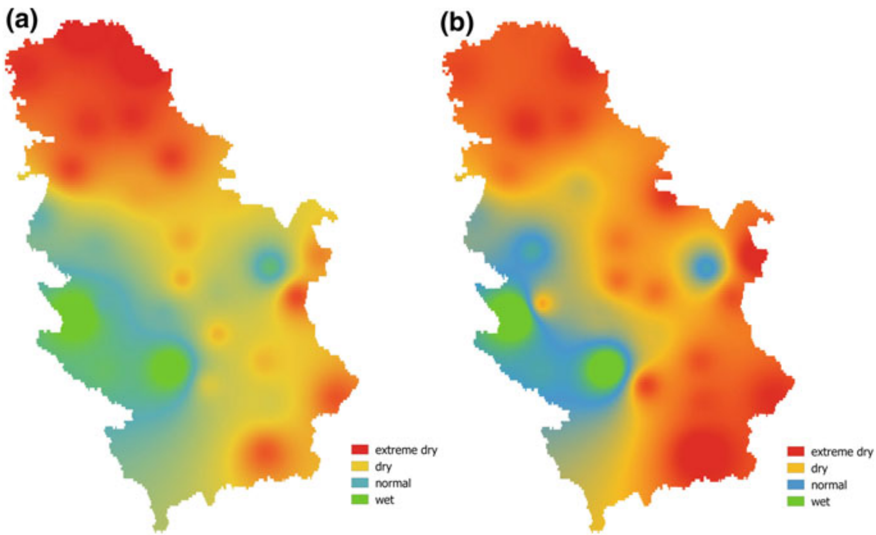


Fig. 11.11 Spatial distribution of drought severity levels throughout **a** 2000 and **b** 2011 year

11.5 Conclusions

Analysing of precipitation is very important for future water resources management. The applied analysis can be used during water resources planning and improvement of irrigation systems in Serbia.

Because of that, the precipitation and drought were analysed in this study using monthly precipitation time series from 28 stations in Serbia from 1946 to 2017. The characteristics of drought were analyzed in terms of the temporal evolution of the rainfall variability index values and the frequency of drought at the country level and for three sub-regions. It is obtained that 16% of the years from 2000 to 2017 belongs to the dry period out of which 4% belongs to the extreme dry climatic regime. Analysis showed that the driest years in Serbia were 2000 and 2011 and spatial distribution showed that the majority of Serbia was affected by extreme drought.

Spatial distribution of annual mean precipitation in Serbia showed that the north part of Serbia is the area with the least amount of precipitation, while the west part is the wettest part. Five stations had the significant increasing trend in annual precipitation out of which four belongs to the sub-region R2.

Further research will be aimed at the detection of the trends of drought in Serbia and comparative analysis of the drought indices based on precipitation and evapotranspiration and their impact on agricultural production.

11.6 Recommendations

Recommendations regarding drought are based on the principles of integrated water management, where the principles are linked with the Water Framework Directive and the Flood Directive of European Union highlighting the drought risk management (Global Water Partnership Central and Easter Europe 2015). The principles can be classified into two groups involving a definition of the main approaches and a drought management plan. Drought policy must be based on the proactive approach and associated with the preparedness plans. Furthermore, the productivity risk assessment of arable land should be the first step in defining the strategy for mitigation the impacts of climate change on soil.

Drought management plan stands out of all plans both as an administrative tool and additional planning document for the enforcement of preventive measures and measures for mitigation drought consequence aiming to mitigate the impact of drought and to improve drought resilience. Documents of the European Commission, especially the Water Framework Directive, provide the legislative framework for the development of drought management plans with a particular emphasis that it should be strived to link drought management plan and national adopted plans and strategies.

According to the Global Water Partnership Central and Easter Europe, the drought management plan consists of the following main elements: indicators and thresholds, early warning system, program of measures, organizational structure, river basin characteristics, historical drought events and risk assessment (Global Water Partnership Central and Easter Europe 2015). The European Commission highlights that using drought indicators, development and timely upgrading of the drought early warning system, adoption and application of measures for each drought stage and defining relevant organizational structure to manage are necessary in order to mitigate drought (European Commission 2007). Mitigation measures are basic component of drought planning. Therefore, strategic measures oriented to problems at water supply systems caused by drought, tactical measures related with expected water scarcity and emergency measures in the situation of drought occurring should be applied not only on national but also on regional level (Water scarcity drafting group 2006).

As an integral part of the drought management plan, the national action plans against land desertification must be included. According to the Serbian national action plan for mitigation the effects of drought and land degradation, measures for drought mitigation related to irrigation, forest and agriculture should be applied (National Action Plan for Mitigation the Effects of Drought and Land Degradation 2015).

Irrigation represents the most efficient measure to eliminate the influence of drought with aim to improve the water regime of the soil (Miljkovic and Skoric 2001). This measure causes the changes in meteorological conditions of the ground air layer and thermal regime of the soil. In order to have the most efficient irrigation effects, it is necessary to have the appropriate location, quantity and especially quality of water. Also, impact analysis of dry winds on agricultural production shows that their impact is much bigger and more dangerous than impact of hot days without rain. The final aim as a solution of this problem is to increase the soil moisture.

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Part VI
Water Resource Management in Bulgaria

Chapter 12
Water Resource Management in Bulgaria

Rositsa Velichkova, Tsvetelina Petrova, Iskra Simova, Georgi Bardarov, Detelin Markov and Milka Uzunova

Abstract Water is a natural resource/good without which human life, development of human business activities, transportation etc. are unthinkable. Each territory features its peculiar, specific waters. It reveals the impact of water as a natural prerequisite and a natural resource on the country's development. Freshwater security is an important indicator of the options for economic development, and the potential to raise the living standard of people in a given region. This chapter includes the information about the water resources in Bulgaria. It is given information for rivers, lakes and damps. Also there is information for water management and law in our country.

Keywords Water resources · Law · Management · Rivers · Lakes · Dams

R. Velichkova (✉) · I. Simova · D. Markov
Department of Hydroaerodynamics and Hydraulic Machines,
Technical University of Sofia, Sofia, Bulgaria
e-mail: rositsavelichkova@abv.bg

I. Simova
e-mail: iskrasssimova@gmail.com

D. Markov
e-mail: detmar@abv.bg

T. Petrova
Department of Energy and Mechanical Engineering, College of Energy and Electronics,
Technical University of Sofia, Sofia, Bulgaria
e-mail: tzvetelina.petrova@tu-sofia.bg

G. Bardarov
Department of Socioeconomic Geography, Sofia University "St. Kliment Ohridski",
Sofia, Bulgaria
e-mail: gburdarov@hotmail.com

M. Uzunova
LR2A.Lab, ECAM-EPMI Cergy-Pontoise, Paris, France
e-mail: m.uzunova@ecam-epmi.fr

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12.1 Essence and Importance of Water

Country's water is a vital component of the natural environment and affects other components—rocks, atmosphere, soils, flora, and fauna. As a component of the natural environment, it is essential for people's living and economic activity. Purposeful use of water makes it an essential natural resource. The waters of Bulgaria include all surface and groundwater resources.

Water is used for energy (power generation, especially nuclear energy), metallurgy, chemical, cement, textile, pulp, paper and food industries. Moreover, this component is also used in agriculture for irrigation of arable land in dry summer months. National water resources are also a vital necessity for settlements—for drinking and household purposes.

According to the World Health Organization (WHO), 1700–2500 m^3s of water supplies per year are required for drinking, domestic and economic purposes for a human body to function normally, in case the intake is in the range 1000–1700 m^3 the body can be considered to be in a water stress, and a water crash occurs if it is below 1000 m^3 (www.bd-Danube.org).

As a natural prerequisite and resource, water has some peculiarities. Water is an exhaustible but renewable natural resource and forms the World Ocean, lakes, swamps and other water basins. Due to the natural water cycle, water can flow down the surface and into lower areas, where it can form water basins, soak into earth layers, occupying cavities and pores, evaporating and humidifying the air, forming clouds from which it will fall down as rain and snow. Used water runs to the seas and is replaced by new water formed by precipitation. At negative temperatures, water will freeze and form ice forms. Regarding quantity, running surface waters are unevenly distributed by seasons and months on an annual basis.

Water resources include all natural waters fit for economical human use.

Its balance represents the ratio between the inflow and outflow of water quantities in each area:

$$P = E + R + S$$

where: P is precipitation, E—water evaporation, R—runoff and S—storage, or water retained in the territory (Fig. 12.1).

Water balance of Bulgaria is characterized by:

- Limited rainfall, i.e. inflow;
- Intense evaporation;
- Predominant surface river runoff;
- Weak water abstractability on the territory.

Water wealth in Bulgaria is not great. In terms of water per capita, it occupies one of the bottom positions in Europe. On the other hand, however, it is essential to consider that almost all water resources of the country originate in its own territory,

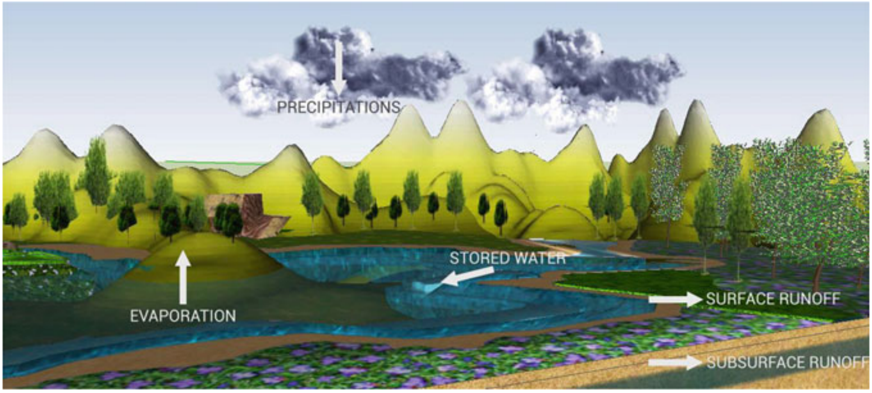

Fig. 12.1 Water balance diagram

which mainly makes it independent in terms of water resources (Ivanov 2016; Ivanov et al. 2000).

From Figs. 12.2, 12.3 and 12.4 are presented these trends. Water resources in Europe are presented in Fig. 12.2. Figure 12.3 displays the water resources per capita. Figure 12.4 shows the independence of the water resources by countries in Europe.

According to the available data which is presented in Figs. 12.2, 12.3 and 12.4, Norway and Russia have the largest reserves while water is most scarce in the Baltic countries, Bulgaria, Albania, Belgium etc.

Mountains in Bulgaria, and especially the Rila—Rhodope mountain region, have the most abundant water resources. Water-bearing is very low in Dobrudzha and Northwestern Bulgaria.

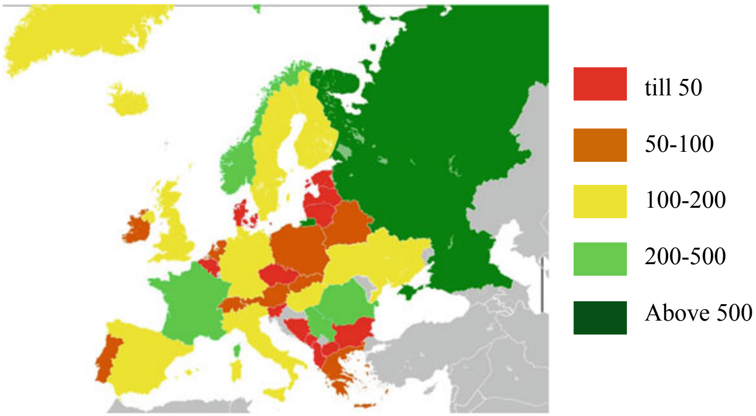

Fig. 12.2 Water resources of Europe (10^9 m^3/per year) (Ivanov 2016; Ivanov et al. 2000)

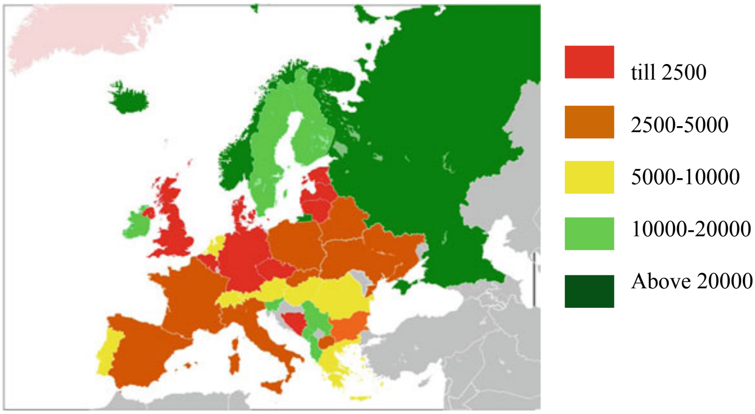

Fig. 12.3 Water resources per capita (m^3/per capita) (Ivanov 2016; Ivanov et al. 2000)

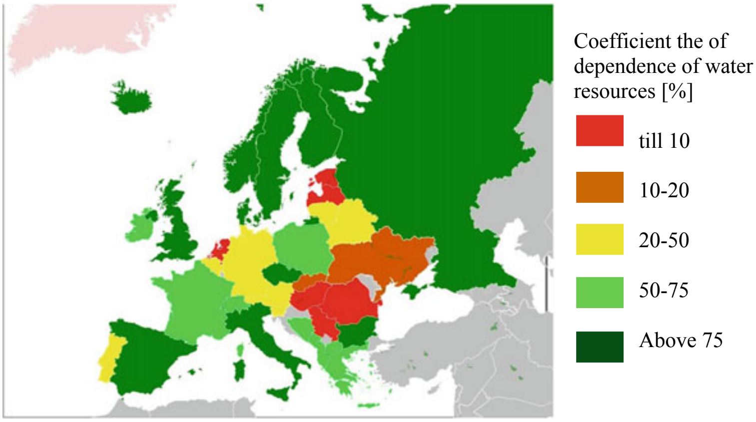

Fig. 12.4 Independence (%) of water resources of individual countries (Ivanov 2016; Ivanov et al. 2000)

Water in Bulgaria is unevenly distributed by seasons and by regions in the country. Runoff of surface water is the greatest in seasons with the highest precipitation (spring-summer in temperate continental climate, winter in Mediterranean climate). The river network is most dense in areas where the landscape is very steep and indented, and the largest groundwater reserves are in the lowlands, valleys, plains and river terraces.

Water has had a direct impact on construction and development of settlements in the country, on selecting the location of enterprises in many economic sectors. The availability of water resources is an important factor for power engineering, metallurgy, chemical industry and others. Water is of great social significance. Moreover, the water bodies secure the necessary quantities of drinking and

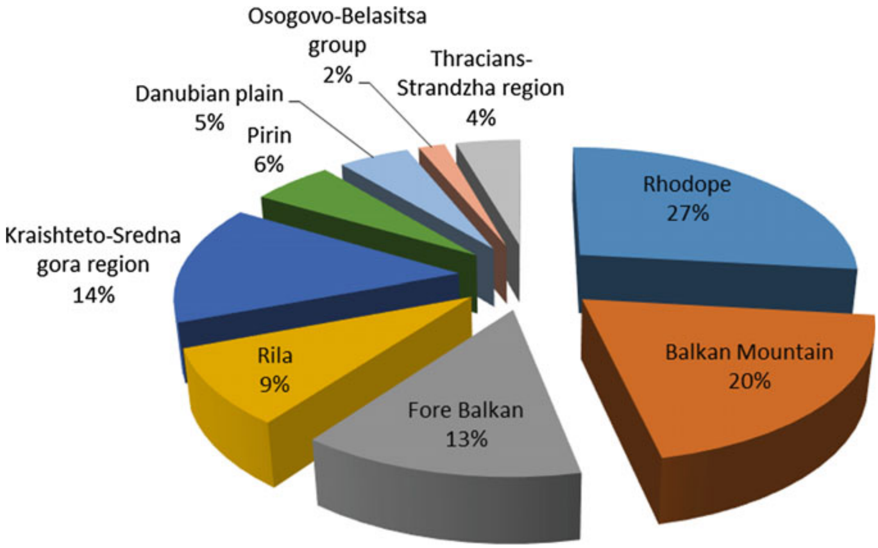

Fig. 12.5 Distribution of water resources

household water, mineral water for balneology etc. for the population of Bulgaria (Ivanov 2016; Ivanov et al. 2000; NSI 2016).

Depending on its location in relation to the Earth's surface, water can be either surface or groundwater. Water formation is a complex natural process where many factors interplay.

The distribution of water resources by nature region is given at Fig. 12.5.

12.2 Water Formation Factors

12.2.1 Climate Factors

Climate plays a significant role in the formation of surface water and is very important for groundwater formation. Aleksandar Voeykov, the Russian climatologist, has been famous for saying that "rivers are children of climate". The great climate diversity in Bulgaria impacts in a different way water quantity, the surface runoff pattern and the level of groundwater.

Of all climate elements, precipitation has the strongest influence in terms of quantity, type, and seasonal distribution. The annual precipitation in Bulgaria is about 650 mm/m^2. However, it is unevenly distributed, and for some locations, it is in the range of 400–1400 mm/m^2. It is also unevenly distributed over the year by seasons and months.

The aggregate type of precipitation also has a significant impact. If snow cover lasts for a long time river runoff goes down. In case of slow snowmelt, runoff toward groundwater increases, while rapid snowmelt results in surplus water in rivers. Precipitation distribution by seasons and duration of snow cover determine to a large extent the pattern of surface water runoff.

Temperature as an element of climate also has a strong impact on water. In case of high temperatures, especially during the warm half of the year, evaporation is very strong, the greater part of the rainfall evaporates, the surface and groundwater runoff decrease.

Influences of **winds** are lesser. It is realized through the temperature of air masses. Transfer of air masses has a primarily negative impact on Bulgarian water resources, and the process is enhanced in case of prolonged warm summer winds—dry winds. They extract moisture from soil and plants and cause lowering of groundwater levels (Ivanov 2016; Ivanov et al. 2000; hydro.bg 2016).

12.2.2 Spreading Surface Factors

The geological structure and the rock foundation also have a strong influence on water formation in the country. The composition, layout of the ground layers, their fragmentation and cracks influence groundwater formation and quantity. Rocks have an impact due to their water permeability and impermeability. When the earth surface is covered with watertight rocks such as granites, gneiss, marls, diorites, mica shale, clayey schists etc., more significant surface runoff and a dense river network are formed. In case of permeable rocks, such as alluvial deposits, loess, etc., a great part of precipitations is absorbed in the upper earth layer and reach the level of groundwater. In the presence of carbonate rocks, a more permanent water regime of springs and rivers occurs, which are recharged mainly by karst waters.

Relief is another significant factor impacting the formation of Bulgarian waters.

Its impact is due to its forms and features—altitude, vertical indentation, inclination and exposure of slopes.

Protruding forms such as mountains, hills, heights, etc. feature fast drainage of surface water and denser river network. That is entirely characteristic of the high mountains in southern Bulgaria.

In the case of depressions and **lower forms** of the relief (lowlands, riparian terraces, alluvial fans, floodplains) there is a significant permeation of rainwater in soil layers and greater evaporation, as the surface runoff is slow.

Impact of relief altitude is expressed through changes in climatic conditions, soil and plant cover. As altitude increases, the amount of precipitation and duration of snow cover go up, while evaporation goes down. That results in higher slope runoff. Therefore, the higher parts of Rila, Pirin, the Western Rhodopes and other mountains have a higher water-bearing capacity.

The degree of slope inclination impacts the velocity of surface water runoff and its magnitude. When the slope is steeper, the surface water runoff becomes faster, and rain and snow water can not be absorbed into the earth layers. More precipitation falls on the northern slopes of the Balkan Mountains and some other mountains. The snow cover lasts longer, and the evaporation is lower.

Slopes exposure impacts water formation due to the varying amount of precipitation on winward and leeward slopes. For example, on the windward northern slopes of the Balkan Mountains and some other mountains, the amount of precipitation is much higher than on the southern, leeward slopes. Slopes exposure also affects the duration of snow cover. Evaporation on them is usually less.

Size and shape of catchment areas influence the formation of river runoff patterns strongly. In larger catchment areas the river runoff pattern is more even. Presence of lakes, marshes, and numerous karst springs, as well as a large share of karst fed catchment areas, also leads to the formation of a more even runoff.

Soils are also a water formation factor. Their impact is due to their strength (thickness) and mechanical composition. Soils containing more clay are watertight. The situation is reversed for sandy soils that let precipitation pass down to lower earth layers. This also applies to soils formed on loess bedrock. Soil processing and irrigation affect evaporation and groundwater level, etc.

Plant cover influences water formation due to its capacity for snow retention, increased infiltration (seepage) of water in soils and accumulation of more groundwater, soil protection from the torrential flow of surface water. In the absence of vegetation, surface water flows very rapidly over the earth's surface and causes floods and removal of topsoil. However, vegetation consumes large amounts of water for growing and due to evaporation from plants.

The Anthropogenic factor also impacts water formation in Bulgaria. Hydrotechnical and hydromelioration facilities change water runoff patterns, capture and store water quantities in periods of high water, which are then used for drinking, electricity, irrigation, industrial purposes etc. Large dams such as "Iskar", "Koprinka", "Kardzhali", "Studen Kladenets", "Ivaylovgrad", "Belmeken", "Al. Stamboliyski" and other have been constructed in Bulgaria. Tapping of numerous springs changes the runoff and water quantity in some rivers.

Anthropogenic influence is often negative. It is expressed by water pollution with toxic substances from industrial water, mineral fertilizers, pesticides and products for plant and biological protection; domestic wastewater and others (Ivanov 2016; Ivanov et al. 2000).

12.3 Rivers

Rivers as permanent water currents in the lowest parts of the earth's surface form a complex river network on the territory of the country. Formation of large catchment areas, large river systems, and large rivers were prevented by the small territory, the considerable indentation of the landscape, the peculiarities of the bedrock, and the proximity to the Black Sea and the Aegean (White) sea. At the same time, the country has a comparatively dense river network—1.18 km/km^2. The highest is the density of the river network (over 2 km/km^2) in Rila mountain (3.0 km/km^2) and the northern slopes of Balkan Mountains and Osogovo mountains. The density of the river network in the low mountainous regions and the heights is average (between 1 and 2 km/km^2). The greater part of Murgash section of Balkan Mountains features significant river network density because of the wide distribution of watertight rocks (schists). The lowest is the river network density (less than 1 km/km^2) in the Danube lowlands, the Danube Plain, and the over-Balkan valleys.

Rivers of Bulgaria have small catchment areas, which is due to the small territory of the country, water borders with the Black Sea and the Danube, the proximity to the Aegean Sea, and the position of Balkan Mountains in the middle of the country. In essence, the latter, besides being a climatic boundary, is also a hydrological boundary, since the greater part of the main watershed of the country and the Balkan Peninsula goes along its ridge.

The flow of rivers in Bulgaria is directed to two runoff basins—the Black Sea and the Aegean. The main watershed that divides the two basins starts at the Bulgarian-Turkish border, runs along the ridge of Strandja Mountain. To the east it turns to the northwest and continues along the ridge of Bakadzhitsite. Then turns to the northeast, follows the ridge of Hisar-bair, climbs up the hump of Aitoska mountain, continues to the west along the ridge of Stidovska and Sliven mountain and reaches the pass Vratnik (1097 m). After that continues to peak Zvezdets (1655 m) to the west in the Balkan mountain close to Etrople. Then it turns south along the hump of Galabets and Vakarelska mountain and reaches the Borovets saddle (1300 m). To the south it climbs up the northern slope of Rila and reaches mount Musala (2925 m), goes round the springs of the Iskar river, crosses the western hump of Belchin mountain and reaches Klisura Mountain (1025 m). After that follows the ridge of Verila, Vitosha, passes across mount Cherni vrah (2290 m) to the northwest toward Vladaya saddle and to the northwest follows Lyulin, Viskyar, keeping track of the southern border of Tran pan-valley, and reaches the border with Serbia.

In terms of size, the largest water catchment area is that of the Maritsa River (21,000 km^2). It is followed by the Struma river (10,797 km^2), the Iskar, the Tundzha, etc. In general, Bulgarian rivers are short. The longest river, running entirely on Bulgarian territory, is the Iskar River (368 km), followed by the Tundzha, the Maritsa, the Struma, etc. The amount of water in Bulgaria rivers is also small, and in summertime water in some rivers is strongly reduced or even dries up. Riverbeds feature steep slopes only in the high parts of mountains.

Springs of almost all Bulgarian rivers are on its territory. Exceptions are the border rivers i.e. the Danube, the Timok, the Rezovska, as well as the Veleka, the Strumenshnica, the Lebnitsa and the Erma. The fact that the lower currents of the relatively high-water rivers (the Maritsa, the Struma, the Mesta, the Tundzha and the Arda) are in the territory of other countries (Turkey and Greece) is more unfavorable. The Erma river springs in Serbia enters Bulgaria and then again flows back in Serbia.

The great indentation of the relief also affects the direction of river flow and to which of the two drainage basins they ultimately belong. The majority of catchment areas and rivers pertain to the Black Sea catchment area—57% of the country area, with only a small part of the territory (12%) being drained by rivers that flow directly into the Black Sea. Most of the Black Sea basin rivers flow into the Danube. The most significant Bulgarian rivers flowing into the Danube are the Topolovets, the Voinishka, the Vidbol, the Archar, the Skomlya, the Lom, the Tsibritsa, the Ogosta, the Skat, the Iskar, the Vit, the Osam, the Yantra, the Rusenski Lom. Some of the larger Bulgarian rivers that flow directly into the Black Sea are the Batova, the Kamchia, the Dvoinitsa, the Hadzhiiska, the Aitoska, the Sredetska, the Fakiiska, the Ropotamo, the Dyavolska, the Veleka and the Rezovska rivers. The rivers that belong to the Aegean Basin are the Maritsa, the Struma, the Mesta, the Arda, the Tundzha and their tributaries. They drain 43% of the country's territory.

These two large catchment basins are separated from each other by the main watershed of Bulgaria. It starts from the ridge of Strandzha Mountain at the Bulgarian-Turkish border, continues northwest along the ridges of the elevations between Strandzha and Bakadzhitsite. After the Bakadzhitsi hill, the direction of the watershed turns to the northeast and follows the ridge of Hissar Hill. Then it climbs the ridge of Karnobat mountain and heads west along the ridges of Stidovska and Sliven mountain reaching Vratnik pass. Then it runs west along the ridge of Central Balkan Mountains and reaches mount Zvezdets in Etropole Mountain. From mount Zvezdets the watershed turns south and passes along the ridges of the Galabets hill, Vakarelska Mountain, Cherni (Septemvriyski) hill, Shumnatitsa mountain, through Borovets saddle to mount Musala. Further, it surrounds from the south the springs of the Iskar river and crosses to the north the west part of Belchinska mountain, passes along the ridge of Verila and reaches mount Cherni vrah in Vitosha mountain. From here it turns west, crosses Vladayska saddle, continues along the ridges of Lyulin and Viskyar mountains, and then surrounds to the south the pan-valley of Tran and reaches the border with Serbia (Fig. 12.6).

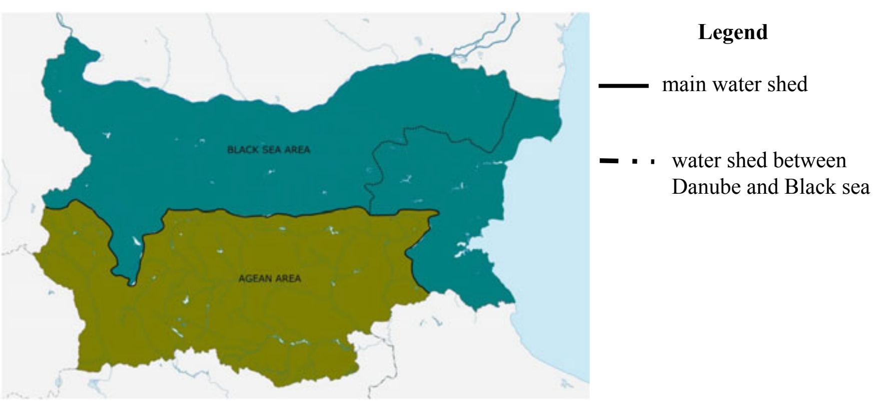

Fig. 12.6 River network by catchment areas

Two main sources recharge rivers in Bulgaria. One of these sources are groundwaters, which have constant runoff that accounts for the stable component of river runoff. The second source—precipitation—features strong fluctuations. Precipitation accounts for the variable component of river runoff. Depending on the type of their recharge, rivers in Bulgaria are divided into 4 types.

The first type of rivers is snow-rain recharge rivers. Such are the rivers that collect their water in the high mountains of Rila, Pirin, the Western Rhodopes, Western and Central Balkan Mountains, Sredna Gora, and Osogovo-Belasitsa mountain range. They have a spring and winter maximum runoff, or minimum runoff in late summer and early fall. The spring maximum runoff is due to intensive snowmelt and increased precipitation amount.

The second type of rivers is rain—snow recharge rivers. Such are the rivers in Sredna Gora, Fore-Balkan, Kraishteto, some parts of the lower zone of the Balkan Mountains and some higher parts of the Danube plain. Their maximum runoff is in spring, and the minimum one is in winter and summer (almost equal as amount). Snowcover is thinner, and water formation is predominant which is due to spring rainfalls.

The third type of rivers is rain recharge rivers. These are the rivers in the eastern half of the over-Balkan valleys, the Eastern Rhodopes, Tundzhanska region and the Southern Black Sea Coast. Their maximum runoff is in winter and the minimum in summer. Snowcover is shortlived, thin and rarely lasts long. The runoff is formed mainly of liquid precipitation in late autumn and early winter.

The fourth type of rivers is karst recharge rivers (karst pattern). These rivers are charged mainly by karst water. These are rivers in Dobrudzha, Ludogorie, part of the fore-Balkan, the Western Balkan, Kraishteto, and others. Such rivers are the Batovska, the Panega, etc.

River runoff in Bulgaria is quite variable. The average multiannual runoff of all rivers is 618 m/s. It has been established that in some periods it is higher, or lower, i.e. with freshets and lows. The maximum and minimum runoff of rivers depends mostly on climate.

Water characteristics are most complete when runoff module data are used. The mean runoff module value is 6 Ls per second per square kilometer (6 l/s/km^2). In terms of territory, the runoff module is very uneven. In Northern Bulgaria, it is 4 l/s/km^2, and in Southern Bulgaria—8 l/s/km^2. The lowest values of the runoff module in Bulgaria are registered in Dobrudzha and Dobruzha plateau (less than 1 l/s/km^2), the Upper Thracian Valley and others. The lower mountain band has a module of 5–10 l/s/km^2, the middle highland band—10–20 l/s/km^2, while the alpine band—more than 20 l/s/km^2 (mount Botev, Petrohanski passage, etc.). The river runoff module is the highest in Rila and Pirin mountains, where it reaches 30 l/s/km^2.

Freshet occurs in different parts of the year. Rivers in the moderate-continental climate region have spring freshet due to the maximum precipitation. Rivers in areas with mountainous climate have spring freshet, but in different months depending on the snowmelt period. While in Rila and Pirin it is in May and June, in lower mountains it is in April and May (Balkan Mountains, Vitosha, Osogovo) and even lower ones, in March. In areas with continental Mediterranean climate, the freshet is in winter, because of the winter precipitation maximum and the short duration of snow cover.

Low water occurs in winter only in the highest parts of the mountains where the snowcover is retained for a long time, and rivers are charged primarily by groundwater. In the other parts of the country low river water occurs in late summer (August) and autumn (September, October). It is due to little rainfall and prolonged period of high temperatures and high evaporation rates. In case of heavy, torrential rains and rapidly melting snow often the levels of some Bulgarian rivers rapidly increase, which results in flooding. Such floodings are caused by the Rositsa, the Maritza the Vurbitsa and other rivers. The rivers that account for the greatest annual runoff share in Bulgaria are the Maritsa with 24%, the Struma—14%, the Arda—10% and other.

A few rivers in Dobrudzha and Ludogorsko plateau have variable river runoff. These are small rivers that flow from the hills and plateau areas and have formed river valleys in karst areas with a small amount of annual precipitation. They gradually lose their water and turn into dry valleys. Such rivers are the Suha river, the Krapinets, the Senkovets, the Harsovska etc.

About 300 waterfalls have originated in the upper reaches of rivers (in mountainous areas). The highest of these waterfalls is Raysko praskalo waterfall in Central Balkan Mountains, near Raiy chalet, where water falls from 125 m. The second highest is Vidimsko praskalo waterfall in Central Balkan Mountains, near the town of Apriltsi (80 m). The third highest waterfall is Skakavitsa waterfall in Rila Mountain (70 m).

Two hydrological areas are distinguished on the territory of the country based on the peculiarities of formation and the river runoff pattern: an area with Mediterranean climate influence and an area with continental climate influence.

The area with Mediterranean climate influence covers the southeastern part of the country and occupies an area of 28.507 km^2 (27.7% of the country). This area accounts for the formation of about 1/5 of the water resources (3810 billion m^3). It covers part of Eastern Balkan Mountains (basins of the Luda Kamchia, the Hadzhiyska, and the Dvoinitsa), almost the entire Upper Thracian Valley, Bourgas Valley, Strandzha and the lowlands of the Eastern Rhodopes, the Struma river valley. The level of Mediterranean climate influence varies in the different parts of the area. It is the strongest in the Eastern Rhodopes, where the highest runoff module is—13.3 l/s/m^2 and in Strandzha region—9.28 l/s/m^2. The Upper Thracian valley and Burgas valley feature the lowest values—2.94 l/s/m^2. The river pattern is characterized by a maximum winter-runoff, while in the Eastern Balkan Mountains, due to the occurrence of two climatic influences, one can observe almost equal levels of winter and spring runoff.

The area with continental climate influence covers the greater part of the country (72.3%). It provides more diverse conditions for river runoff pattern formation. Therefore, it is divided into two sub-areas: plain and hilly, and mountainous.

The plain and hilly sub-area covers the Danube plain, the Fore-Balkan, and Sredna Gora. Small precipitation and high evaporation characterize the water balance. As a result, the average runoff module is low—2.84 l/s/m^2, and the water volumes—small (4885 billion m^3).

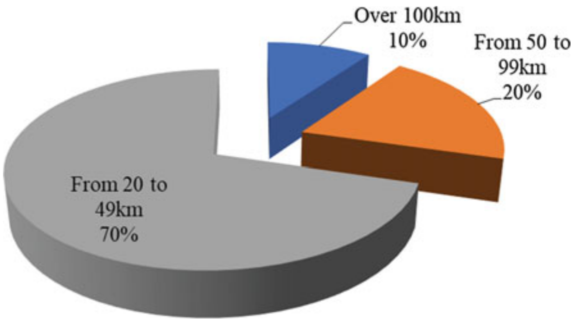

Fig. 12.7 Distribution by the length of rivers over 20 km in Bulgaria

The mountainous sub-area occupies 30,214 km^2 and covers the western and central part of Balkan Mountains, Rila, Pirin, the Western Rhodopes, the Vlahinsko-Belasitsa mountain range, the high-valley area. Conditions for river runoff formation are favorable. The average annual module is over 10 l/s/km^2, and the annual volume of water resources—10,303 billion m^3. The Rila-Pirin region is characterized by the highest average drainage module—14.23 l/s/m^2, followed by Balkan Mountains—13.50 l/s/m^2 and the Western Rhodopes—11.53 l/s/km^2. Kraishteto has the lowest drainage module of 5.09 l/s/km^2 (Ivanov 2016; Ivanov et al. 2000; NSI 2016; Water low 2017).

There are 325 rivers in Bulgaria whose length is over 20 km. Their share by a length over 20 km is given in Fig. 12.7 (www.moew.government.bg) (Hristova 2000).

Table 12.1 lists in alphabetical order all 48 rivers Bulgaria over 70 km, providing information about their length, catchment area, spring, and mouth (bg.wikipedia.org).

12.4 Lakes

Bulgaria is relatively poor in lakes, lake water, and resources. The existing over 400 lakes in the country are insignificant in size, featuring small depth and small water volume. Their total area is 95 km^2 and the fresh water volume contained in them is 64 million m^3. Depending on their origin the lakes in the country are: glacial, coastal, riverside, tectonic, karst and landslide.

Glacial lakes in Bulgaria are the most numerous—about 330, of which 259 are permanent. Their total area is 3.6 km^2. They are mostly located at bottoms of the circuses, and only a few of them are formed by partitioning of a stone-river (moraine) valley. They were formed during the glaciation of the high parts of Rila and Pirin mountains. They are located at an altitude from 1900 to 2700 m. Most numerous are the glacial lakes at an altitude between 2200 and 2400 m. Several lakes connected to each other can be found in complex circuses. The famous lakes in Rila are the Seven Rila Lakes, Ribnite, Marichini, Musenski, and those in Pirin include Banderishki, Vasilashkite, Valiavishki, Vlahinski. The biggest lakes are Smradlivoto lake (21.2 ha) and Gorno Ribno (17.6 ha) in Rila, and Popovoto

Table 12.1 Rivers in Bulgaria with length above 70 km (bg.wikipedia.org; Hristova 2000)

River	Length		Catchment area (m^2)	Spring	Flows into
	Total	Of which within the territory of Bulgaria			
Arda[a]	278.3	241.3	5201	Ardabashi	Maritsa
Beli Lom	140.7	140.7	1279	Daachashme	Rusenski Lom
Veleka[a]	147	123	994.8	Mountain Strandzhza	Black Sea
Vit	188.6	188.6	3225	The merging of the Cherni Vit river and Beli Vit	Danube
Varbitsa	98.1	98.1	1203	The merging of the Big river and Small river	Arda
Vacha	111.5	111.5	1645	Merging the of the Bunovska river and Chairdere	Maritsa
Golyama reka	74.7	74.7	663.3	Lisa mountain	Yantra
Dzhulynitsa[a]	85.3	85.3	891.6		
Dospat	96.2	96.2	633.5	Peak Shipoko	Mesta
Danube[a]	2860	470	46,930	Mountain Black Forest	Black Sea
Iskar	368	368	8646	Rila mountain	Danube
Kamchiya	244.5	244.5	5358	The merging of the Big Kamchiya river and Luda Kamchiya	Black Sea
Kanagyol	109.6	109.6	1745	Samoilovskite hights	Danube
Lefedzha	91.8	91.8	2424	The merging of the Big river and Small river	Yantra
Lom	92.5	92.5	1140	Peak Mindzhur	Danube
Luda Kamchiya	200.9	200.9	1612	Peak Vratnik	Kamchiya
Luda Yana	74	74	685.3	Peak Bich	Maritsa
Malki Iskar	85.5	85.5	1284	Peak Murgana	Iskar
Maritsa[a]	507.6	321.6	21,084	Marichini Lakes	Aegean Sea
Mesta[a]	216.9	125.9	2767	The merging of the White river and Black river	Aegean Sea
Mochuritsa	85.9	85.9	1278	Balkan mountains	Tundzha
Nishava[a]	218.9	40	330.9	Peak Kom	South Morava
Ogosta	144.1	144.1	3157	Chiprovska river	Danube
Osam	314	314	2824	The merging of the White Osam river and Black Osam river	Danube
Provadiyska reka	119	119	2132	Samoilovski Heights	Lake Beloslav

(continued)

Table 12.1 (continued)

River	Length		Catchment area (m^2)	Spring	Flows into
	Total	Of which within the territory of Bulgaria			
Rezovska reka	112	112	183.4	The merging of the Paspalderesi river and Velika river	Black Sea
Rositsa	164.3	164.3	2265	Kalofer mountain	Yantra
Rusenski Lom	196.9	196.9	2947	The merging of the Cherni Lom river and Beli Lom river	Danube
Sazliyka	145.4	145.4	3293	Peak Ruya	Maritsa
Senkovets	101.6	101.6	553	Kosa cheshme	Danube
Skat	134	134	1074	Mountain ridge Veslets	Ogosta
Struma[a]	372	290	10,797	Vitosha mountain	Aegean Sea
Strumeshnitsa	114	114	1900	Mountain Plachkovitsa	Struma
Stryama	110.1	110.1	1394	Peak Vezhen	Maritsa
Suha reka	125.8	125.8	2404	Fragnensko highlands	Danube
Timok[a]	189	35	4630	Svarlishka Mountain	Danube
Topolnitsa	154.8	154.8	1789	Peak Bunaya	Maritsa
Topchiyska reka	88.6	88.6	659.8	Ludogorsko highlands	Danube
Tundzha[a]	397.4	349.5	7884	Peak Urashka Gramada	Maritsa
Fakiyska reka	87.3	87.3	641	Strandzha Mountain	Madrensko Lake
Harmanliyska reka	91.9	91.9	956.3	Velichka	Maritsa
Harsovska reka	90.8	90.8	997.3	Stana highlands	Canora river
Tsaratsar	108	108	1062	Samoilovi hights	Danube
Tsibritsa	87.5	87.5	933.6	Peak Kostin	Danube
Chepelarska reka	85.9	85.9	1010	Pamporovo	Maritsa
Chepinska reka	82.7	82.7	899.6	Peak Malka Sutkya	Maritsa
Cherni Lom	130.3	130.3	1549	Lilqskoto highlands	Rusneski Lom
Yantra	285.5	285.5	7862	Peak Atovo padalo	Danube

[a]Rivers flowing through other countries are marked in bold

(12.4 ha) in Pirin. The highest located lakes are Gorno Polezhansko Lake (2710 m) in Pirin and Ledenoto in Rila. The lowest located lake is Lokvata (1858 m) in Rila. In general, these lakes are not deep—most often from 2 to 5 m. The deepest of all glacial lakes is Okoto (37.5 m maximum depth) from the group of the Seven Lakes and Popovo Lake (29.5 m) in Pirin. The water in these lakes is crystal clear. Some of the biggest Bulgarian rivers start from them. In few of them, there are small islands—Golyamo Vasilashko lake, Vasilashko Tevno lake in Pirin.

Coastal lakes are the largest in area in Bulgaria. They are of great economic significance. By the type of their formation, they come in two groups: lagoon lakes and firth lakes.

Lagoons are formed by partitioning an area in a gulf by a sand bar. Examples from Bulgaria include Pomorie Lake, Atanassovsko lake, Alepu, Arkoutino, Stomoplo, etc. To this group also belong other three lakes (Touzlas on the northern coast—Balchishka Touzla, Nanevska Touzla, and Shablenska Touzla). These three touzlas are small very salty lakes—in July their salinity can reach up to 200‰. Balchishka and Nanevskata Touzla can be considered to be landslide lakes. Pomorie Lake is very shallow and is about 50 cm below the sea level. It is separated from the sea by a 6 km long sand bar. It is recharged with sea water through seepage in the sand. Atanasovsko lake is a super-salty lagoon. It is the largest coastal lagoon lake in Bulgaria. Its area is 16.90 km^2 holding 4.3 million m^3 of water; its depth is 0.8 m. In dry summers salinity of its water reaches 250‰. Some of the lakes are swampy. Such are Alepu, Arkoutino, Stomoplo, and Dyavolsko. In summer time, salt is extracted from Atanasovsko lake via evaporation of sea water.

Firth lakes represent drowned estuaries—Varnensko, Beloslavsko, Burgasko, Shablensko, Durankulashko (Blatnishko), Ezeretsko lakes. Bourgasko Lake is the largest lake by area in Bulgaria with an area of 27.6 km^2. Its long axis is 9.5 km and the short one—4.5 km. Its depth varies from 0.5 to 1.5 m. The second biggest in area is Varnensko (17.4 km^2) lake, and it is also the deepest one—20 m. It has the most water of all Bulgarian lakes—around 170 million m^3. Mandrensko Lake is very shallow—110 cm average depth. Durankulashko, Ezerets and Shabla lakes have been overgrowing with water plants and are becoming swampy. Some firth lakes are freshwater lakes, but most are salty.

Riverside lakes originated in places of old river beds. There used to be many such lakes and wetlands in the past in our country, in the alluvial lowlands along the Danube River and some larger Bulgarian rivers such as the Maritsa, the Iskar, the Yantra, the Tundzha, the Mesta, the Struma. Now they have been drained. Only Srebarna lake in Aidemir lowland has been preserved. Srebarna is a small lake—about 2.5 km^2 and 2 m deep—which is located 1 km from the Danube river.

Tectonic lakes resulted from movements of earth layers, which led to depressions in the Earth's surface, and which now are filled with water. They are few in our country. The biggest of them, and the only one of economic importance is Rabishkoto lake. Its level had been raised, and it was converted into a dam. It is situated at the foot of Rabishka mound and has an area of 95 ha. Kupensko Lake (north of Mount Golyam Kupen) in Central Balkan Mountains and Panichishte Lake in Rila mountain, by the town of Sapareva Banya, are small and have no economic importance. Skalenskoto lake in Stidovska Mountain (Eastern Balkan Mountains) is located in a sinking of the earth layers on a ridge plateau. Its depth is between 2 and 4 m.

Karst lakes are considerably more in number than tectonic lakes; their size is insignificant, some of them even dry up in summer. They are surface lakes and ground lakes. Surface lakes formed in clogged karst depressions—hollows. They are small and often change their area and depth. Damp water and karst springs recharge them. The most typical and numerous lakes are Devetashki Lakes in Devetashko plateau. Of these, the most important are Dedevets (2.1 ha) Geranishte (1.2 ha) and Sinovishte. In summer and early autumn, the level of karst lakes goes down significantly, and some lakes even dry up, as Suhoto Lake in Dobrudzha, which dries up in summer.

Landslide lakes are formed as a result of sliding of earth layers and formation of depressions in the earth. Such are the lakes along the Northern Black Sea coast—Balchishka Tuzla, Shablenska Tuzla, Nanevska Tuzla near Aladzha monastery, and Smolyanskite Lakes. Smolyanskite Lakes are arranged in tiers, they are small in size and are not deep. The largest of them Miloushevsko Lake is about 3 m deep. Lake mud from some of these lakes is used for commercial purposes—Balchishka Tuzla, Nanevska Tuzla.

In the past, there were many marshes along the Danube in our country. After World War II almost all of them were drained and converted to farmland. Only a few have been preserved. The most famous among them is Garvanskoto Marsh (Leshtava) in Silistra district, whose area is about 200 ha, while its depth is 0.5 m. Straldzhansko and Aldomirovsko marshes are also popular. Marshes can also be found in mountainous areas. They are located in depressions of the Earth's surface. Such is Choklyovskoto swamp in Konyavska Mountain. It is located in the central part of Konyavska Mountain in a lowering of a denudation surface. It is used for peat extraction and fishing. Other swamps are located in the lower parts of the valleys (former Straldzha swamp, Dragoman swamp etc.). Swamps can also be found in Sofia valley—Aldomirovsko and Dragomansko, which are about 1 m deep. There are small marshes of insignificant size in the northern sinking part of the valley near the villages of Gnilyane and Kutina (Ivanov 2016; Ivanov et al. 2000; Water low 2017, www.moew.government.bg; Velchhev et al. 2011).

Artificial lakes (dams) result from purposeful economic activities. Their construction and use are prerequisites for better utilization of water resources. They impact the water runoff pattern significantly. Over 2200 dams of different size have been constructed in the country and serve as a sort of artificial equalizers for water runoff pattern of rivers. Their maximum water capacity is about 7 billion m^3, or about 33% of the fresh water potential in Bulgaria. The volume of over 97% of the dams is less than 10 million liters, and the volume of only 0.1% of them exceeds 500 million liters. Most numerous are the dams in Balkan Mountains—470, followed by the Rila-Rhodopes region—370. The largest dam is Iskar dam, whose volume is 670 million m^3. Large dams are Ardino cascade dams—Ivaylovgrad, Kardzhali and Studen kladenets, in the Western Rhodopes—“Dospat”, “Batak”, on the Tundzha River—“Koprinka” and “Zhrebchevo” dams, “Al. Stamboliiski” (on the Rositsa River), Ogosta, etc. The main dams in Bulgaria are given in Table 12.2 (Ivanov et al. 2000; NEK 2007).

Table 12.2 Main dams in Bulgaria (Ivanov et al. 2000; NEK 2007)

Name	Location, municipality	Built in	Year of commissioning	Water catchment area (km$^{2)}$	Total storage (million m^3)	Altitude (m)
Aleksandar Stambolijski	Veliko Tarnovo	Rositsa river	1954	11.4	205	190
Batak	Pazardzhik	Matnitsa river	1959	22	310	1107.8
Belmeken	Pazardzhik			4.53	144	1923
Vacha	Pazardzhik	Vacha river	1975	4.9	226	540
Golyam Belik	Pazardzhik	Kriva river	1951	4.1	62	1528
Gorni Dabnik	Pleven					
Dospat	Smolyan, Pazardzhik	Dospat river	1969	22	449	1200
Jrebchevo	Stara Zagora	Tundzha river	1966	22.4	400	269
Ivaylograd	Kardzhali	Arda river	1964	15	188	120
Iskar	Sofia	Iskar river	1954	30	673	817
Jovkovtsi	Veliko Tarnovo	Veselina river	1979	25.6	92	365
Kamchia	Burgas	Luda Kamchiya river	1973	9.6	233	260
Koprinka	Stara Zagora	Tundzha river	1955	11.2	140	400
Kardzhali	Kardzhali	Arda river	1963	16	539	331
Ovcharitsa	Stara Zagora	Ovcharitsa river		6.3	45	140
Ogosta	Montana	Ogosta river	1986	23.6	506	186
Pqsachnik	Plovdiv			9.1	103	290
Studen kladenets	Kardhzali	Arda river	1957	27.8	489	227
Ticha	Shumen	Golyma Kamchiya river	1973	18.7	311	185
Topolnitsa	Pazardzhik	Toplolnitsa river	1963	5.7	137	370
Trakiets	Haskovo	Harmanliyska river	1965	8.2	114	250
Tsankov kamak	Smolyan	Vacha river	2010	3.4	111	688
Tsonevo	Varna	Luda Kamchiya river	1974	23.9	330	185
Shiroka Polyana	Pazardzhik	Kerelova river	1963	4	24	1500

12.5 Groundwater in Bulgaria

Groundwater is widely spread in Bulgaria and plays an important role both in shaping the environment, and, as water resource, in meeting different needs of people and agriculture.

To evaluate the role, place, and importance of groundwater as a water resource and environmental factor, it should be considered that unlike surface water, groundwater has a different origin (infiltration, sedimentation and mixed), and because of that, various physical and chemical properties and composition. It has several stocks—dynamic, static, elastic and operational. In terms of bedding of aquifers, waters can be unconfined, confined (artesian) and semi-confined (layered aquifer). Different types of groundwater have their own fields of occurrence (pools) where hydrodynamic and hydrochemical processes of their quantitative and qualitative formation occurred and still occur. Processes and dynamics of contamination and self-purification also differ. In principle, confined groundwater is naturally protected from direct contamination from the surface. Unconfined groundwater is susceptible to contamination to a varying degree. Groundwater is mainly fresh cold water, which is a major source of water for drinking and domestic purposes. Pollutants of groundwater are many more than pollutants of river water, and self-purification processes are slow and take years. Protection of groundwater from further contamination and depletion is a major national issue (Ivanov 2016, www.moew.government.bg).

Groundwater in Bulgaria is divided into three main types by origin, physical and chemical properties, and utilization purposes: fresh cold, mineral, and highly-mineral.

Highly-mineral water—comes from the sedimentogenic (sea) genetic cycle (sigenetic and epigenetic) and is distributed in deeply buried geological structures in Northern Bulgaria, where it has undergone profound metamorphosis. Its total mineralization ranges from 50 to 200 g/dm^3, at some places higher. Water is hot and contains many salts and chemical elements (iodine, bromine, strontium, etc.), and at a number of locations, it has industrial importance—used as raw material for some sectors of the chemical and medical industries, and for balneology. Operational resources are mainly at the expense of elastic stocks. Currently, it is not much used because of insufficient research.

Mineral water—Nature has been relatively generous, endowing our country with that type of groundwater, which can be sub-divided in fresh and mineralized thermal water.

Fresh thermal water (from infiltration genetic cycle) is distributed mainly in southern Bulgaria, where it forms a number of fissure water pressure systems. Water features active water exchange and comes to the surface as springs (more than 600 pcs.). That is the type of mineral water used for current development of balneology in Bulgaria. Water is used primarily for medical treatment and less for heating of residential buildings and greenhouses, swimming pools, for drinking, for manufacturing of soft drinks etc. The operational resources of fresh thermal water are estimated to be approximately 8 m^3/s at water temperature from 25 to 100 °C—on average about 50 °C. Currently about 2 m^3/s are used. Operational resources are mainly at the expense of dynamic stocks, and less so of static and elastic stocks (Benderev et al. 2015).

Stratified (layered) mineral waters are mainly distributed in northern Bulgaria and some valleys in southern Bulgaria. They originate from the sedimentation cycle or can be mixed—infiltration and sedimentogenic. They have different chemical and gas composition, with total mineralization ranging from 1 to 50 g/dm^3, higher in some places. Considering their potential as spa resources, they have several advantages over fresh thermal waters from fissure water pressure systems. Layered mineral waters have big potential for the future development of spa and resort activities in northern Bulgaria. Water reserves are significant, but now it is difficult to give an accurate estimate of the operational stock, which will be mainly at the expense of elastic stocks.

Fresh cold water—is the most widespread groundwater in our country. In term of quantity and operational stock, it is second only to river water. It is and will be the main source of drinking-water supply for settlements, agricultural entities, and industrial enterprises that need drinking water. As before, this water will continue to be used in future as process water supply in industrial enterprises. Irrigation and fish farming reservoirs, power generation facilities (HPPs Tazha, Razlog, Hubcha, etc.) have been constructed on many of the larger springs.

Fresh groundwater (confined, karst and fissure) feature an active water exchange, and unconfined water is hydraulically connected to rivers. At some sites and sections, rivers recharge groundwater, at others, they drain it. That hydraulic connection requires a joint and comprehensive consideration and rational use of both river and groundwater fresh water resources in the country.

The main recharge sources of fresh ground water are infiltrated precipitation and river water, infiltrated irrigation water (where irrigation systems are in place) and condensation of water vapors in the aeration zone. Unfortunately, in many places, there is recharge from household and industrial wastewater.

Based on historical meteorological observations it has been established that the average volume of precipitation in our country is 74.10^9 m^3. The share drained as surface and groundwater runoff from that volume of water in an average dry year is 18.8×10^9 m^3/per annum on average, where groundwater accounts for about 6×110^9 m^3/per annum. In a dry year, the groundwater runoff is on average 4×10^9 m^3/per annum. The minimum runoff of rivers in the country in prolonged dry periods (without precipitation) is exclusively at the expense of drained groundwater—i.e., the groundwater runoff.

Besides groundwater runoff (dynamic stock), fresh layered groundwater has a large static stock that is estimated to be several hundred billion m^3, where only in the quaternary deposits of pan-valleys it amounts to about $20 \times 10^9 m^3$ (here it can be easily accessed for operation).

A prerequisite for broader opportunities to use fresh groundwater in irrigation is the fact that irrigation is seasonal and therefore the static stock that will be recovered during the non-irrigation season can be operated and mostly at the expense of infiltration of unregulated river runoff and groundwater runoff that is not used for other purposes. The hydraulic connection between river water and fresh groundwater creates favorable conditions in case of capturing a part of the static stock (creating an empty volume) for turning aquifers into powerful underground reservoirs for complex regulation of river and groundwater runoff and its rational use. Creation of underground reservoirs to regulate river runoff that is not used in case of intense groundwater exploitation is the future solution for full and rational utilization of fresh water resources in the country. Underground reservoirs have a number of advantages over surface ones. Opportunities to create underground reservoirs in our country offer almost all pan-valleys, the Danube plains, and some karst basins.

Expanding the use of fresh groundwater for water supply is related to protection of groundwater from pollution. In principle, all confined groundwater in the area of pressure is practically safe from surface contamination. Confined water may be contaminated only through purposeful pumping into its aquifers (using injection wells) of contaminated wastewater or underground storage of radioactive and other toxic substances. The situation is different when we consider unconfined groundwater, especially when it is shallow bedded, where the free water level coincides by area with the area of its distribution and the rocks in the aeration zone of water permeability—that water is vulnerable (unprotected by nature) to surface contamination.

By nature, pollution is of two types: bacteriological and chemical and organic, and inorganic.

Bacteriological pollution occurs when pathogenic bacteria and viruses that can cause various diseases in humans and animals penetrate in groundwater, and that water is used for drinking without prior decontamination.

Chemical pollution occurs when new chemicals penetrate in groundwater, or when the content of naturally contained chemical components goes up, which deteriorates water quality. In many cases, chemical contaminants (organic and inorganic) worsen the organoleptic characteristics of water, in other, higher concentrations are harmful to human and animal health, especially toxic pollutants—copper, zinc, cyanide, pesticides, detergents etc.

Pollutants of unconfined groundwater are much more in number and type than those of river water. Moreover, polluted rivers themselves are a source of contamination of groundwater: under natural conditions, in the areas where they recharge groundwater, under artificial conditions—where wells interacting with rivers are constructed.

The main sources of pollution of unconfined groundwater are use of chemicals in agriculture, wastewater from settlements without sewerage systems. Wastewater from livestock farms and complexes, industrial wastewater, polluted river runoff, polluted precipitation as a result of air pollution, tailing ponds, quarries for crushed stone, quarries for sand and gravel, outdoor storage of household and industrial waste, damages in underground facilities (gas and oil pipelines, sewage systems) etc.

Pollutants penetrate fresh unconfined groundwater in different ways, the main ones being: filtration through the aeration zone and direct penetration and absorption in aquifers.

Dynamics of contamination and self-purification of unconfined groundwater are closely related to the lithological nature of aquifers, their filtration properties, recharge and drainage conditions, strength and filtration properties of rocks in the aeration zone. Considering all that, the following types of vulnerability to surface contamination have been established:

1. Highly vulnerable waters—these include karst waters with open sinkholes. Ponor forming river water and precipitation mainly recharge karst waters, and if the latter are contaminated, they cause direct contamination of karst water.
   Currently, a significant part of karst waters with open sinkholes are not contaminated because their basins are situated in the alpine mountain band where no serious pollutants exist. Evidence of their strong vulnerability to pollution is the abrupt change in spring runoff and turbidity in case of intense rainfall.
2. Vulnerable waters—these comprise karst waters with covered karst and pore water in alluvial river terraces.
   Covered karst is widespread in Dobroudzha region (Sarmatian and Lower Cretaceous aquifer). Loess serves as a cover, and in some places Pliocene under it as well. Loess plays the role of an absorbent of pollutants infiltrated with water. Karst water is recharged primarily by the runoff of "hanging rivers and gullies" that cut through the loess, but their beds do not reach the level of karst water. In this connection, pollution of karst water should be expected mainly in the valleys of recharging waters and ravines.
   Underground streams have originated in river terraces, providing a hydraulic connection with rivers. Their water levels are at a small depth from the Earth's surface (from 0.5 to 5 m, and rarely deeper), while rocks in the aeration zone are permeable. Contamination of groundwater streams is due to chemicals used in agriculture, polluted river runoff, urban and industrial wastewater, and many other pollutants. In many places, water in groundwater streams is already polluted and unfit for drinking and household purposes (Ivanov 2016; Ivanov et al. 2000; www.moew.government.bg; Gartsiyanova 2018).
3. Vulnerable and less vulnerable waters—these comprise confined groundwaters in quaternary alluvial and semi-alluvial deposits of pan-valley and fracture-karst water. Stratified nature of the common aquifer is characteristic of the quaternary deposits in valleys. Water is vulnerable to surface contamination in the uppermost aquifer stratum (layer), while at the bottom lying strata it is less vulnerable. Fracture—karst waters are vulnerable to pollution in areas where there is no cover, but slightly vulnerable where there is quaternary cover.
4. Slightly vulnerable waters—these comprise mainly fracture waters with shallow circulation. Contamination is mostly local.

12.6 Economic Assessment–Use and Protection

12.6.1 Use of Water

Surface and ground water are primarily used for water supply to settlements. In Bulgaria, the majority of the settlements have a water supply system. Many springs were captured; dams and water pipes were built. Nevertheless, most of the settlements and mostly large cities experience a severe shortage of drinking water.

Secondly, water is used in electricity for electricity generation. Because of the limited water resources, hydroelectric power stations have a small share of the electricity produced in Bulgaria. More than 100 hydropower plants, the majority of which have low power, have been built. Due to water scarcity, they are usually included in the hours of peak power consumption.

Thirdly, much of the water is used for irrigation of agricultural land. Large irrigation systems have been built in the Danube Plain, the Upper Thracian Plain, the Bourgas Lowland and elsewhere.

Fourth, large quantities of water are used for industrial purposes. Large water users are metallurgical plants, chemical plants, pulp, paper, textile, sugar, petroleum, thermal power plants and others.

In the fifth place, a number of mineral springs are used as a resource for the development of tourism, especially the balneological activity. These are the springs built sanatoriums and hotels where various water treatments are carried out. Such facilities are built in Hisarya, Velingrad, Varshets, Sandanski and many other settlements in the country.

Some of the water sources are used in a complex way—for drinking, electricity, industrial, sports, recreational and other. Some of the lakes and dams are used for fishing and fishing. And in some seaside lakes, there is salt.

Even though Bulgaria is poor in water resources, there is a high level of water consumption per capita in our country. In fact, much of the water is scattered. This violates the water balance of Bulgaria.

12.6.2 Water Protection

There are a number of unfavorable hydrological phenomena in Bulgaria, which cause damage to settlements and to economic activity. Such are the floods after heavy rainfall and very rapid melting of the snow cover. They are very characteristic of the rivers Arda and Varbitsa (in the Rhodopes), Ogosta and Rositsa in the Balkan Mountains region, Mativir in the region of Ihtiman valley and others. There are also the rivers, which especially very much at the end of summer and the beginning of autumn very much reduce their water quantity and even dry up.

A major problem is the deterioration of freshwater quality due to the disposal of industrial and domestic wastewater. A large part of our waters, especially the rivers, are heavily polluted by wastewater and sewage waters of the settlements. This makes them unusable for drinking and domestic purposes, for irrigation, etc. The water of the Provadiyska river is the most polluted. The Iskar River is very polluted after Sofia, Yantra after Veliko Tarnovo, the river Topolnitsa, and other Bulgarian rivers.

The industry is the most polluting water—about 86% of all pollution. Industry sectors are the most polluting industries and companies in the chemical, petrochemical and rubber industries—74%. They are also heavily polluted by metallurgy and pulp—paper industry. Communal—household activity has a relative share in total pollution of only 3.2% and agriculture and construction by about 1%.

Agricultural activities also significantly pollute the waters. The pollution is predominantly with nitrates, sulphates, and chlorides due to the inadequate fertilization of the arable land with mineral fertilizers, the inadequate irrigation of specific areas of the arable land. Strongly pollute water and wastewater from livestock farms.

Transport, mainly river transport along the Danube, is also a dangerous pollutant. River water is polluted by the wastewater of a number of large settlements in Central Europe. However, part of their pollution is also the result of transport by dumping of polluted water, spent fuel, spillage of oil and oil products in the Danube waters, etc.

As a result of the pollution of the running waters, there is already a sharp shortage of drinking water in a number of areas of the country, and especially during the warm half-year, the settlements pass into a water supply regime. This is particularly true for the regions of Northwestern Bulgaria.

Stringent measures are needed for the rational and full use of water and its conservation—the construction of water treatment plants, the multiple uses of water, the reduction of leakage from watercourses, etc. (Ivanov 2016; Ivanov et al. 2000; www.moew.government.bg; hydro.bg; www.bd-Danube.org).

12.7 Water Management in Bulgaria

The national water management in Bulgaria has a long history with following milestones:

- Common state water programme—1920
- United water management plan—1950
- First Bulgarian Water Act 1969
- Bulgarian Water Act 1999—Introduces the river basin principle of water management and the requirement of production of River basin management plans (RBMPs)
- Bulgarian Water Act 2006—harmonization with EU water legislation (www.inbo-news.org).

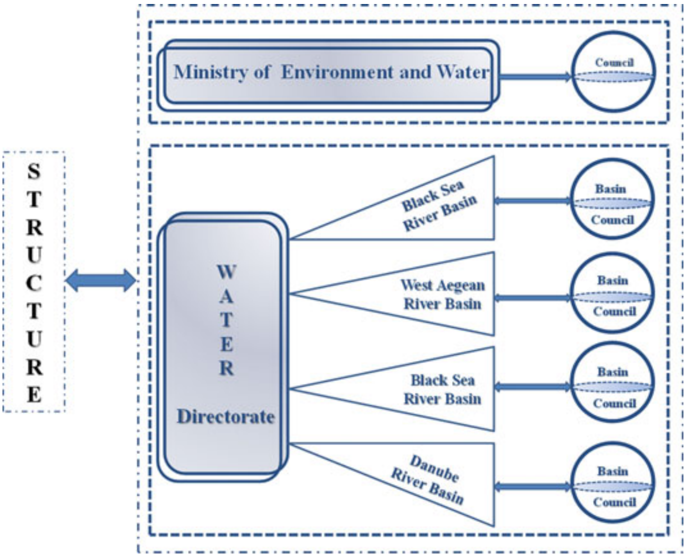

Fig. 12.8 Structure of water management in Bulgaria

Bulgaria became a member-state in 2007, but the country was following all the requirements of the Water Framework Directive from 2002 (www.moew.government.bg).

The structure of water management in Bulgaria is given in Fig. 12.8.

12.7.1 Legislation of the Republic of Bulgaria on Water Resources

In modern Europe, effective management of water resources is governed by various EU directives on the basis of which each country has to formulate its policy on management and conservation of available water resources. Integrated management of water resources is one of the main goals set by the Water Framework Directive of the European Parliament and the Council—2000/60/EO (earbd.org). Water policy in individual European countries is governed by normative acts of different legal force. In Germany, Switzerland, and Latvia, the water resources regulation is set at the constitutional level. In other countries, water ownership and management are governed by a single law or by different pieces of legislation.

The applicable law in Bulgaria is the Water Act (Water law 2017) which entered into force on 28.01.2000, and its latest amendments are as of 03.02.2017. According to Art. 151 of the Water Act, the Minister of Environment and Water shall develop and propose to the Council of Ministers a National Strategy for Management and Development of the Water Sector, which should be further submitted for approval to the National Assembly. In 2012 a National Strategy for Management and Development of the Water Sector in Bulgaria was adopted, which set the key objectives, stages, tools and methods for development of the sector (www.moew.government.bg). One of its stages includes the development of an Action Plan to the National Strategy for Management and Development of the Water Sector in the Republic of Bulgaria in a short-term (2013–2015), medium-term (2016–2021) and long-term (2022–2037) perspective.

The Strategy sets clear rules in the water sector—legal and regulatory framework, ownership and management of water infrastructure, and funding options. Detailed analyses have been carried out by a wide range of specialists for the purpose of achieving the most efficient management of water facilities in order to secure sufficient and good-quality water for drinking, and allow water industries to develop under the effective and integrated management of the water resources used.

A detailed analysis of the current situation and forecasts for the future development of the water sector has been developed, as well as a SWOT analysis of the water sector, goals and possible alternatives for its development.

This document sets out the long-term strategic objective of the country in the water sector, namely "sustainable use of water resources ensuring to the optimal extent the present and future needs of the country's population and economy, including those of water ecosystems" The National Strategy for Management and Development of the Water Sector in the Republic of Bulgaria, (www.bd-Danube.org) sets targets and sub-targets. They guarantee water to "the population and the businesses in climate change conditions conducive to droughts"; to preserve and improve the "surface and groundwater status"; to improve "the efficiency of integrated water management as an economic resource" and to reduce the risk of flood damage.

Water management in Bulgaria is implemented at national and basin level. The Water Act defines four river basin management districts called Basin Directorates (BDs) and in accordance with Directive 2000/60/EC: BD Danube Region with headquarters in Pleven, BD Black Sea Region with headquarters in Varna, BD East-Aegean region with headquarters in Plovdiv, and BD West-Aegean region with headquarters in Blagoevgrad, for which the respective Basin Directorates are responsible. River basins defined by the Water Act do not follow the administrative-territorial division of the country. Management of water economy systems is based on a technological and basin principle in compliance with the terms and conditions of the permits for water use and use of the water bodies for various economic activities and for the discharge of wastewater in them.

At the national level, responsibilities for water resources are shared among several ministries. Under the Water Act, water management at national level is carried out by the Ministry of Environment and Water. The Ministry of Regional Development and Public Works is responsible for water supply and sanitation systems and facilities of settlements and prevention from the harmful impact of water beyond the boundaries of settlements. The Ministry of Agriculture, Food and Forests is responsible for irrigation systems and facilities and prevention from the harmful impact of water. The Ministry of Energy is responsible for hydropower systems and sites. The Ministry of Energy through the National Electric Company (NEC and State Enterprise “Dams and Cascades” with NEK EAD is responsible for the management, technical exploitation and maintenance of all dams for drinking and household purposes in Bulgaria regardless of their ownership.

Water resources represent the usable part of natural waters resulting mainly from precipitation and manifested as surface water and groundwater. By the Water Act, the National Institute of Meteorology and Hydrology (NIMH) makes an estimate of water resources, including precipitation. Also, it is responsible for the development of early warning systems in case of high water. NIMH broadcasts operational data on precipitation, snow cover, rivers and groundwater, preparing daily, weekly and monthly analyses based on data received from the operating stations in the country. Section Hydrology with NIMH prepare monthly and annual reports on the state of rivers (hydro.bg) to be submitted to the Ministry of Environment and Water.

Ordinance No 1 of 10.10.2007 regulates the specific requirements for groundwater research, use, and protection against pollution and deterioration, including mineral waters (Water low 2017).

Each month the Ministry of Environment and Water (MoEW) provides information about the status of complex and important dams (www.moew.government.bg). The MoEW prepared and published on its site a monthly schedule for water use from the complex and important dams. If needed, given the available thick snow cover and the expected water runoff due to snowmelt, the MoEW orders that additional volumes should be secured to accommodate the expected water runoff. The MoEW stipulates that the maintenance of prescribed volumes should be secured by HPPs or, failing that, by means of the main outlet. Operations of RBDs are coordinated by Water Management Directorate with the MoEW. Pursuant to the requirements of Art. 14, para. (1) b of the Water Framework Directive 2000/60 and the Public Information Plan for the Preparation of a River Basin Management Plan (RBMP), the four Directorates prepare an interim review of significant water management issues.

That review reflects the views of stakeholders as a result of public consultations in 2006 and 2007. Based on the analyses of the state of water bodies, each Directorate prepares a 6-year River Basin Management Plan (from 2010 to 2015).

On the basis of the water body status analyses, each directorate comes up with a RBMP. Detailed River Basin Management Plans are published on the sites of the four Basin Directorates (www.bd-Danube.org, www.bsbd.org, www.wabd.bg, https://earbd.org). The first RBMP is for the period 2010–2015 and the second RBMP is for the period 2016–2021.

The National State of the Environment (SoE) Reports of the Republic of Bulgaria are published on the website of the Executive Environment Agency (eur-lex.Europa.eu).

In the National State of the Environment Report of the Republic of Bulgaria in 2009, (eur-lex.Europa.eu), i.e. the year before the first RBMP was adopted, the following opinion was given:

“Based on the information gathered from the National Environmental Monitoring System in the period 1990–2009, the trend toward improvement of water quality observed in recent years has been preserved, but there are still water bodies at risk. To this end, the River Basin Management Plans (RBMP) published in 2009 set out a number of programs of measures to achieve the objectives of the Water Framework Directive—achieving good environmental status by 2015." (eea.government.bg).

"In 2009, there were 73 municipal wastewater treatment plants (UWWTP) operating by order of the government, to which 91 settlements and settlement formations were connected. In 2009, 5 new WWTPs with secondary treatment were registered. There are 46 cities with over 10,000 people without wastewater treatment plants." (eea.government.bg).

"The Danube Basin Management Area features sustained a good quality of river waters by key indicators—dissolved oxygen, biochemical oxygen demand and chemical oxygen demand. Regarding nutrients, single exceedances are observed." (eea.government.bg).

The biological assessment of river waters in the Danube basin district is that they are in good condition (low to moderately polluted) remain the Ogosta River and the rivers west of Ogosta, except for some sites with worsened status—the Timok River—near the town of Bregovo, the Ogosta River—after the town of Montana. The waters of the Osam River and the Yantra river are of moderate quality (medium pollution), and poor quality is found only in the points—for the Osam river—after the town of Troyan and at the estuary, the Yantra River—after the town of Gabrovo and before its junction to the Danube River. The trend observed in previous years for the poor quality of the waters of the Rositsa River has been preserved. Water in the Rusenski Lom river features medium pollution, except for several sections, which are in a very bad condition—the Roussenski Lom River—before Beli Lom dam, after the town of Razgrad and before its mouth.

"There has been an improvement in the state of water in the Erma River compared to 2008." (eea.government.bg).

"In general, good quality of river water has been observed in the Black Sea Basin Region in 2009 in terms of dissolved oxygen, biological oxygen demand and chemical oxygen demand." (eea.government.bg).

The biological assessment of river water in the Black Sea region shows that "there has been no significant change in the state of river water compared to the last few years". Significantly influenced by human activity are the Provadiyska, the Vrana, the Batova, the Kriva and the Aitoska rivers. "The water of the Luda Kamchia river is in good condition, as well as the upper stream of the Kamchia river. The water of the Veleka River remains slightly polluted." (eea.government.bg).

"In the East-Aegean Basin, good water quality in rivers is preserved by key physicochemical indicators." (eea.government.bg).

In this area, biological assessment of river water shows "more significant pollution of the Maritsa, Topolnitsa and Tundzha rivers. The valley of the Arda river is in a better condition. Water quality of some of the Maritsa river tributaries is in the range of polluted to moderately polluted (the Kayalika, the Banska, the Luda Yana, the Pirdopska River). The section between Dimitrovgrad and Svilengrad on the

Maritsa river remains in poor condition. The sections around the village of Chavdar and the Topolnitsa dam on the Topolnitsa River are heavily polluted. The upper stream of the Topolnitsa River is in a better condition. The water of the Byala Arda is in good condition, while most of its tributaries (the Elhovska River, the Madanska River, the Cherna River, the Varbitsa River) are moderately to slightly polluted, except for the section after the town of Kardzhali, where the state of the river deteriorates abruptly."

"Quality of river water in the West Aegean Basin area in 2009 is preserved by key indicators." (eea.government.bg).

Biological assessment of river water in this region shows that sites with medium to slightly polluted water prevail in the valleys of the Struma and the Mesta River. The section of the Struma river after the town of Batanovtsi, as well as part of the tributaries of the Struma River—the Dzherman River, the Blagoevgrad Bistritsa River, the Sandanska Bistritsa River—after the town of Sandanski, the Strumeshnitsa—after the town of Petrich are in a worse state (with polluted water). Before the border, the state of the Strumeshnitsa river water improves. Water in the Glazne River and the Dospat River—after the town of Dospat in the Mesta River valley is polluted. The Konska River, the Arkata River and the Rilska River, and the tributaries of the Mesta River—the Damyanitsa River, the Sotovchenska Bistritsa River and the Kanina River—are in a better condition than the tributaries of the Struma River.

The report points out that nitrates are the main pollutant of groundwater in the country. "There was no exceedance of pesticide in 2009 in groundwater across the country, but only single exceedances in the quality standards for individual heavy metals." (eea.government.bg).

The following opinion is given in the 2015 National Report on the Status and Protection of the Environment in the Republic of Bulgaria (eur-lex.Europa.eu) (after the end of the first RBMP 2010–2015):

"The observed trend for improved water quality in recent years has been preserved in the period 1996–2015. Despite this trend, there are still water bodies at risk, and programs of measures for achieving good environmental status have been prepared to enhance their condition." (eur-lex.Europa.eu).

"In 2015 the trend for improvement of surface water quality in Bulgaria in relation to basic physical and chemical indicators, both in the short term and longterm aspect, is preserved" (eur-lex.Europa.eu).

"For the Danube Region in 2015, in the River Basin west of the Ogosta river, the majority of the points are in good and excellent condition, and in comparison to previous years, the condition is improving. The river Timok at the village of Bregovo is traditionally in poor condition. Most of the points in the Ogosta basin are in good and excellent condition, and a moderate state has been established after the Ogosta dam and Montana, after Krivodol and Byala Slatina. The Vit river basin features poor condition only after the town of Pleven, which has been a long-standing trend. The Nisava River at Kalotina exhibits a trend for the deterioration of the state from good to moderate. The improved condition was established in Danubian Dobrudzha rivers, except for the Dobrich river, for which the state is moderate. The majority of the points in the Osam River and the Roussenski Lom River are in a moderate state. The Beli Lom River after the town of Razgrad is traditionally in poor condition. In the last few years, there has been a lasting tendency in the Yantra riverbed toward the improvement of the the Yantra river state after the town of Garmovo and in the town of Novgrad on the mouth from bad to moderate. The water state in the basin of the Iskar River is traditionally worse, but in 2015, there was an improvement to moderate after the town of Novi Iskar" (eur-lex.Europa.eu, https://www.parlament.bg).

The Black Sea region in 2015. In the basin of the Black Sea Dobrudzha rivers, only the Echrenska River was monitored, and it is in good condition. Improvement of the condition of the Provadiyska river from bad to moderate after the town of Kaspichan has been reported in the Provadiyska basin. No significant changes have been reported for the tributaries of the Madara and the Devnenska rivers. In the basin of the Kamchiya River, the condition of the Poroyna River and the Vrana River, after the town of Targovishte is very bad, which is a long-term trend. The North-of-Bourgas River basin retains the very poor state of the Aitoska river after the town of Aitos, with worsening of the river state after the town of Kameno and at the estuary. In the basin of Mandrenski rivers, the majority of the points on the Rousokastrenska River and the Sredetzka River are in good condition and on the Fakiyska River in excellent condition. In the river basin south of Burgas, the deterioration was reported of the Poturnashka River at the estuary (Oasis complex) and the Arapia River at the estuary (Arapia camping). There is no significant change in the state of the Veleka river and the Rezovska river.

East Aegean Region in 2015: similarly to previous years, there are many river sections in poor and very bad condition in the Maritsa basin. Probably resulting from pollution due to untreated urban and industrial waters. The Topolnitsa river in the section from the mouth of the Medet River to Topolnitsa dam, the Elshishka river after Panagyurski Mines EAD (Elshitsa village). The Chepelarska River after the town of Asenovgrad and after the town of Chepelare, the Stryama River at the mouth (after discharge of "Svinevadstvo" EAD), the Harmanliyska river, after Harmanli.errr4jh At the Vucha river, the state of water is good, and it deteriorates to moderate after the town of Devin and after the town of Krichim. In the valley of the Tundzha river and the Arda river, the majority of the points are in a moderate state. The Arda river tributaries in good condition are the Borovitsa, the Varbitsa, the Krumovitsa, and the Malka Arda, in a moderate state are the Madanska and the Chepinska, and in a poor state is the Cherna river after the town of Smolyan.

The West Aegean region in 2015: the state of water in the basin of the Dospat river ranges from excellent to good, which is a long-term trend. In the Struma River Basin, improvement of the state of the Banshtitsa river from very bad to moderate after the town of Kustendil has been reported; there has been a deterioration from good to moderate of the condition of Stavroshnitsa river in the last two years. The Sandanska Bistritsa river after the town of Sandanski has also been in a very poor state for a long time. In the basin of the Mesta River, there has been a tendency for improvement in the state of the Glazne River from bad to moderate, the Zlataritsa river is in poor condition at the river mouth (after Eleshnitsa), which is a lasting trend.

In a very bad condition is the Nevrokopska river after the urban collector of the town of Gotse Delchev."

According to the 2015 National Report on the State and Protection of the Environment of the Republic of Bulgaria, the biological assessment of river water is as follows:

The Danube Basin Management Area: good water quality is preserved in relation to the main indicators—dissolved oxygen, BOD5, and COD."

The Black Sea Basin Area: in 2009, as whole good water quality was observed in relation to dissolved oxygen, biological oxygen demand, and chemical oxygen demand.

The East-Aegean Basin Area: in 2009, good water quality was preserved in relation to the main physical and chemical indicators.

The West Aegean Basin Area: in 2009 there was preservation of water quality in relation to the main indicators.

Groundwater: according to the 2015 National Report on the Status and Protection of the Environment in Bulgaria (https://eea.government.bg/bg/soer), "there has been a gradual improvement in groundwater quality in relation to most of the indicators". The percentage of points where the annual average values exceed groundwater quality standards (QS) exhibits a downward trend in relation to all indicators. This downward trend is stronger for manganese, total iron, and sulphate indicators, in percentage points with QS exceedances, while for chlorides the decrease is low. There is a slight increase in nitrates compared to 2014—12.06% and 14.67% in 2015.

In the period 1995–2015, the average annual concentrations of the indicators, calculated on the basis of their mean values in 1995 (baseline), exhibit values below the baseline average and show declining trends, with the exception of phosphates, where values over the years were above the baseline, but after 2007 also showed a decrease, while nitrates regularly feature slight exceedances of the baseline value in different stages of the 21-year period.

Trends related to changes of nitrate content in groundwater for the following two four-year periods—2008–2011 and 2012–2015—show different ratios at the prevailing points of uncovered groundwater depending on water level depth. The shallowest (level 0–5 m)—exhibit prevalence of high increase; at water level of 5–15 m—there are mostly points of high increase; at water level of 15–30 m—points with a slight decrease of nitrate content prevail, while the deepest groundwater (level > 30 m) the percentage of points with a strong decrease in nitrate concentration prevails (24.4%). Confined groundwater features equal percentage of slight decrease (29.41%) and strong increase (29.41%), while in karst springs the share of points with a slight decrease, or a missing trend is the highest.

Data analysis of measured water levels in wells and spring flows for the period 2006–2015 exhibit well-pronounced positive trends in springs and equalization of percentage points for positive and negative trends in wells. Negative trends in wells and flow of springs are observed in cases when water levels are dropping (water column height) and vice versa, positive trends are observed when water levels of wells and flow of springs are rising. In the ten-year period, the trends of spring flow increase (in about 60% of the observed groundwater basins) and equalization in the percentage of wells respectively, with the respective rise and drop in water levels (42%), are more pronounced. Negative trends in the flow of springs are observed in 31% of groundwater basins."

Prevention of natural disasters, including floods, is a topical issue, so flood risk awareness is imperative. Flood risks assessment and management is the subject of Directive 2007/60/EU (eur-lex.Europa.eu) also known as the European Floods Directive, in force since 26.11.2007, and transposed in the national legislation through an amendment to the Water Act of August 2010.

The four basin directorates in the country are responsible for flood risks assessment and management. They develop flood risk management plans following a methodology of MOEW, and the Council of Ministers examines and accepts the developed plans.

The 2016–2021 Flood Risk Management Plan for each basin directorate is available on their respective websites (www.bd-Danube.org, www.bsbd.org, www.wabd.bg, https://earbd.org).

12.8 Conclusion

Bulgaria's water resources are limited and unevenly distributed within its territory. Problems with providing the necessary water resources due to limited water sources in Bulgaria have approximately 500 settlements with about 1.17 million inhabitants (15% of the population). Most of these settlements are Vratsa, Gabrovo, Pernik, Montana.

The annual river flow in Bulgaria is 19 billion m^3: 34% for the needs of the population, 22% for agriculture, 29% for industry, 15% others.

70% of the water supply in Bulgaria comes from surface water and 30% comes from groundwater. Drinking water losses for the country are about 52%. The water consumption per person per day is 120 l with a tendency to decrease due to the increased water price and improved accuracy of the measurements.

Rational utilization and conservation of water resources are vital for the sustainable development of Bulgaria.

In conclusion, water is a very valuable, vital resource for Bulgaria. It provides vital needs for the population. This natural, natural renewal wealth should be reasonably used, stored and preserved. This is in the interest of the people of Bulgaria.

12.9 Recommendations

A major problem is the deterioration of fresh water quality due to the disposal of industrial and domestic waste water. A large part of our waters, especially the rivers, are heavily polluted by wastewater and sewage waters of the settlements.

As a result of the pollution of the running waters, there is already a sharp shortage of drinking water in a number of areas of the country, and especially during the warm half-year the settlements pass into a water supply regime. This is particularly true for the regions of Northwestern Bulgaria.

Stringent measures are needed for the rational and full use of water and its conservation—the construction of water treatment plants, the multiple use of water, the reduction of leakage from watercourses, etc.

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Chapter 13
River Systems Under the Anthropogenic and Climate Change Impacts: Bulgarian Case

M. Chilikova-Lubomirova

Abstract River systems as main surface freshwater transportation systems play a significant role in the natural and man developed processes. They are connected both to the aquatic and terrestrial ecosystems function and services and man related needs and activities gratification. All related processes are under continuous interaction between the on-going natural cycles and man developments. As a result, various type impacts occur with regard to the anthropogenic and climate change influences. One of them is connected to the water availability. It is vital for the ecosystems function and in a great term result on the developed man activities. Thus the understanding how various type impacts influence on its state is of great importance. For the purpose many crosscutting tasks are constantly developed: scientific investigations concerning the on-going processes, various types applicable to the practical solutions, strategies planning and management approaches. To balance the possible connected problems equitably and to guarantee their sustainable implementation different legislative measures are also obtained.

To clarify the presented the material is focused on the existing problems in the area with regard to the Bulgarian river systems quantification status. It is connected to the following issues:

– Basic description of the Bulgarian river systems, accounting the influence of topological and climate issues;
– Legislative and management clarification with regard to the implementation of the Water Framework Directive, Floods Directive, Blueprint to safeguard European waters, and related documents;
– Specification and delimitation between the connection to the river systems water natural regime, extreme and risk events.

For their better clarification in the material briefly are presented some of the most applicable methods that are used worldwide, in the EC and Bulgarian practice. Described aspects are examined with regard to the needs and functions of the

M. Chilikova-Lubomirova (✉)
Fluid Mechanics Department, Institute of Mechanics—Bulgarian Academy of Sciences, Acad. G. Bonchev Str., Bl.4, Sofia, Bulgaria
e-mail: milasemail@yahoo.com

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ecosystem. Presented issues are illustrated by the results of original assessments and practical examples from both real flood and drought investigations.

Keywords Water management · River systems · Water extremes · Floods · Droughts

13.1 Introduction

The important role of river systems as main surface freshwater transportation systems significantly depends on many factors connected both to the anthropogenic, climate and climate change influences. Practically all the elements: as river sources and streams, main rivers, river tributaries, river mouth and related floodplain, watershed, wetlands, etc. are under constant pressure. Climate specifics connected to the local properties as topography, ground cover, existing soil type, its physical properties and state, land coverage, available artificial structures, etc. predetermine the local natural conditions. However, sectors as water supply, irrigation, electricity production, industry, transport and navigation, recreation, etc. also impact on the water state. As a result, some of river system elements widely vary, affecting the related aquatic and terrestrial ecosystems and environmental function. Such variations are observed temporary, seasonally or for a long time, causing in many cases continuous modifications associated with anthropogenic, climate or climate change impacts. Some of these alterations are not negative, but in many cases, they are the reason for occurring of harmful impacts and damages. Related outcomes effect on all the related environment and society or on the ecosystems as a whole. Thus of great importance becomes timely and systematically to protect the vulnerable ecosystems, their function, and services, and to keep the resultant economic and social welfare in an equitable manner.

To keep such balance, an appropriate decision is the implementation of best applicable management practices. This opportunity is connected to the establishment of sustainable river basin management implementation with regard to the integrated water management principles based on the ecosystem approach. Presented approaches allow well to balance all connected needs and interests: from man to ecosystems, from the society to related sector needs holistically. Their implementation is connected to a very good knowledge of the on-going natural and man-handled processes with the main accent on water as a resource. For the purpose, its state is of vital interest and point of continuous in situ monitoring and additional investigations as short- and long-term forecasting, projections, and usual, extreme and risk events diagnostics.

In Bulgaria presented processes are very well developed and point of interaction within the requirements of the European Community. As an EU Member State Bulgaria strictly follows all connected EC Directives and Regulations, transposed into the domestic legislation. Main requirements are strictly implemented: the current rivers water status is permanently determined; second stage of River Basin

Management Plans (RBMPs) and Flood Risk Management Plans (FRMPs) are under implementation; investigations connected to drought and water scarcity are also delivered; future predictions and projections studies are also provided.

To clarify the presented following briefly will be described main connected aspects with regard to the Bulgarian river systems and obtained measures with regard to the anthropogenic and climate and climate change impacts. Briefly will be considered the rivers hydrography with a special accent on natural, extreme and risk events, and ecosystems specifics. Some authors investigations in the area will also be presented, accompanied within a short description of the main EU and world-wide most usable practices and enforced legislation.

13.2 Bulgarian River Systems Specification

Bulgaria is a country situated in southeastern Europe, on the Balkan Peninsula. Its geographical location and topographical, hydrogeological and soil properties, natural habitats of the certain flora and fauna and the anthropogenic and climate specifics are determinable for the character of the Bulgarian river systems.

Bulgaria covers a territory of 110,994 square kilometers. It is surrounded by four countries, as follow: on the west by Serbia and North Macedonia (FYROM), on the south by Greece and Turkey, on the north by the Danube River as a natural water border with Romania. On the east, the Black Sea Coastline is a natural water border. On such relatively small area, wide natural forms and species can be observed. There are mountains with a high-mountain relief and altitude above 1,600 m, plain territories, meadows, woods, valleys, rivers and gorges, Fig. 13.1.

The northern part of Bulgaria is covered by the Danubian Plain. Its territory is hilly, with numerous plateaus and river valleys. It goes south of the Danube River and runs until reaching the Balkan Mountains. There are some of the important Bulgarian natural protected areas as the Srebarna Natural Reserve, Perisna Nature Park, Rusenski Lom Nature Park. Srebarna is a freshwater lake home of almost 100 species of birds and 22 protected rare or endangered species.

The Balkans Mountain spreads from the Vrashka Chuka Peak that is situated on the Bulgaria-Serbia border on the west to the Black sea to the east. It is a natural limit that separate Bulgaria on two main northern and southern parts. Its highest peak is Botev at elevation 2,376 m. There are the river sources of almost all the northern situated rivers that tribute to the Danube river—the rivers Lom, Ogosta, Vit, Osam, Jantra, Rusenski lom. Only the Iskar river runs from the southern part of Bulgaria from the Rila mountain. There are several important protected areas as Central Balkan National Park, Vratchanski Balkan Nature Park, Bulgarka Nature Park, etc. It hosts most of the Europe's large mammals such as broun bear, wolf, boar, chamois, deer, etc. On the south of the mountain is situated the Sredna Gora mountain that borders on the south with The Upper Thracian Plain.

The Upper Thracian Plain is situated southern from the Sredna Gora mountains and northen from the Rhodopes, Sakar and Strandza mountains, the Black Sea

Fig. 13.1 Map of Bulgaria, based on Google

coastline delimitate it at the eastern part. It is a fertile agricultural region. The Maritsa, Tundzha, Stryama, Topolnitsa, Vatcha and their tributaries are the most important rivers in the area, playing an important role in the social life and economy.

The Rhodopes Mauntain is a widespread mountain range running south to the Greece border. Its highest peak is Goljam Perelik at elevation 2,191 m. The range gives the name of the terrestrial ecoregion Rodope montane mixed forests, belonging to the Temperate broadleaf and mixed forests Biome and the Palearctic ecozone.

Western from the Rhodopes is situated the Pirin mountain with the highest peak Vihren at elevation 2,914 m. The northern part of the range is protected by the Pirin National Park—a UNESCO World Heritage Site from 1983 with rich flora and fauna and relicit species. It is separated by the Mesta river from the Rhodopes range and the Predela saddle from the Rila mountain.

Rila mountain hosts the highest peak Musala with an elevation of 2,925 m—the hightes peak on the Balkans. Among the Rila mountain are the Seven Rila Lakes a group of glacial lakes situated between 2,100 and 2,500 m elevation. Significant territories of both mountains are National Parks.

Bulgarian Black Sea Coastline covers the entire eastern border of Bulgaria—378 km coastline with sandy beaches running approximately 130 km. Part of the coastline in the northern part is characterized by rocky headlands with cliffs up to 70 m high. Rivers as Ropotamo, Kamchia, Veleka, etc. flows there. Some of the coastline and connected areas are part of National Parks as Strandzha Nature Park, Kamchia Biosphere Reserve, etc.

With regard to the specific conditions, Bulgaria is one of the countries with the highest biodiversity in Europe. Bulgaria's biodiversity is conserved in national parks, nature parks and biosphere reserves under the Natura (2000), Fig. 13.2.

Bulgaria has a population of about 7.2 million people. It is unevenly distributed across the country, and a high proportion of the population live in towns.

Bulgaria has a variable and complex climate that is influenced by the strongly contrasted continental and Mediterranean climate and connected topological and land coverage specifics. Great emphases cause the main Bulgarian geomorphological regions as the Danubian Plain, the Balkans Mountain, the Upper Thracian Plain and Rilo-Rhodope region. As a result, five main climatic zones are formed, Fig. 13.3 (Donchev and Karakashev 2004; Alexandrov 2005; National Programme for Action 2014):

- Continental zone—Danubian Plain, Pre-Balkan and the higher valleys of the Transitional geomorphologic region;
- Transitional zone—Upper Thracian Plain, most of the Struma and Mesta valleys, the lower Sub-Balkan valleys;
- Continental-Mediterranean zone—the southernmost areas of the Struma and Mesta valleys, the eastern Rhodope Mountains, Sakar and Strandzha mountains;
- Black Sea zone—along the coastline with an average length of 30–40 km inland and

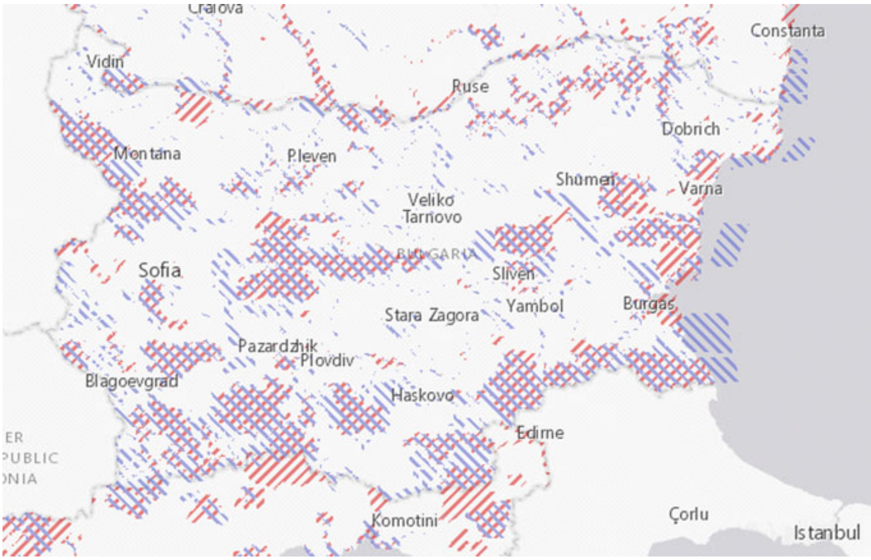

Fig. 13.2 Natura 2000 sites, covering Bird Directive Sites (SPA) and Habitat Directive sites (pSCI, SCI or SAC), *Source* Natura (2000)

Fig. 13.3 Bulgarian climatic zones, based on Agronet (National Programme for Action 2014)

- Alpine zone—in the mountains above 1000 m altitude like Central Balkan Mountains, Rila, Pirin, Vitosha, western Rhodope Mountains, etc.

The most important climate-forming factors are the Atlantic Ocean thought the atmospheric circulation of the Icelandic cyclone and the Azors anticyclone and the influence of the Mediterranean Sea influence, mainly throught the Mediterranian cyclones.

On the Danubian Plain, because of the flat and open to the north relief, the continental air masses easily flow into the flat and open to the north relief. During the spring, summer and autumn moist air masses easily occur, as in the winter the territory falls under the Eastern European anticyclone, that brings cold Arctic air mass and abundant snowfalls, about 12% of all precipitations there are form the snowfalls (Donchev and Karakashev 2004; Alexandrov 2005). The Balkans mountains become a natural barrier that stops the cool air masses coming from the north and the warm masses from the south. As a result, on average northern Bulgaria is about one-degree cooler and receives about 192 mm more rain precipitation than the lowlands of southern Bulgaria. The Rilo-Rhodope Massif deterrent the warm Mediterranean air masses and decrease the Mediterranean influences to the southern valleys of the rivers Struma, Mesta, Maritsa, and Tundzha. The influence of the Black sea affects approximately a 30–40 km strip along the coastline, where the breeze circulation is most pronounced (Donchev and Karakashev 2004).

For the majority of the country mean temperatures are higher than the relevant on the same latitude with 0,5 to 1,0 °C. The mean annual temperature varies from –3.0 °C—on the highest peak Musala to 13.9 °C at the town of Sandanski, in the southern Struma valley, and Sozopol town, near the Black Sea. The average temperature at the Danubian Plain is 11.4 and 13.9 °C at the Upper Thracian Plain. The highest temperature in the lowlands and the hilly regions is in June thus in the higher mountains is in August. The lowest temperatures are measured in January and February. Many valley basins scattered across the uplands have temperature inversions resulting in stagnant air. Sofia is located in such a basin, but its elevation (about 530 m) tends to lead to moderate summer temperatures and relieve oppressive high humidity.

Precipitations are not uniformly distributed on the Bulgarian Territory and over the year. They are closely linked to the atmospheric circulation peculiarities. The average precipitation in Bulgaria is about 630 mm per year. The north-eastern town of Dobrudja and a small part of the northern Thracian Plain usually receive precipitation less than 500 mm. The remainder of the northern Thracian Plain and the Danube Plateau get less than the country's average of rain. Summer droughts thus take effect in these areas. Elevated regions, which receive the most rainfall in the country, may average over 2,540 mm per year. In northern Bulgaria, the highest precipitation is in May-June, while in southern Bulgaria are during the winter.

Bulgarian river systems specifics are strongly influenced by the above-presented factors. As a result of the topography, the Bulgarian river systems network is dense, but with small relevant water catchments. There are not any large inland rivers. Crucial for the formation of the river is the Balkans Mountain that forms the natural watershed between the Black Sea and the Aegean Sea catchments.

One of the catchments is situated to the north of the Balkans, covering the rivers that tribute to the Danube River, the Rivers West of the groundwater shed of the Malm-Valange horizon and the Black sea rivers. There are distributed the main rivers Lom, Ogosta, Iskar, Vit, Osam, Jantra and Rusenski Lom and their tributaries that tribute to the Danube river, an international river, flowing to the Black Sea. Presented rivers source from the Balkans mountains, except the Iskar river, that is the only Danubian tributary that rise in the Rila Mountains, passes through the Sofia valley and after crossing the Balkan Mountains flows to the Danube. All of the presented rivers flow through the Danubian Plain, thus are under the connected continental zone climate influence.

Other rivers as Provadijska, Kamchija, Aheloy, Ropotamo, Veleka, etc. flow directly to the Black Sea. Most of them are typically short, except the Kamchija River. The Black Sea zone climate influences them.

On the south of the Balkans are situated the main rivers Struma, Mesta, Maritsa, Arda, Tundzha. They are transboundary rivers which upper part is situated in Bulgaria. Some of them after the Bulgarian borders confluence, e.g. Arda and Thudzha join to Maritsa (Evros, Gr. or Meriç, Tr.). All of them flow to the Aegean Sea.

The Sruma River sources from the Vitosha Mountain, flowing first westward, then southward gathering the waters of some of the highest Bulgarian Mountains—Rila and Pirin. The Mesta River sources from the Rila mountain and flow in between Rila, Pirin and Rhodopes Mountains reaching the Bulgarian-Greece border. Connected upland rivers tribute to both rivers. The upper parts of both rivers are under the Alpine zone climate influence, as the lower parts are impacted on the under the Continental-Mediterranean one. Presented circumstances contribute to the specific hydrological regime of the rivers.

Main rivers situated in southeastern Bulgaria are Maritsa, Thundza, and Arda. The Maritsa River sources from the Rila Mountains, flowing southeast through the Thracian Plain, passing between the Balkans, Rhodopes and Sakar Mountains, reaching the Bulgarian-Greek border, forming the Greek-Turkish border afterwards. Its main tributaries are the rivers Tundzha and Arda. The Tundzha river sources from the central part of the Balkans Mountain, flowing afterward east till Yamol city, where makes a sharp turn to the south, crossing the Upper Thracian Plain and reaching the Bulgarian-Turkey border. On the territory of Turkey, it join the Maritsa River. The Arda river sources from the Rhodope Mountains and afterward flows eastward until crossing the Bulgarian-Greek border. At the confluence of the Arda and Maritsa rivers lie the border between Greece and Turkey. With regard to the local topology presented three rivers are under both Transitional and Continental-Mediterranian zone climate influences that impact on the regime of the river.

In Table 13.1 are presented the main characteristics of some of the biggest Bulgarian rivers, based on the information presented in the Bulgarian River Basin Management Plans and connected literature (RBMP-DRBD 2016; RBMP-EARBD 2016; RBMP-WARBD 2016; RBMP-BSRBD 2016).

Bulgaria has about 400 natural lakes with a total area of 95 km^2. There are 179 glacial lakes in Rila and 164 in the Pirin. There are around 2,200 reservoirs serving different purposes—for water supply, electricity production, irrigation. The largest one is Iskar Reservoir, Ogosta Reservoir, Dospat Reservoir, Batak Reservoir, Kardzhali Reservoir, Studen Kladenets Reservoir, Koprinka Reservoir, Ticha Reservoir, etc. In Table 13.2 for some of them is presented brief information (RBMP-DRBD 2016; RBMP-EARBD 2016; RBMP-WARBD 2016; RBMP-BSRBD 2016).

Table 13.1 List of some of the biggest Bulgarian Rivers characteristics (based on the information, presented in RBMP-DRBD 2016; RBMP-EARBD 2016; RBMP-WARBD 2016; RBMP-BSRBD 2016)

Name	Length total, *, in the BG part (km)	Source	Catchment (km^2)	Mouth
Maritsa	480 (321*)	Rila Mountain	53 000 (21 084*)	Aegean Sea
Struma	415 (290*)	Vitosha Mountain	10 797	Aegean Sea
Mesta	230 (126*)	Rila Mountain	2 767	Aegean Sea
Tudzha	350	Balkans Mountain	7 883	Maritsa
Kamchia	244	Balkan Mountains	5 358	Black Sea
Yantra	285	Balkan Mountains	7879	Danube
Vit	189	Balkan Mountains	3 220	Danube
Iskar	368	Rila Mountain	8 684	Danube

Table 13.2 Specification of some main Bulgarian Reservoirs (based on the information, presented in RBMP-DRBD 2016; RBMP-EARBD 2016; RBMP-WARBD 2016; RBMP-BSRBD 2016)

Reservoir	Area (km^2)	Volume (m^3)	Province
Iskar	30	673 000 000	Sofia City
Ogosta	23.6	506 000 000	Montana
Dospat	22	448 220 000	Pazardzik, Smolyan
Ticha	18.7	311 000 000	Shumen
Koprinka	11.2	140 000 000	Stara Zagora
Kamchia	9.6	233 550 000	Bourgas

13.3 Legislation and Management Issues

Bulgaria is a Member State of the European Union. With this regard, European Union policies and legislation are transposed and enforced into the Bulgarian practice. Leading principle concerning WATER is the accepted ecosystem management approach with main connected documents:

- Water Framework Directive (WFD 2000). Directive 60/2000/EC;
- Directive 2007/60/EC (Floods Directive 2007);
- Directive 92/43/ECC (The Habitats Directive 1992);
- Common implementation strategy for the WFD, River Basin Management in a changing climate (CIS TR-2009-040 2009);
- River Basin Management Plans 2016 and connected documents,
- Convention on Biological Diversity (CBD 1992);
- United Nations Framework Convention on Climate Change (UNFCCC 1992) and connected The Kyoto Protocol (1998) and Paris Agreement (2015), etc.;
- Accepted issues are based both on integration between water, ecosystems and climate-related specifics. In help following National legislative documents are in force:
- Environment protection Law (2014);
- Water Law (2015);
- Regulation No 1/11.04.2011 (2011);
- Regulation No. H-4 from 14.09.2012 (2012);
- Regulation of terms and conditions for technical and safe exploitation of dams and associated facilities, as their technical state control (2016);
- Biodiversity Law (2017);
- Protected Areas Law (2013);
- National strategies and documents (National programs in the field of protection and sustainable development of waters, Marine Strategy, National Strategy for Management and Development of the Water Sector), etc.;

Main responsibilities for their best implementation at National Level carried the Ministry of Environment and Water (MOEW) and connected to it four River Basin

Directorates and sixteen Regional Inspectorates of Environment and Water, focused on the following main issues, (http://www.moew.government.bg/en/water/):

- Development and implementation of the Plans for River Basin Management and the Marine Strategy as main tools for integrated water management;
- Provision of sufficient quantity and quality of water for the needs of the population, economy, and ecosystems;
- Control of water resources and discharges of wastewater and development of monitoring systems;
- Mitigation of adverse climate impacts, associated both with floods, droughts, and water scarcity—development and implementation of specific preventive and protective measures, such as Plans for Flood Risk Management, etc.;
- Inland and transboundary waters protection and sustainable management.

River Basin Directorates operate on the following River Basin Districts:

- **Danube River Basin District**. It stretches between the Balkan Mountains and the Danube River, bordering with the East-Aegean River Basin Directorate to the southeast, West-Aegean River Basin Directorate to the Southwest and the Black Sea River Basin Directorate to the east. West border of the District is the National border with Serbia. This District spreads over 18 regional authorities, covering an area of 47 235 sq. km, about 42,5% of the Bulgarian territory. The territory is large and diverse—from mountain areas to wide plateaus. Main rivers associated with the District are the Danube, Ogosta, and rivers west of Ogosta, Islar, Vit, Osam, Yantra, Rusenski Lom, Danube Dobrudzha rivers, Erma, Nishava. All rivers flow from south to the north tributing to the Danube river. The Iskar river is the only river in Bulgaria that cross the Balkan mountains flowing to the north. There are artificial reservoirs as Iskar, Aleksandar Stambolijski, Yovkovci, Ogosta, and natural lakes and protected and zones like Sreburna, Persina, etc. Centre of the District is Pleven city.
- **Black Sea River Basin District**. It covers inland waters that directly tribute to the Black Sea and connected internal coastal waters. The district borders to the Danube River Basin District to the northwest and East-Aegean River Basin District to the southwest. The Black Sea forms its natural eastern border, 378 km long. It spreads over 8 administrative authorities, covering an area of 16 568 sq. km, about 15% of the Bulgarian territory. Most of them are important tourist centers. As a result, the population is irregularly distributed and significantly increases during the tourist summer season. Main rivers in the District are Shablenska, Provadijska, Kamchija, Fakijska, Ropotamo, Veleka, Rezovska, etc. There are situated complex water systems and dams as Kamchija, Ticha, Suedinenia and natural lakes as Shablensko, Durankolashko, Atanasovsko, Pomorijsko, etc. Centre of the District is Varna city.
- **East Aegean River Basin District**. It is situated in the central, southeast part of Bulgaria, bordering with the West-Aegean River Basin District to the west, the Black Sea River basin district to the east and the Danube river basin district to the north. South border of the District is the National border with Turkey.

It covers a territory of 35 230 sq. km, about 32% of the Bulgarian territory, situated in 12 regional authorities. The territory covers from mountain to plain areas, covering parts of the Balkans mountain system, Podbalkan, Upper Thracian Plain, Sakar-Strandja and the Rilo-Rhodope Massif. Main rivers are Maritsa, Tundzha, Arda, Byala. All of them sourced from the Bulgarian territory, forming the Maritsa transboundary river basin that tribute to the Aegean Sea. There are situated complex water systems and dams as Belmeken, Dospat, Vucha; natural lakes as Gurlata, Kabilsko lake, protected zones as Ormana, etc. Centre of the District is Plovdiv city.

- West Aegean River Basin District. It is situated in the southwest part of Bulgaria, bordering with the East-Aegean River Basin District to the east and the Danube River Basin District to the north. Its southern and western borders are formed by the Bulgarian national borders with Republic of Greece, North Macedonia (FYROM) and Serbia. It covers the territory of 11 965 sq. km, about 11% of the Bulgarian territory, spread by 6 regional authorities. A huge part of the territory is situated in the mountain areas of Rila, Pirin, and Vitosha, where sources the most of District rivers. Main rivers are Struma, Mesta, and Dospat. A specific of the District is that covers transboundary rivers both to Greece (Struma, Mesta, and Dospat), Serbia (Dragovistica river) and North Macedonia (Strumeshica and Lebnica rivers). There are artificial reservoirs as Pchelina, Stijkovci; natural lakes as Dospat, Gorno Gabrensko ezero, Rilski ezera, and protected areas as Messta valley, Rupite-Strumeshica. Centre of the District is Blagoevgrad city.

Presented river basin districts are organized with regard to the Bulgarian natural drainage districts, described following in part *4.2. Bulgarian River Systems Regime. Extreme and Risk Events Characterization.* Described River basin districts are graphically presented in Fig. 13.4. (RBMP 2016).

As it was already presented there is a huge variety concerning the Bulgarian river systems. This is connected to the size of the catchment area, the geology, altitude, slope, geology, flow regime, etc. In many cases, there are outer anthropogenic impacts that can be associated with the water utilization—both to water withdrawal and consumption. Thus in many cases, natural conditions are widely affected and heavily modified. This once again brings the matter to the attention of river systems appropriately investigation that requires implementation of suitable and reliable methods and tools for their real conditions description. In help of the Bulgarian Academy of Sciences Institutes and other organizations provide investigations in the area, supporting all processes of water policy preparation, improvement and implementation.

The effective water management processes connected to river systems level implementation requires good knowledge and information of many tasks. It is needed to be familiar with the water quantity and quality issues, water utilization, ecosystems needs, and function. Moreover, all the presented tasks are interconnected. However, to be considered in the reliable way many specialized works must be implemented. This material is focused on the river systems quantification

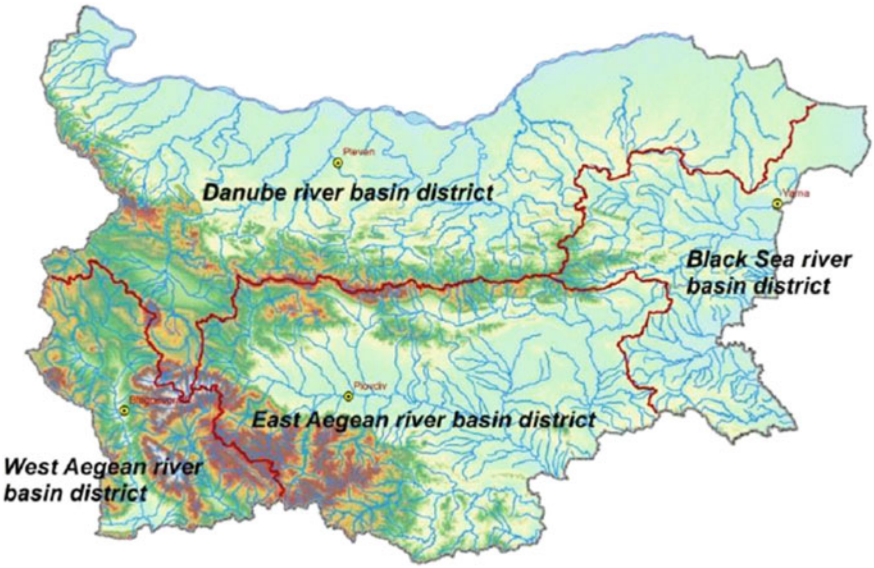

Fig. 13.4 Bulgarian River Basin Directorates (RBMP 2016)

specifics. This includes both the river regime and extreme and risk events occurrences, as both issues are interconnected. For this purpose, the main connected basis is briefly presented with regard to the EU and Bulgarian experience in the area.

13.4 Bulgarian River Systems Regime

River systems behavior closely depends on various factors as local climate and topography, ground cover, existing soil type and connected physical properties and state, available artificial structures, etc. Presented issues are basic drivers for the water (hydrological) cycle that logically explain all the connected events. Atmospheric waters move by air currents before falling in precipitation form as drizzle, rain, snow, sleet, hail, etc. to water surfaces or land, forming there surface and subsurface flows. Part of surface waters flows in the form of surface runoff forming streams and rivers moving towards the sea. Part of runoff is filtered close to the surface forming soil moisture or groundwater discharge or stores into lakes, reservoirs or wetlands. Some waters infiltrates deep into the ground, moving along flow paths of varying length before reaching areas of discharge or store freshwater in aquifers for long periods of time. Groundwater moves slowly in contrast to surface runoff. Thus a clear differentiation of both physical processes is needed for proper evaluation and investigation of their impacts especially in case of their proper quantitatively description and understanding. Part of the groundwater form springs. Over a time period, water flows to the sea. Simultaneously processes as evaporation, transpiration, and sublimation runs allowing processes as condensation and water storage into the atmosphere. The water cycle adequately explains such water movements, and connected as a consequence of different occurring events. But to become reliable impression of importance is to account connected local specifics.

Bulgarian river systems include more than 325 small and large rivers. Respectively to the small territory in Bulgaria rivers are with small watersheds. Connected to the local topography rivers network is dense, especially in the mountain areas, but most of the rivers are short—229 rivers are less than 50 km in length, compared to 96—of more than 50 km in length. Mean drainage density in Bulgaria is 1.18 km/km^2. In mountain areas (Rila, the Balkan Mountains, Osogovo) it is more than 2 km/km^2, thus in some areas of the Danube Plain it is less than 1 km/km^2. With regard to the local conditions, the Bulgarian rivers flow to two main drainage basins—the Black Sea and Aegean. 57% of Bulgarian rivers drain to the Black Sea, and respectively 43% drain to the Aegean basin. Both basins are separated by the Balkan Mountain that, moreover, a natural climate border plays the role of a main drainage divide. Only 12% of the Bulgarian rivers flow directly to the Black Sea. The other part of the Black Sea drained rivers (45%) join the Danube River that flows to the Black Sea. All other Bulgarian rivers drainage to the Aegean Basin, outer to the Bulgarian territory, thus all of them are transboundary rivers.

For Bulgarian river systems, key formation role play both climatic and landscape factors. Landscape factors play serious role for the river systems networks formation. The existing topography, ground cover and its physical properties and state, available artificial structures and water transfers also predetermine the structure of the rivers network. From the climatic factors most significant are the precipitations (in liquid and solid form), surface temperature and evaporation.

Bulgarian rivers recharge is formed by two main sources—precipitations and groundwaters. There are rivers with snow-rainfall recharge. Such are the up-stream mountain rivers as Rila, Pirin, Balkan Mountains. They are characterized with significant recharge from the snow melting during the spring, and connected spring floods, summer, and winter regime is characterized by low flows. Other rivers are with rainfall—snow recharge. Such rivers are situated in the lower mountains as Predbalkan Mountain, Sredna gora, etc. Their spring recharges from snowmelt is not so indicative, while, normally summer and winter low flows occur. Some rivers are with typical rainfall recharge. Such rivers are situated near the south Black sea coastline, south of Rodiopes, etc. Their regime is forming mainly by the rainfall. There are rivers with karst groundwater recharge. Such rivers are situated in Dobruja, as Panega, etc. There are also some intermittent rivers. Some of them are situated in south Bulgaria, Dobruja, etc. As an illustration, following on Fig. 13.5 are presented the hydrographs of some of the Bulgarian rivers. They visualize the rivers monthly regime (Chilikova-Lubomirova et al. 2016).

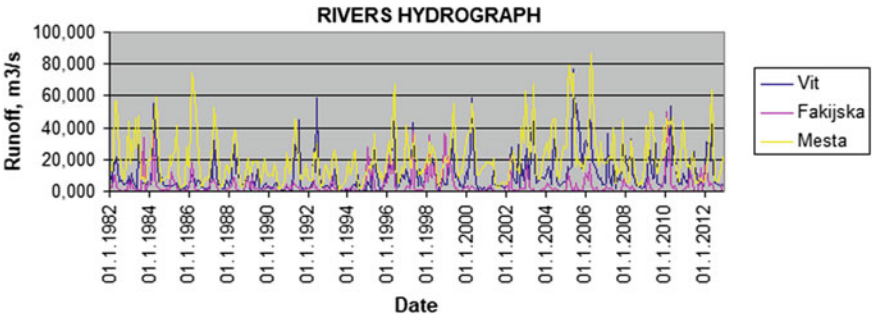

Fig. 13.5 Rivers hydrograph (Chilikova-Lubomirova et al. 2016)

13.5 Extreme and Risk Events

Along with the regular river regime, there are some unusual events, often accompanied with harmful impacts to the rivers and connected artificial structures and ecosystems. Such water events are floods and droughts. In many cases, their occurrences tend to significant exposure and vulnerability, and adverse impacts as a consequence. Thus usually they are classified as extreme or risk events with strong attitude to the disasters. Their occurrence is strongly connected to the natural performance, but can be a result of anthropogenic works, or to both impacts. Thus during the process of their investigation, both nature and man activities must be properly accounted. For importance is to observe alterations in the connected physical systems behaviour and to account for the connected outer impacts, including climate change influences. This is connected to surveying of associated hazards and exposures, considering occurring or expected extreme or risk events. Risks of natural disasters in a very general sense is a combination of hazard and vulnerability (UN/ISDR-10-2007). Its proper consideration account all of the risk elements as follow:

RISK = HAZARD * VULNERABILITY * EXPOSURE

where:

Risk or Disaster risk represents the potential disaster losses or the likelihood over a specified time period of severe alterations in the normal functioning of a community or a society. It is connected to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery.

Hazard is a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage;

Exposure—people, property, systems, or other elements present in hazard zones that are thereby subject to potential losses;

Vulnerability—the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard.

Such definition is punctual and comes to be clarified in the main water documents with regard to the main task connected to the risk managing and mitigation. This is well presented in the Flood Directive (2007) where: "flood risk" means "the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event".

In the context of drought (Blauhut and Stahl 2015), risk can be empirically estimated as the likelihood of impact occurrence. Drought risk is a combination of hazard and vulnerability, and managing risk requires understanding these two components and related factors in space and time (Chilikova-Lubomirova 2016).

13.5.1 Flood Events

Flood events are well defined in the Flood Risk directive (2007). There "flood" is characterized as "the temporary covering by water land not normally covered by water. This shall include floods from rivers, mountain torrents, Mediterranean ephemeral water courses, and floods from the sea in coastal areas, and may exclude floods from sewerage systems".

They are rapidly developed processes, in time of several minutes to several days, with the main cause of appearance—the abnormal amount of water. In most cases, the initial reason is connected to observed heavy precipitation or sudden snowmelt. Rivers connected structures operation or damages can also contribute to the flood occurrences. However, of importance are also the state of the river bed and channel, the river banks and floodplain with regard to connected aggradations or backwater effects. Aggradations are observed when the channel sediment volume is more than the flow can remove. In such cases sediment usually is deposit into the channel, making the existing river bed shallower, causing changes in the river channel gradient and decreasing flow velocities. Moreover, when reduced riverbanks are overtaken by the increase from floods discharges, overflow events can be observed even to slighter compared to the past conditions. Backwater effect occurs when the river flow meets obstructions that restrict its flow. Such effect can be observed in case of in-channel sediment deposits, river confluences, landslips of river banks, levees and dams, culverts, bridges, etc. In such cases river flow can break-through, creating a new channel or divert to an old one to bypass the deposited sediment.

When floods occur, it is distributed downstream as a wave. Observing it at a particular point, the water amount rises to a unique maximum (flood peak) over the overall normal flow (baseflow) and then recedes slowly. Such progress is presented in Fig. 13.6 (Chilikova-Lubomirova 2017).

In regards to the basic hydraulic principles, such flow can be considered as gradually varied unsteady flows, characterized by high temporal and spatial

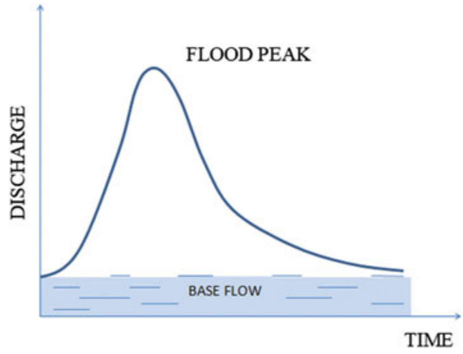

Fig. 13.6 Flood wave propagation at a certain point of the river (Chilikova-Lubomirova 2017)

variations. In the basis of all flow descriptive models stay the Navier-Stokes equations (Jeppeson 1974; Popesku 2014; Lamb 1994; Lisev et al. 2013).

$$\rho\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\mu\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)+\rho g_x$$

$$\rho\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\mu\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right)+\rho g_y \qquad (1)$$

$$\rho\left(\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)+\rho g_z$$

where u, v, w, are the velocity components in regards to the rectangular coordinates x, y, z and time t; p is the pressure, ρ represents the density and μ represents shear viscosity.

They represent the balance of momentum. However, to estimate the flow with regard to practical solutions, additional data and information are needed. This information can be gain by the continuity equation and boundary data introduction. Such solutions can be obtained with the help of numerical modeling and computer simulations with regard to the adopted assumptions and initial conditions. For this reason, the following approaches are used in practice (Jeppeson 1974; Popesku 2014; Lamb 1994; Lisev et al. 2013):

(a) the method of characteristics
(b) the finite difference methods and
(c) the finite elements methods.

They are used for floods propagation characterization.

Considering the flood occurrence at a given point of importance is to investigate the event overflow over a specific threshold and connected recurrence intervals and probabilities of occurrences (Marchinkov 1973; Wilson 1980; Shaw 1994; WMO No. 1044 2010, Holmes and Dinikola 2010; Zeleňáková et al. 2017). For the purpose floods are characterized by the probabilities of occurrences connected to

Table 13.3 Flood recurrence intervals and probabilities of occurrences (Chilikova-Lubomirova and Zaimes 2017)

Recurrence intervals and probabilities of occurrences			
Recurrence interval, in years	The probability of occurrence in any given year	Percent chance of occurrence in any given year	Annual exceedance percentage
100	1 in 100	1	1
50	1 in 50	2	0,50
25	1 in 25	4	0,25
10	1 in 10	10	0,10
5	1 in 5	20	0,05
2	1 in 2	50	0,02

the probability of the peak streamflow occurrence at a given location in any year. Connected thresholds are presented in Table 13.3.

Initial information for such studies are data obtained from the river gauging stations. In case of data absence for ungauged sites, regionalized streamflow statistics methods are used. Most commonly used methods are the:

(a) index-flood procedure,
(b) ordinary-least-squares regression procedure,
(c) weighted- and generalized-least-squares regression procedure and
(d) region-of-influence procedure.

Recently some methods using satellite images for floods events characterization are also developed. Of importance is to account that the flow at any particular point depends on local river bed and floodplain conditions with regard to the riverbed slope, floodplain shape, impoundments of streamflow, existing river regulation structures or reservoirs, water intakes and transfers, etc.

Flood events influence the associated river and floodplain conditions. Such influences can be positive, considering that the floodplain is watered and enrichment by the minerals from rivers sediments. However, they can also cause negative impacts, considering the severe outcomes and possible observed damages connected to the river segments and connected riparian zones, rivers and terrestrial ecosystems, existing artificial structures and economics. In some cases severe local areas and social disturbances are also observed; consequences as reduce agricultural production and damages connected to fences, farm buildings and houses, equipment and animals, roads, electricity, water supply and sewage infrastructure, communications, etc. Other related impacts can be connected to the evacuation of people and animals, people and animals victims, social disruption and financial costs. Their range closely depends on the severity of the flood. Thus the proper event characterization must account for them in the related assessment process.

In Bulgaria recently are observed floods with various consequences (Chilikova-Lubomirova 2017). Some are connected to extremely heavy precipitations that seriously impact on the existing infrastructure; others are as a result of the precipitations impacts on the existing infrastructure. For illustrative purposes following are presented some of the observed events.

Such event occurs in the Batulijska river watershed and connected areas in 2014, presented in Fig. 13.7.

Batulijska river average flow near Batulija village is 2,7 m^3/s. As a result of a heavy rainfall, its streamflow significantly increases in several hours. In some places, the water level raised up to 1 m. Large areas were flooded including river banks, streets, houses, a whole section of villages. Some infrastructure was destroyed such as roads, bridges, electric infrastructure while water supply was interrupted. On August 1st 2014 a state of natural disaster was declared in the area for the villages: Vlado Trichkov, Lukovo, Rebrovo, Batulija, Bakjovo, Ogoja, Jablanitza, Bukovetz, Tompsan, Redina and Leskov dol. Some of the connected consequences are presented in Fig. 13.8 (Chilikova-Lubomirova 2017).

Common consequences were observed after the severe flood damaging Varna area, Eastern Bulgaria, near the Black Sea, June 2014—illustrated in Fig. 13.9.

In Belosem village area, situated in Southern Bulgaria, Upper Thracian Plain, Sept. 2015 such events also occur—Fig. 13.10.

Floods caused by artificial structures disturbance as a result of heavy precipitations were observed in the Tzar Kalojan village area, Aug 2007 (Danube Plain); Biser village area, Feb 2012 (Southern Bulgaria), etc. Both floods were caused by caused by closely situated dams disturbance. As a result in the first case more than

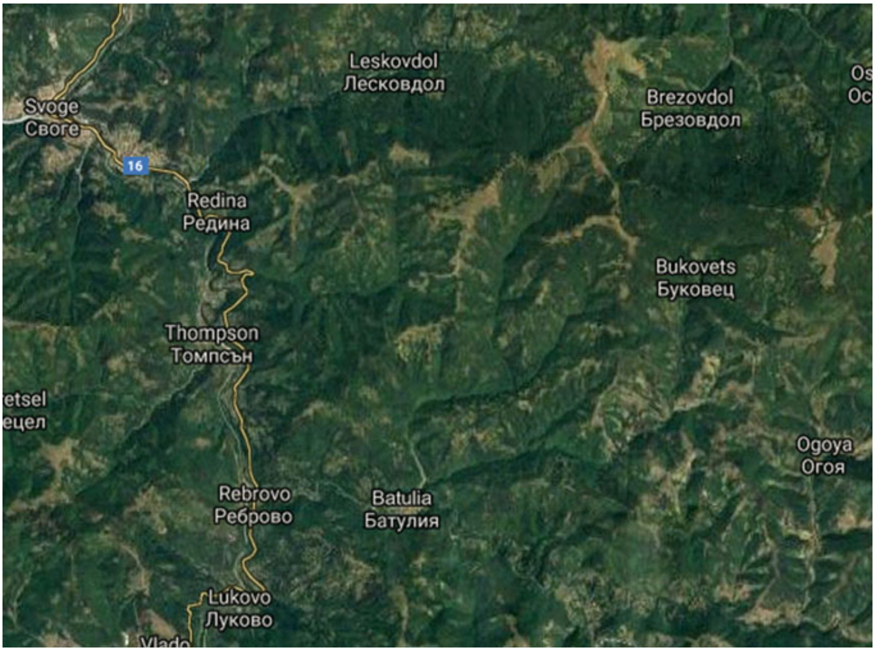

Fig. 13.7 Batulijska River Location, Western Bulgaria, *Source* Google Map

Fig. 13.8 Floods damages **a** Leskovska river, **b** Batulijska River area (Chilikova-Lubomirova et al. 2017)

Fig. 13.9 Flood event in Varna area: **a** flood propagation, **b** flood consequences (Chilikova-Lubomirova et al. 2017)

1000 properties were affected, 21% of the properties significantly endangered or collapsed, about 70% of infrastructure collapse and eight humans lost their life. The second flood also caused significant damages, ten people lost their life. Some of damages are illustrated in Fig. 13.11 (Chilikova-Lubomirova 2017).

The last presented floods can not be identified as extreme events, but the main reason for their occurrence can be accepted as a result of extreme events.

Fig. 13.10 Flood in Belozem, Southern Bulgaria, Sept 2015 (Chilikova-Lubomirova et al. 2017)

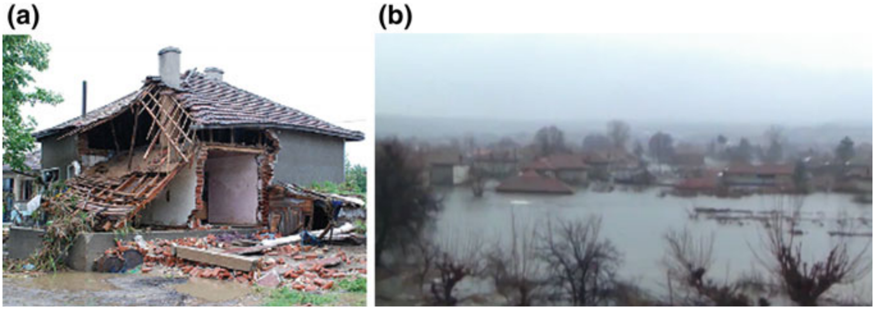

Fig. 13.11 Floods resulting of artificial structures damages: **a** Tzar Kalojan village, Aug 2007, **b** Biser village, Feb 2012; (Chilikova-Lubomirova et al. 2017)

To mitigate such events with regard to the WFD (2000) and Floods directive (2007), following the preliminary flood risk assessments, the European Member States are required to prepare floods hazard and risk maps and Flood Risk Management Plans (FRMPs). For this purpose, all the four River Basin Directorates in Bulgaria also produced Flood Risk Management Plans, 2016–2021 (FRMP-DRBD 2016; FRMP-EARBD 2016; FRMP-WARBS 2016; FRMP-BSRBD 2016). They consider various aspects of water management including connected preventive, protective and preparedness works in six years period. For this purpose, various aspects of past flood events and areas with significant flood risk were considered. Such plans outline the main frame for future investments in the area for mitigation, preventive and preparedness works on a National level. In help, additional investigations are also conducted. They are connected to the possibility of additional measures providing (Chilikova-Lubomirova and Zaimes 2017; Zeleňáková et al. 2017; Ganová et al. 2017).

13.5.2 Droughts

Drought is a natural phenomenon that is characterized as "a temporary decrease of the average water availability due to e.g. rainfall deficiency. (http://ec.europa.eu/environment/water/quantity/about.htm)". It is a complex process connected both to meteorological, soil moisture and hydrological aspects of the water cycle, all observed as extreme events. With this regard usually following aspects or drought types are considered (Beran and Rodier 1985; COM 673 Final 2012; Merida et al. 2014; Chilikova-Lubomirova 2016):

- Meteorological or atmospheric drought, characterized as a prolonged period of precipitation deficiency, leading to hydrological imbalance or lower snowcaps, going along with high temperatures, high winds, low relative air humidity, increasing sunshine, low clouds cover, etc., causing serious effect on soil moisture and surface and subsurface waters.
- Agricultural or soil moisture drought, associated within periods with soil water deficiencies, causing plant water stress, reduced biomass and yield, and decreased recharge to surface and subsurface waters.
- Hydrological drought, considered as the abnormally low amount of water, affecting surface and subsurface water. It is associated with reduced streamflow, inflow to reservoirs, lakes, and ponds; reduced wetlands, and impacts on wildlife habitats.

As a consequence in many cases further stress to different sectors, the society and ecosystems are also observed. For this purpose, the problem is well considered by different practices, including water and climate change issues. The Intergovernmental Panel on Climate Change (IPCC) is focused on it as one of the recent challenges connected to observed extremes with impact on crop yields, general ecosystem functioning, water resources, and electricity production. The Water Framework Directive (2000) as main authoritative water addressed prescription of the EC and connected documents as: COM 673 Final 2012; Guidance document N24 2009 are also focused on it.

To clarify the problem with regard to river systems, various investigations were provided in time. And contrary to floods, which are simpler to be measured and quantified, droughts very often seem to retain qualitative connotations. In the past usually low flow were addressed to the problem. But accounting that low flow can represent a casual state of the river flow, to investigate the problem new approaches emerge. The basis was introduced stressing that there is a significant difference between streamflow drought and low flow: Low flow represents the lowest sustaining flow during base streamflow conditions. It is connected to the physical development of flow and represents the regime of a stream. It is connected to the average annual cycle of the streamflow, and the terms 'low flow period' and 'high flow period' are used to describe the normal annual fluctuations of streamflow linked to the annual cycle of the regional climate. For example in the Continental climate zone (representative for Bulgarian conditions) the regime of a stream can show one or more low flow and high flow periods during a year. Contrary the streamflow drought is more general phenomenon. It is addressed to prolonged untypical period, described by characteristics as duration, time of occurrence, starting and ending date, severity and minimum flow, when looking at the series in a specified period of time. Thus the particular low flow is a particular characteristic of drought, but not necessarily represents a drought. This very fine distinction between the two processes in many cases hampers both processes differentiation and properly investigation. In help of the practice various investigations recently were provided. One of the outputs was the drought indexes evaluation. For the streamflow drought investigation such opportunity provides implementation of the Standardized Runoff Index—SRI (Shukla and Wood 2008; Chilikova-Lubomirova 2013; Merida et al. 2014). It is a standardized evaluation of flow allowing accounting and grading its abnormal state. It is common to the Standardized Precipitation Index—SPI (McKee et al. 1993; Guttman 1999) and has common ground but in the process of evaluation the streamflow specifics are used for the index calculation. Evaluation scale proposed by the Expert Group on Water Scarcity & Drought, EC is:

(a) $-0.84 \geq SRI \geq -1.28$ corresponds to moderate drought;
(b) $-1.28 \geq SRI \geq -1.65$ corresponds to severe drought;
(c) $SRI < -1.65$ corresponds to extreme drought.

On this base, and on a monthly basis, some drought investigations were provided for some main Bulgarian rivers (Chilikova-Lubomirova et al. 2013, 2016). Rivers were selected with regard to investigate the possibility of streamflow drought occurrences diagnostics on the Bulgarian territory. For the purpose in the material are presented investigations connected to three different rivers, two of them: the Ogosta and Iskar Rivers are situated in neighboring watersheds in the Nort West Danube floodplain, and the third one—the Ropotamo River is situated near to the Black Sea. Investigations were provided with direct monitoring discharge data from the following monitoring points: Ogosta River—HMS 16850, Iskar River—HMS 18850, Ropotamo River—HMS 83620. Selected investigations present the drought diagnostics results for 2013 that can clarify the behaviour of rivers with different hydrological and hydro-morphological regime, flowing through different geographical, topological, climate, etc. conditions. The investigation results are presented in Table 13.4 and illustrated on Fig. 13.12.

Obtained results show that during the year streamflow drought was observed on the Bulgarian territory. For Ropotamo River moderate streamflow drought was identified for the months August and September. For Iskar River drought was identified as follow: severe drought—during months August and September and moderate drought—during the months from October to December. On the neighboring to the Iskar River, Ogosta River existence of a streamflow drought was not observed. Presented results can be interpreted as drought diagnostics results. They show that although Ogosta and Iskar rivers are rivers flowing in neighborhood watersheds, characterized by some common climate and meteorological, in some

Table 13.4 SRI-1 values for the Rivers Ogosta, Iskar and Roporamo (Chilikova-Lubomirova et al. 2016)

SRI-1	Ogosta	Iskar	Ropotamo
	HMS 16850	HMS 18850	HMS 83620
January 2013	–0,451	–0,697	0,029
February 2013	–0,461	–0,562	0,837
March 2013	0,197	–0,086	0,639
April 2013	2,075	0,582	0,682
May 2013	0,463	–0,706	–0,075
June 2013	0,147	–0,752	–0,306
July 2013	–0,010	–0,251	–0,597
August 2013	–0,334	–1,312	–0,841
September 2013	–0,445	–1,455	–0,863
October 2013	–0,382	–1,111	–0,527
November 2013	–0,434	–1,170	–0,596
December 2013	–0,397	–1,142	–0,793

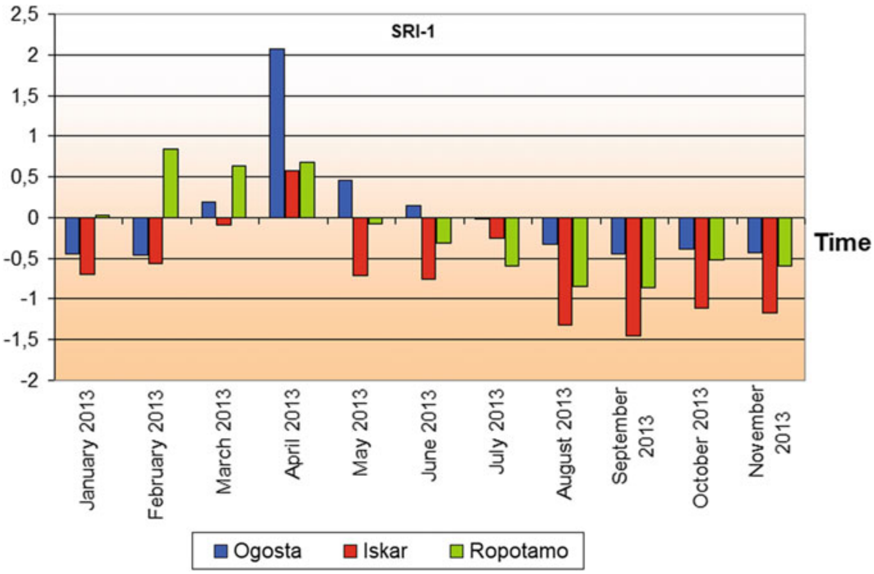

Fig. 13.12 Monthly diagram of SRI-1 values for Ogosta, Iskar and Ropotamo rivers (Chilikova-Lubomirova et al. 2016)

cases conditions, they do not represent common drought behaviour. At the same time Ropotamo River, which flows in particularly different climate, meteorological and topographic conditions, with no connection to the previously presented rivers

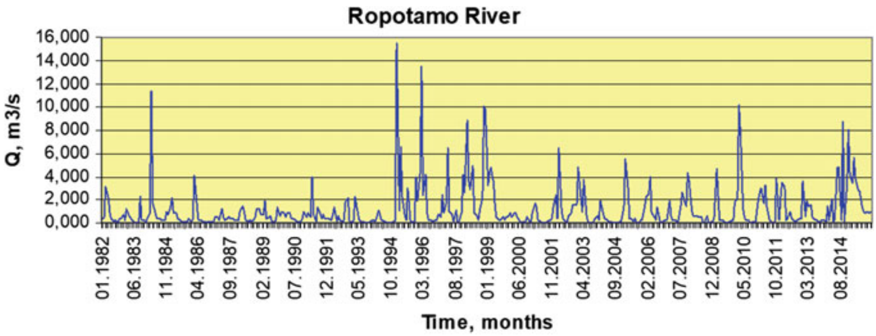

Fig. 13.13 Ropotamo River, HMS 83620 (Chilikova-Lubomirova et al. 2016)

and their watersheds, drought events was also observed and occur. This once again confirms the spatial heterogeneity of the drought processes.

To clarify the drought process, some additional investigations connected to Ropotamo River were also provided. They aimed to investigate the River behaviour in time. For the purpose connected streamflow for the period of 1982–2015 was investigated. Its hydrograph is presented in Fig. 13.13 (Chilikova-Lubomirova et al. 2016).

Connected drought investigations were also provided by the implementation of the Standardized Runoff Index. Estimated SRI-1 values for the observed period are illustrated in Fig. 13.14 (Chilikova-Lubomirova et al. 2016).

Investigations show that during the period 1982–2015 there were observed cases with moderate, severe and extreme droughts. Such events generally occur during the summer time, in parallel with the low flow periods. Results show that there were observed some extreme droughts in 2009 and 2008, complemented by severe drought events that follow the drought genesis logics and connected recharge issues. Most significant detected drought periods cover 1982–1983, 1993–1994, 1997, 2001–2011. During the last pointed period, there were detected severe and moderate drought events that last in most cases from June to November. As most vulnerable can be specified August and September, but in some cases, July and October are also vulnerable to severe impacts. Investigations for the recent time periods confirm droughts occurrences during the August and September period. Results are presented in Fig. 13.15 (Chilikova-Lubomirova et al. 2016).

Presented approach was provided and can be implemented in future with regard to the WFD requirements for negative impacts mitigation instruments implementation, connected both to:

- general basin characterization under drought conditions;
- the river basin's experience on historical droughts;
- characterization of droughts within the basin;

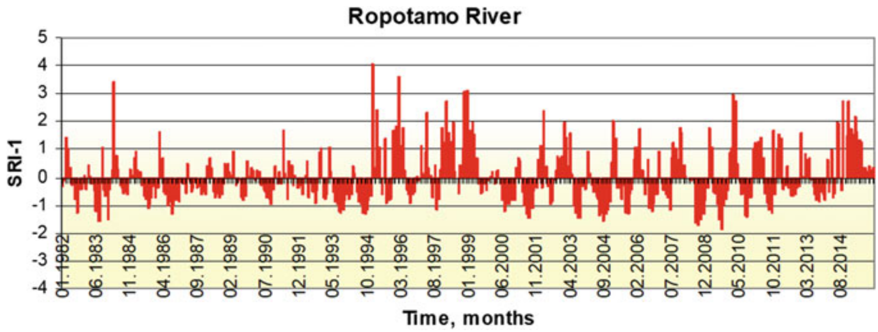

Fig. 13.14 SRI-1 Ropotamo River, HMS 83620 (Chilikova-Lubomirova et al. 2016)

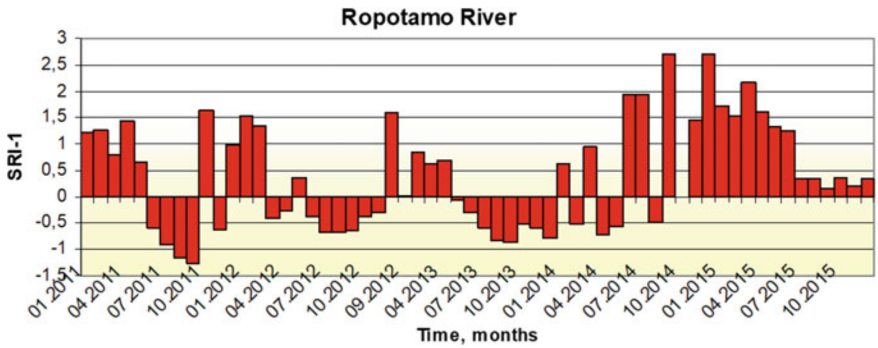

Fig. 13.15 SRI-1 diagram for Ropotamo River, HMS 83620, 2011–2015 (Chilikova-Lubomirova et al. 2016)

- drought warning system implementation;
- program of measures for preventing and mitigating droughts linked to indicators systems.

Such investigations are important also considering the significant influences on the ecosystems. Drought, and low flows, in particular, associated to the very limited and scarce waters in rivers for sure impact on the aquatic and connected terrestrial organisms. For this purpose in Bulgaria, additional measures connected to their normal function are provided. They are connected to minimum permissible flow in rivers providing. This is regulated by the Bulgarian Water law (2015): For protection of aquatic ecosystems and wetlands, there shall be determined "a minimum permissible streamflow into the rivers"—Article 117 (1). With regard to §125 at the current stage, the minimum permissible streamflow in rivers shall be set at 10 percent of the mean multiannual run-off, but not less than the minimum average monthly water quantity with a 95 percent availability at the point of each facility for regulation of the streamflow or for water abstraction.

13.6 Conclusion and Recommendations

Bulgaria is a country with a dense river systems network, resulting of the topological specifics of the territory. It is influenced both by the Atlantic Ocean and Mediterranean Sea atmospheric circulation influences. As a result, five climate zones with Continental, Transitional, Continental-Mediterranean, Black Sea and Alpine climate specifics are formed. Such specifics directly impact the river systems hydrological regime and as result, rivers are characterized with periods of spring floods and summer and winter low flows, formed with regard to the precipitations and groundwater recharge.

As an European Community Member State Bulgaria accept and strictly implement in practice the EC legislation and connected practices. In help, main tools as River Basin Management Plans (RBMPs) and Flood Risk Management Plans (FRMPs) are elaborated. They account for the National and local specifics and the importance of regime and extreme events investigations. In help of the activity, various additional examinations are provided. For clarification purposes in the material briefly are presented main connected issues with regard to the Bulgarian topological, climate and hydrologic specifics. To better understand main considerations about the extreme events main analysis approaches are briefly presented. The main point is a description of water-related extremes: floods and droughts. For the purpose aspects connected to their theoretical base is briefly presented. And connected observed and investigated cases are also shown. Some floods and drought cases specification for the Bulgarian territory is used as an illustration. Briefly, the results of the connected analysis are also presented.

From the considered cases it can be concluded that on the Bulgarian territory both floods and drought events occur. They are irregularly distributed in space and time, showing various grades and emerging significant impacts in many cases. In recent years there were observed floods with very severe outcomes—some of them connected to significant damages concerning affected areas, households, infrastructure and economics, social and life lost. Considering the regime of the particular river their occurrences is not connected to the typical high flow conditions and can be connected to the particular weather events as it was presented with the selected for the illustration cases. Drought events were also observed. Their examination was provided to three Bulgarian rivers: the neighbour Watershed Rivers Iskar and Ogosta, and Ropotamo River that is situated in totally different from first two geographical, climatic and topological conditions. Presented results show the presence of drought events that are irregularly spread in time and space. Making a parallel between the observed rivers results it was proved that there is no connection between the observed drought events. To clarify the drought nature performance the results of additional time series investigation connected to the historic Ropotamo River streamflow droughts are also briefly presented. The result show that in many cases drought occurrences was observed during the low flow periods with a grade from moderate to extreme drought. Information about the most significant for the river drought periods is also presented.

All the material proved that extremes of appearance could be connected both to the particular climate and weather events, the existing topographic conditions and anthropogenic impacts. Of importance is to remark that the particular river bed conditions and connected watershed territory, land covering specifics, etc. also play a greater role. All this is connected to the related ecosystems that in case of extremes are of significant risk. To mitigate such outcomes various legislative and practical measures are implemented in practice. One of them is providing of specific water management measures, including ecosystems protection, briefly presented within the Bulgarian site. Another is initiation and performance of additional activities, based on the particular river basins studies and characterization. This course of interconnected implementation of legislative, theoretical and practical developments is the only way to guarantee best results are obtaining.

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Part VII
Water Resource Management in North Macedonia

Chapter 14
Water Resources Management in Republic of North Macedonia

Ivan Radevski, Svemir Gorin and Vladimir Zlatanoski

Abstract There are significant water resources in the country but unequally distributed. According to the precipitation regime, the western part is 5 times richer in precipitation than the central part of the country. All of the 10 largest water springs are located in the western part of the country, spring area of river Vardar and river Crni Drim basin. The eastern part is much dryer, poor in spring waters and predominantly depends from the accumulated water in the dams. The most significant surface water resource is two lakes in the country Ohrid Lake (50.7 km^3) and Prespa Lake (4.75 km^3). The more organized managing of water resources started in the post war period in the 20th century with establishing Water Management Authority. With this public body largest irrigation systems were created in 50ies and more than 300 dams were built to keep the water obtained in the wet period and use it in the dry period of the year, mainly used for water supply of population, industry and agriculture. Today main managing body for country water resources is Ministry of Agriculture Forestry and Water Management. Recently there is high demand for improvement of capacity, financials and human resources in this public body for better water management.

Keywords Anthropic impact · Irrigation · Reservoir Vulnerability · Water quality

14.1 Introduction and Water Resources in the Country

The Republic of North Macedonia is country located in the central part of the Balkan Peninsula with a total area of 25713 km^2. The relief is predominantly hilly-mountainous, with the parallel distribution of basins and mountains with an altitude range of 2764 m amsl (Korab Mountain) to Gevgelija basin (54 m amsl.). The elevation altitude is 2710 m. The highest mountains are located in the western

I. Radevski (✉) · S. Gorin · V. Zlatanoski
Institute of Geography, Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Skopje, North Macedonia
e-mail: radevskiivan3@gmail.com

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part, while the lowest is a central part of the country, composed by fluvial relief forms made by river Vardar and its main tributaries Treska, Crna Reka, Pchinja and Bregalnica (see Fig. 14.1).

This landscape results with very complex climate conditions with variations from basin to basin. The wealthiest part of the country with precipitation are mountain ridges across the border with Albania. Jablanica Mountain, Korab, Deshat, Krchin and Shar Mountain and whole catchment of Radika River has precipitation higher than 1200 mm, with a maximum on Jablanica and Korab Mountain above 1400 mm per year. Transported by the west wind, wet air masses are weaker from mountain to mountain with decreasing of annual precipitation going east far, so the Tikvesh basin in the central part of the country is driest with annual precipitation sum of 370 mm. Going eastward, the precipitation is increasing because of the higher elevation (Kozjak, Osogovo, Maleshevo and Belasica Mountain), with maximum average annual precipitation of 950 mm.

These precipitation conditions feature different river regime conditions. In rivers with the natural regime, there are two main types of stream regimes, moderate Mediterranean and continental. The larger area of the country is covered with continental river regime with floods registered in autumn and spring, but also in the south-eastern part of the country, there are several small streams with typical

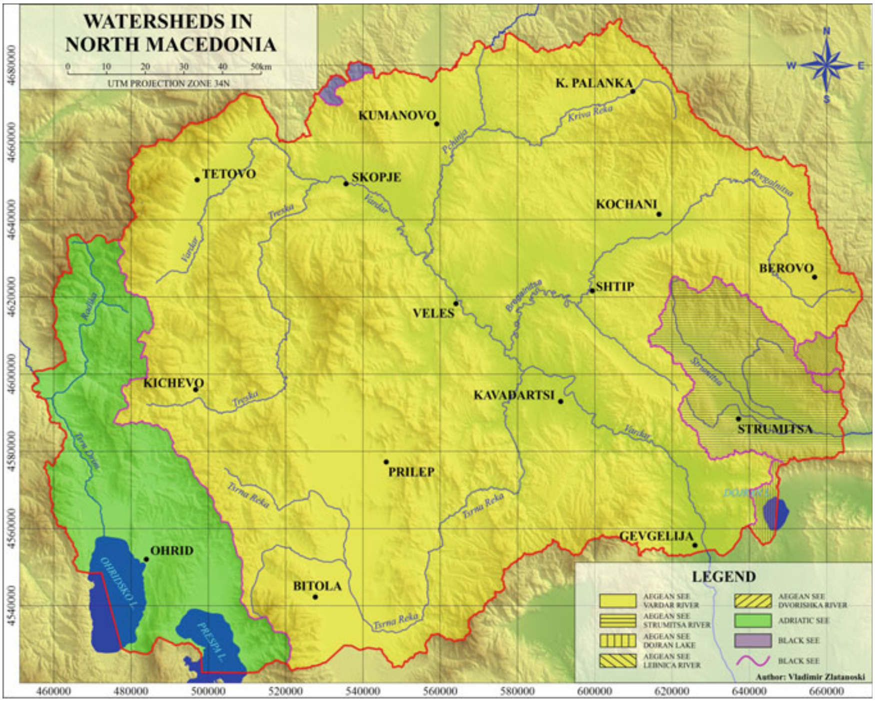

Fig. 14.1 Country main basins *Source* NASA 2011

Mediterranean river regime (floods in winter and dry riverbed in summer). In general, in both river regimes, there is a long summer period poor in precipitation, and most of the streams are periodical. The water is gone where is necessary for water supply of population, industry, hydro power plants and agricultural supply.

Underground waters (aquifers) in the country are located predominantly below the bottoms of the basins on different depth, depending on the type of aquifer. The infiltration process is the main factor for underground water accumulations, very significant for water supply in the country and obtaining wet soils in the alluvial plains and directly connected with river regimes. Because of the mountainous relief, there is water circulation from the upper mountains water and accumulation in the alluvial aquifers. In the nearby terrains on larger streams in the country (Vardar, Crna River, Bregalnica etc.) there are rich aquifers in the whole year, obtaining enough water supply thru sewer systems for the smaller towns in the country (Berovo, Delchevo, Negotino and Gevgelija) in the second half of 20th century.

The phreatic wells are spatially distributed in all plains, but they are located on different depths (from 3–20 m). The artesian wells are located in the almost all plains (except Kocanska and Debar Basin) much deeper located on the depths of 50 m to the 450 m in Strumica Basin. The most common depth of the artesian waters is 60–80 m. The richest basins with artesian aquifers are Pelagonija and Strumica Basin.

The springs in the country have a different regime and flow, depending mainly from hydrogeological conditions (a type of the rocks). The Karst Mountains in the western part (Galichica, Bistra, Suva Gora, Luben, Zheden, parts of Jakupica, Stogovo and Jablanica are significant alimented areas for largest karst springs in the country. The aquifers in the eastern part are predominantly made by magmatic and metamorphic rocks with fractured porosity with larger dry areas without any spring features. It results with features of smaller springs below 5 l/s.

The total flow from the whole 1100 springs in the country published in Cadastre of Springs (1968) was 23 m3/s. The main problem for the majority of the springs is their variability, so those are predominantly periodic, which decreases its chances for water supply usage, especially in the eastern part of the country. Ss. Naum spring is the largest in the country with average discharge 8 m3/s, with a maximum flow of 11 m3/s with more than 1/3 from the total discharge of all spring water in the country. The main water is coming from Galichica Mountain and sinking holes in the Zavir Bay (Albania) in Prespa Lake, which is concentrating relative large amount of water in one karst spring which is main surplus in the Ohrid Lake. The second largest spring area is 5 karst springs of Crna River with the total amount of 5 m3/s, located below the Luben Mountain. The largest is called Crna Dupka with a maximum flow of 2.5 m3/s. The third is spring Rasche with average flow 4–4.5 m3/s, which is the most constant karst spring, located on the west from the capital city of Skopje. This spring is the main water supply source for Skopje, a city with 560,000 inhabitants (2002). Next larger karst spring is Vrutok is the main for the river Vardar, located below the Shar Mountain, west far from the town of Gostivar. Its outflow is 1.5 m3/s. It is exciting phenomena that those springs have water inflow from Shar Mountain, but also from several sink holes on Bistra Mountain, which topographically belongs to Adriatic Basin, River Radika which is a right tributary of Crni Drim (Gashevski 1972). Other significant karst springs are Studenchica (Bistra Mountain) with 0.7 m3/s (Radevski et al 2018), Izvor (Stogovo Mt.—eastern part) with 1 m3/s, Babuna Spring on Jakupica Mountain is the largest high mountain spring in the country, with an average flow of 1.5 m3/s. Also, it is the unique large karst spring located in the central part of North Macedonia (Middle Povardarie Region).

The surface waters in the country are distributed in generally in dendritic stream network, because of predominantly fluvial and denudation processes. The river basin is separated between Aegean basin, Adriatic basin and Black Sea basin (very small area on Skopska Crna Gora Mountain). Anyway, it is rare to exist parts of three different basins on such a small territory of 25713 km2.

The largest basin is Aegean, divided between river Vardar catchment with 20525 km^2 and two right tributaries of Struma River (Strumica River catchment with 1535 km^2 and Lebnica River catchment with 129 km^2 in the eastern part of the country). The total area of Aegean basin in the Republic of North Macedonia is 22189 km^2. The main river Vardar has a spring called Vrutok, located in the Upper Polog Plain, near the town of Gostivar, on the altitude of 683.5 m (Gashevski 1972). The total length of the river in the country is 301 km. This river is flowing thru 5 plains and 4 gauges. First is the Polog Plain, than Derven Gauge, Skopje Plain, Taor Gauge, Veles Plain, Veles Gauge, Tikvesh Plain, most famous in the country—Demir Kapija Gauge and Gevegelija-Valandovo Plain. The valley of the river Vardar is composite, with successive changes between plains and gauges.

The river Lepenec is the first larger tributary of river Vardar. Its spring area is located on North foothills of Shar Mountain in Kosovo. The second half of the stream after flowing thru Kacanik Gorge is in North Macedonia, passing thru north part of Skopje Plain between Shar Mountain on the west and Skopska Crna Gora on the east. The total length of the stream is 75 km and a basin area of 770 km^2. The average discharge at the confluence is 10 m^3/s.

Pchinja River is second larger left Vardar's tributary with spring area is located in Serbia, on Mountain Dukat on 1664 m. In North Macedonia, the stream is streaming near to famous Prohor Pchinjski Monastery and then streaming thru Kumanovo Plain and Baderska Gauge streams in river Vardar. The total surface of the basin is 2840 km^2 and average length slope 11‰. Average streamflow of Pchinja is 16 m^3/s.

Bregalnica River is the largest left tributary of River Vardar. Its spring is located east far on Bulgarian border near the town of Berovo, and below Cengino Kale cote (1720 m). The valley of the river is also composite with several gauges and Kocani-Shtip and finally the confluence point in Tikvesh Valley. The stream length is 225 km and a total basin area of 4307 km^2. The average value of streamflow at the confluence point is 28 m^3/s. The larger two right tributaries are Treska and Crna Reka. These rivers are streaming to the area rich in water especially in their spring area, with the average multiannual amount of precipitation larger than 900 mm.

The river Treska has its karst spring Izvor with 1 m^3/s below Stogovo Mountain, streaming thru Kicevo Plain enters in Porece Basin, changing course to the north and adding waters from short streams but rich in water from karst spring water (Pitran, Beleshnica etc.). Before entering in Skopje Plain, there are three successive dams: Kozjak, St. Petka and Matka Dam, managed by ELEM (Electricity management system of the Republic of North Macedonia). The last dam is made on one of the most imposing canyon—Matka Canyon. The confluence point (261 m amsl) is located in Skopje Plain, near Saraj Village with average streamflow of 30 m^3/s. The total catchment area is 2068 km^2.

Crna Reka's spring is located in Demir Hisar region, highly karstified area below the Luben Mountain. There're 5 larger karst streams (the larger Crna Dupka in Zheleznec Village is main spring of Crna Reka) are successive feature downstream of Cersko Pole. Near the village of Buchim, the stream is entering in largest country Pelagonija Plain, to the village of Skochivir, where the Skochivir Gauge starts (80 km length). The confluence point in river Vardar is located in Tikvesh Valley. The average annual streamflow is 37 m^3/s. The total length of the stream is 207 km, the catchment area is 5890 km^2 (5130 km^2 in the country) (Table 14.1).

The second largest basin is Adriatic, which is the whole spring area of river Crni Drim (two largest lakes Ohrid and Prespa and also Radika catchment with a total area of 3350 km^2. It is interesting the underground connection between two largest lakes below the Galichica Mountain. The locality called "Zavir" on Albanian coast area is a place where the water is sinking, and it features on the Ohrid Lake coastal area near Ss. Naum and Tushemishte Spring in Albania (Table 14.2).

The smallest is Black Sea basin with spring area of river Binacka Morava called Tanushevska River, small stream with 44 km2, located north far on Skopska Crna Gora Mountain. The total drainage length is 7637 km, and drainage density is 0.30 km/km2. Drainage density in Vardar, Crn Drim and Strumica River Basin are almost identical. Minor deviations are noticeable in drainage density comparison between water management divisions (Table 14.3, Fig. 14.2). The largest drainage density is in water management division Gorna Bregalnica while null drainage density is in Dojran water management division, where is no surface hydrography (Public Gazette of Republic of North Macedonia 2008), except several periodical creeks.

From the basic river characteristics, there are three outflow points in the country. The largest outflow point is river Vardar near Gevegelija with the average multi-annual flow of 145 m^3/s. The second largest is river Crni Drim, located west far in

Table 14.1 Main country basins with the area (km^2)

Catchment name	Surface
Total area	**25713**
Vardar	20535
Crni Drim	3350
Strumica	1535
Dojran Lake	120
Lebnichka	129
Binachka Morava	44

Source Water Strategy for Republic of North Macedonia

Table 14.2 Characteristics of main rivers in the Republic of North Macedonia (Public Gazette of Republic of North Macedonia 2008; Water Strategy for Republic of North Macedonia 2009)

River	River basin	Gauge	Catchment area km^2	River length km	Average annual flow m^3/s
Vardar	Vardar	Gevgelija	20661	301	145
Treska	Vardar	Saraj	2068	139	24.2
Lepenac	Vardar	Lepenec	770	75	8.7
Pcinja	Vardar	Katlanovo	2841	137	12.6
Bregalnica	Vardar	Shtip	4344	..	12.2
Crna Reka	Vardar	Rasimbegov M	4985	228	29.3
Bosava	Vardar	Boshava	468	52	23.4
Crn Drim	Crn Drim	Shpilje	3359	45	52.0
Radika	Crn Drim	Boshkov Most	*	*	19.3
Strumica	Strumica	Novo Selo	1649	*	4.2
Binachka Morava	Binachka Morava	/	44	*	*

*determined by Ivan Radevski and Svemir Gorin

the Debar Plain and the third is river Strumica in the southeast part of the Republic of North Macedonia with average streamflow of 4.2 m^3/s.

14.2 Water Management Structure

The Water management structure became importantly issue in the second half of the 20th century. The main management body in the North Macedonia was Water Management Authority, with a serious amount of finances and employment staff. This body had centres in all larger cities according to the catchment division (Table 14.4).

Water division regions are determined according to the North Macedonian Water Strategy, divided into 16 different areas. The most of the divisions (12) depends in Aegean Basin, which means river Vardar with its largest tributary basins (Treska, Lepenec, Bregalnica, Crna, Boshava and Anska River basin), and river Struma basin, with its main tributary in North Macedonia, Strumica River. The smaller area and 4 divisions belong to Adriatic basin (two large lakes, Ohrid and Prespa, Radika and Crni Drim basin) (Table 14.5).

14.3 Accumulated Water

Besides the natural lakes, in the country, it is necessary to have dams for accumulating the water for the dry summer period when there it is in high demand. In the country, there are 318 big, small and micro accumulations. The relief is mainly suitable for the building of this dams (predominantly 80% hilly mountainous).

Table 14.3 Hydrographic stream characteristics of river Vardar and its main tributaries

River		Spring alt. (m)	Confluence alt. (m)	Length (km)	Watershed length (km)	Average slope (‰)	Catchment area (km^2)	Average altitude (m)	Average flow (m^3/s)
1	Vardar	683	44	301	1450	2.1	22475	793	174
2	Treska	740	261	130	293	3.7	2068	1010	30
3	Lepenec	1860	253	75	160	21.4	770	955	10
4	Pchinja	1664	191	135	324	10.9	2840	738	16
5	Bregalnica	1720	137	225	338	7	4307	722	28
6	Crna River	760	129	207	379	3	5890	863	37

Source Water Strategy for Republic of North Macedonia

Fig. 14.2 Tectonic, glacial and artificial lakes in the Republic of North Macedonia *Source* NASA 2011

Artificial reservoirs in the Republic of North Macedonia started to be built from 1938 when the first accumulation of Matka, west of Skopje, was built before the inflow of the river Treska into the river Vardar. This process of building artificial reservoirs lasts until today, following the trend of man's needs for managing water resources as the main foundation for development. Meanwhile, the accumulation lakes began to require a more diversified perspective: tourism, the supply of drinking water and water for industrial use, fish farming, irrigation, etc. (Mihu-Pientele et al. 2014; Romanescu 2014; Romanescu and Stoleriu 2013, 2014; Romanescu et al. 2011). The building of artificial reservoirs in the world, and especially in the Republic of North Macedonia, is closely related to three basic conditions: necessary, natural opportunities and economic justification (Gjuzelkovski 1997). Today in Republic of North Macedonia there are 318 accumulations, of which 206 are built for their functional purpose (water supply, irrigation, exploitation of hydroelectric potential, fishing, etc.), and 112 are caused by various human activities in nature (exploitation of natural resources, such as sand and ore) (Dimitrovska et al. 2012).

Table 14.4 Water management divisions in North Macedonia according to Water Strategy for Republic of North Macedonia (Public Gazette of Republic of North Macedonia 2008)

No	Water management division	River Basin	River basin district	Area km^2	%
1	Polog-Debarsko	Crni Drim	Adriatic	265.26	1.03
2	Debarsko	Crni Drim	Adriatic	775.67	3.02
3	Ohrid-Struga	Crni Drim	Adriatic	1489.44	5.79
4	Prespa	Crni Drim	Adriatic	765.31	2.98
5	Polog	Vardar	Aegean	1443.99	5.62
6	Treska	Vardar	Aegean	2028.65	7.89
7	Pelagonija	Vardar	Aegean	3068.29	11.93
8	Skopsko	Vardar	Aegean	1605.11	6.24
9	Sreden Vardar	Vardar	Aegean	2624.75	10.21
10	Sredna and Dolna Crna Reka	Vardar	Aegean	1940.65	7.55
11	Dolen Vardar	Vardar	Aegean	1088.02	4.23
12	Pchinja	Vardar	Aegean	2317.96	9.01
13	Gorna Bregalnica	Vardar	Aegean	1068.82	4.16
14	Sredna I Dolna Bregalnica	Vardar	Aegean	3208.37	12.48
15	Dojran	Struma	Aegean	116.05	0.45
16	Strumica	Struma	Aegean	1526.64	5.94

Source Water Strategy for Republic of North Macedonia

Table 14.5 Basic hydrology characteristics of main streams

Surface area, km^2	Precipitation mm	Fallen water in a million m^3	Outflow and inflow water in a million m^3			Outflow coefficient	Watercourse (basin)
			total	inflow waters in a million m^3	outflow water in a million m^3		
25 713	**742**	**19 088.3**	**7 874.2**	**1 091.2**	**6 783.0**	**0.35**	**Republic of North Macedonia**
20 655	707	14 603.0	5 439.0	604.0	4 835.0	0.33	Vardar (to border) and Dojran
3 350	933	3 125.6	2 175.0	487.2	1 687.8	0.54	Crn Drim
1 535	791	1 214.1	216.6	–	216.6	0.18	Strumica
129	890	114.8	34.4	–	34.4	0.30	Cironska and Lebnica
44	700	30.8	9.2	–	9.2	0.30	Binachka Morava

Source Water Strategy for Republic of North Macedonia

Large reservoirs in the Republic of North Macedonia, generally with a multi-functional purpose, are located in the valleys of the larger rivers (Treska, Crna Reka, Drim with Radika, Bregalnica, etc.), but the smaller accumulations, mostly with a monofunctional purpose, are located in the peripheral parts of the valleys. The southernmost accumulation is "Kalkovec" (40°53’49" N), which is located south of the City of Bitola, the northernmost reservoir is "Otoshnitsa" (42°11’56" N) built on the southern slopes of Mount German. The most western is the accumulation of Shpilje (20°31’37" E), while the most eastern is the "Drazevo 5" (22° 57’54" E) in the eastern parts of Strumitsa Field. According to the large vertical differences of the Republic of North Macedonia, the lowest point (54 m amsl. exit of the river Vardar from the Republic of North Macedonia) and the highest point (2.764 m above sea level peak Korab), there are made categorization of artificial lakes according to the altitude (Table 14.6).

From the above table, it is concluded that the artificial reservoirs are mostly located in two groups: the first group at an altitude between 201 m, and 400 m. (total number of 105) and the second group of 601–800 m above sea level. The large number of reservoirs in the group of 201–400 m is due to the numerous accumulations of the type of accumulations formed from human activity in the geographical landscapes (most commonly sand exploitation along rivers shores).

This type of accumulations is mostly located in the lower course of the river Vardar in the Skopje valley, then the lower course of the Pchinja River (before the inflow in the river Vardar) and the lower course of the river Kriva Lakavitsa (downstream from the dam of Lake Mantovo). The second largest group (601–800 m amsl) is composed of the accumulations that are built on the contact between the valleys and the mountains. The characteristic example can take of the accumulations that were constructed in Pelagonija valley. The number of accumulations in this group is significantly enriched by coal excavations in the excavation of REK Bitola—Suvodol and the excavation of REK Oslomej—Oslomej.

Table 14.6 Artificial lakes by elevation zones in the Republic of North Macedonia

No	Elevation zone (*m*)	Number of artificial lakes
1	100–200	24
2	201–400	105
3	401–600	57
4	601–800	91
5	801–1000	31
6	>1000	10
	TOTAL	**318**

*determined by Vladimir Zlatanoski

14.4 Basic Characteristics and Classification of Artificial Lakes in the Republic of North Macedonia

The artificial reservoirs in the world have different classifications, especially when their volume is the main criteria. Large countries as the USA, China and Russia have adopted vary parameters from Europe. The classification of the artificial reservoirs in the Republic of North Macedonia is in accordance with the European Water Directive, where specifications for big accumulations are: water volume is more than 1 million cubic meters or the height of the dam exceeds 15 meters. The remaining accumulations are in the range of small accumulations. In addition to this classification, there are other classifications, such as classification according to the functionality. There are distinguished two types: monofunctional and multifunctional accumulations. The first type includes almost all small and micro accumulations, while the large accumulations are included in multifunctional ones, without excluding the possibility that some of the small ones may acquire a multifunctional character.

14.4.1 Artificially Built Accumulations

It is about purposely built dams on the river streams for accumulating river waters. The main purpose is exploiting water benefits such as irrigation, generating electric power etc. Today, 206 artificial accumulations have been built in the Republic of North Macedonia.

These type of reservoirs, the riverbed is partitioned from many different materials, such as soil-embankment, soil-rock embankment, soil fill and concrete. Comprehensive hydrogeological, static and seismic terrain researches were done for finding suitable locations for the biggest accumulations. Waterproof layers such as clay is another characteristic typical of this type of dams. The core is made with this type of waterproof layers. On the other hand, external dam parts are made with gravel (most common) and bigger stone blocks. External composition prevents internal dam parts form erosion. Materials form the native river valley are the most commonly used for building dams of the small accumulations. That is the reason why smaller artificial accumulations are cost-effective.

14.4.2 Artificially Created Accumulations

They are created accidentally and with no purpose. This group counts 112 objects. Their presence in the Republic of North Macedonia is linked with the places where exploitation of natural resources (ex. coal) is expressed or near the bigger energy facilities. Also, they can be present near the river streams. The process of sand exploitation has created the most artificial accumulations of this type in the Republic of North Macedonia. Such locations in the county are:

- Upper flow of the Vardar river, before the river leaves Skopje's field;
- Flow of the Crna river, near Rosoman village;
- Downstream Mantovo dam, near the Kriva Lakavica river;
- Before the Pcinja river inflows into the Vardar river.

As a second sub-type of artificially created lakes are accumulations which are created by energy-mining facilities. Their presence is characteristic for the following locations:

- Near the Suvodol, in the south-eastern parts of the Bitola field where a group of accumulations has been created;
- Oslomej—16 accumulations are registered in the Kicevo Basin;
- Marble Factory Sivec (near Prilep), with its long-established activity in the waterproof marble layers has created a few shaped accumulations.

The third type of created accumulations is reserved for accumulations which are created in the mineshafts—Bucim, Tajmiste and Majdan are specific mining locations in the Republic of North Macedonia where artificial accumulations of this sub-type are recognized.

14.5 Classification of the Artificial Accumulations by Their Usage

Modern human society is becoming more and more developed and therefore has improved the management of water resources. Using waters during the whole year for so many different purposes is one of the modern requirements which leads to constructing artificial lakes. The requirements are getting higher in areas where the river network is not developed so thickly. Additionally, precipitations in this areas are very low and insignificant. This weather phenomenon is characteristic for summer days.

Classification of artificial accumulations by their purpose:

- water supply (8 accumulations);
- supplying industrial facilities (1 accumulation);
- supplying animal husbandry (1 accumulation);
- gypsum waste water landfills (1 accumulation);
- dumping mining waste (5 accumulations);
- sand exploitation (50 accumulations);
- irrigation (134 accumulations);

- watering trough (35 accumulations);
- recreation (27 accumulations);
- retention (15 accumulations)
- fishing farms (28 accumulations);
- sports fishing (43 accumulations);
- hydropower (9 accumulations).

14.5.1 Hydropower

With artificial accumulation, Matka, which was built on the river Treska in 1938, starts the period of building artificial accumulations for hydropower purposes in the Republic of North Macedonia. The global trends for using renewable resources to their highest limits are followed by this country. Accumulation Sveta Petka, which has already been built, and plans for building new accumulations in the near future such as Cebren, Galiste, Boskov Most and Lukovo Pole, are clear signs that this country tends to follow global trends. Nowadays, in the Republic of North Macedonia 9 hydropower plants have been built (Kalimanci, Strezevo, Spilje, Mavtovsko Lake, Globocica, Kozjak, Matka, Tikves, Sveta Petka), with the total installed power of 428.170KWA.

14.5.2 Water Supply

The second and more significant purpose for building artificial accumulations is water supply. Accumulations such as Lisice, Strezevo and Knezevo (which is a part of the Zletovica river hydro system), are well known artificial accumulations of this type in the Republic of North Macedonia.

14.5.3 Irrigation

A lot of agricultural lands is possessed by the Republic of North Macedonia. On the other hand, agricultural development depends on the climate characteristics in the country. Building artificial accumulations for irrigation is very significant because they have a huge impact on increasing total amounts of yields for some crops. As a result of past experiences, small accumulations, which had been built in the nearest neighbourhood, helped Prilep Field to increase their tobacco plant production by 80% per unit area.

14.5.4 Supplying Industrial Facilities with Water

The bigger industrial facilities are, the higher the demand for water is, but the quality of the water is not necessary to be on a high level. This means that using artificial accumulations positively affects the relieve of the already existing and limited capitates for water supply. For example, in the Strezevo accumulation, a special canal for satisfying MEC Bitola water demands was built. In the steel manufacturing "Zelezarnica" four accumulations have been built for cooling factory machines. There are similar examples of this type of accumulations all over the country where the mine exploitation is expressed.

14.5.5 Watering Trough

Animal husbandry, which is typically developed in the higher altitudes, faces with problems caused by lack of water. Mariovo is the most characteristic area in the Republic of North Macedonia where 13 accumulations which are used as water troughs have been built. This type of accumulations is also common for the mountains Galicica and Osogovski.

14.5.6 Recreation Fishing and Fish Farming

Almost all artificial lakes with clean water at the territory of the country are fish stoking, and it provides prerequisites for the development of recreational fishing. On the other hand, the largest lakes has built cages for growing fish.

14.5.7 Recreation

Despite primary purposes, water accumulations also can be used for recreational activities. Mavrovsko Lake is a typical example for this type of accumulations. Building accumulation in this area has brought weekend settlements around the lake into existence. Settlements are hosting tourists all year long. In Skopje, the capital city of the Republic of North Macedonia, three artificial accumulations only for recreational purposes have been built. Approximately 10 km north was built Treska Lake with a total surface of 137000 m^2.

14.5.8 Retention

One of the main aims for construction of artificial reservoirs is preventing floods in populated areas and arable agricultural lands from large waters. The Treska river is a typical example of this type of accumulations. In the river's down flow has been built 3 accumulations, which minimizes the risk for the city of Skopje to be flooded.

14.5.9 Lakes for Depositing Mining Waste (Tailings)

In the Republic of North Macedonia, there are 6 flotation hydro-tailings, while 4 of them are still active. The first one was built in 1982 in Lojane (in the Kumanovo Basen). On the other hand, the active ones are Bucim (for copper exploitation), Toranica, Sasa and Zletovo (for Tin and Zinc exploitation). In the area of the Kocilari village (located in the southern of the city of Veles), a soil—embankment dam was built, for depositing gypsum wastewaters. This lake covered area of 28,900 m^2.

There is another type of accumulations which have been created as a result of many activities in nature, but they don't have any usage. Lakes which are created as a result of the process of exploitation of natural resources are typical for this category of artificial accumulations. Most of them are created as a result of sand exploitation near the river streams. This group counts 33 objects in total, are located along riverbanks of Vardar, Pchinja and Kriva River. Accumulations which are created as a result of coal exploitation count a total sum of 27 objects, and seven artificial lakes which are created as a result of marble exploitation.

14.6 Classification of the Artificial Accumulation by Their Volume

One of the most important classifications for the artificial accumulations is classification by their volume. How much water will be accumulated in the lake depends on the dam's dimensions? Differences between total accumulation capacity around the globe are very considerable. In addition, there are so many different terrain morphologies. Distinct places—distinct morphological terrains. The distinctions result with a problem—there is no worldwide standardized and accepted classification. The Republic of North Macedonia follows the European Union standards, in fact, the classification is established by "Water Framework Directive". Classification divides artificial accumulations into two main groups: small accumulations and big accumulations. Because so many small accumulations are registered in the Republic of North Macedonia, an additional group was a necessity to be created. The group was called micro accumulations, and it will be explained later in the text.

14.6.1 Big Accumulation

Reservoirs with more than 1 million m^3 water and their dam are higher than 15 m belong in the group of big accumulations. There are 21 such accumulations in the Republic of North Macedonia. Their distribution on the territory of the country is irregular, by volume most of the accumulated water is in the west and central parts. Lakes of Spilje, Globocica, Mavrovo lake, Stezevo, and Kozjak are on the west part of the country, on the southern part is Lake of Tikvesh, and at the east side are Lipkovo, Glaznja, Kalimanci, Ratevsko Lake, Turija, Mantovo and Vodaca.

Kozjak Lake. The largest artificial lake in the Republic of North Macedonia, Kozjak, is located at the altitude of 471 m in the middle course of the river Treska, i.e. 25 km upstream from the inflow in the river Vardar. Its main purpose is the production of electricity, then recreational fishing, irrigation and retention of the high water flows form Treska river. In 1994 the construction of the dam had begun, and it was completed ten years later. By partitioning the river profile of the Treska River, the artificial accumulation Kozjak accumulates 550,000,000 m^3, making it the largest accumulation in the Republic of North Macedonia. The useful volume of this accumulation is 260,000,000 m^3. In terms of morphometric characteristics, the lake is narrow and long, generally extending south-north, 33 km long, the maximum width is 400 m, while the lake mirror covers an area of 13.5 km^2. In terms of the dam, it belongs to the type of soil—embankment with a clay core and scattered stones on top. The height of the dam is 126.1 m, the length of the crown is 305 m, while the width is 10 m. The useful accumulated volume of 260,000,000 m^3 is used for generating electricity. For this purpose, a machine part composed of two aggregates with a total power of 80 MW, which generates 150 GWh per year.

Spilje Lake. The artificial accumulation Spilje is located in the western parts of the Republic of North Macedonia, near the city of Debar. It is built on the river Crn Drim, downstream inflow river Radika in river Crn Drim, at an altitude of 587 m. Its main purpose is to utilize the favourable hydropower potential of the river Crn Drim, as well as irrigation of the Debarsko field. The dam construction had begun in May 1964, and it became fully functional in October 1969. This artificial accumulation drains the waters in the drainage area of 4189 km^2, 3941 km^2 of which are used for hydropower plant “Spilje”. The difference in surface area occurs from the Gorna Radika drainage area whose waters are transferred to the basin of the Vardar River through the Mavrovo accumulation. In terms of flow, the average dam flow is 1852000000 m^3 water. In terms of its basic morphometric characteristics, it can be noted that it has a narrow shape in a north-south direction, and it spreads out in the northern part. It is 21 km long, the width is 1.8 km, and the lake mirror covers an area of 13.2 km^2. The dam type is soil—embankment with a clay core. The core is spilled with gravel. The length of the crown is 330 m, it is 10 m wide and 112 m high, which makes it the second highest altitude dam in the Republic of North Macedonia. For the utilization of the hydroelectric potential, downstream of the dam a machine part in which three aggregates are installed. The power of the turbines is 66 MW and the average annual output is 384 GWh. As noted at the beginning, the secondary application of the accumulation is irrigation of the Debar Field. After the construction of this hydrological facility, 1980 ha of fertile land is irrigated, while annual needs in the average dry year for irrigation are just over 6 million cubic meters of water.

Tikves Lake. This artificial lake is located in the southern part of the Republic of North Macedonia, more precisely the exit of Crna Reka from its gorge part. The dam is built 27 km from the inflow of Crna Reka into the river Vardar, at an altitude of 269 m. The purpose of this accumulation is the production of electricity and irrigation of the Tikves field. Downstream of the dam, this accumulation drains waters from a drainage area of 5361 km^2. Annually through the dam flows 1188,000,000 m^3 of water. The artificial lake Tikves accumulates 475 million cubic meters, of which 240 million cubic meters for the production of electricity and 120 million cubic meters for irrigation. The length of the reservoir is 28 km, the width is 300–700 m, while the lake mirror covers an area of 14 km^2. The dam is built on a clay core. On top of the core, there are scattered rocks. This dam is currently the highest in the Republic of North Macedonia with a maximum height of 113.5 m. It is 338 m long, while its width at the top is 10 m. Downstream of the accumulation, a hydropower plant has been built, which has been developed in two phases. In the first phase, two aggregates with an individual power of 22 MW have been installed. In the second phase, the power is doubled with the instalment of two more aggregates which concludes that the total installed capacity is 88 MW. The average annual production of electricity from this hydro system is 207 GWh. With the construction of the artificial accumulation, another problem of the region has also been solved, the irrigation. With the construction of pipelines with a capacity of 12.08 m^3/sec, 18300 ha of fertile soil are irrigated.

14.6.2 Small Accumulations

According to the “Cadaster for built small dams and accumulations”; one accumulation will be recognized in the group of small accumulations if it has 15 m high dam as an upper limit or the dam can be 10 m high but at last 500 m wide. As a second condition, the total capacity of the accumulation cannot be bigger than 1×10^6 m^3. This group of small accumulations counts 128 accumulations. Most of the small accumulations are scattered all around the country, while in the Region of Pelagonia these small accumulations are more concentrated.

14.6.3 Micro Accumulations

As a standard, accumulations with the area below 0.5 m^2, are classified in the group of micro accumulations. A total number of micro artificial lakes in the territory of the Republic of North Macedonia is 169. They are scattered around the country.

Even if their capacity is very small, they can be very significant in the process of the development of society. In the most cases, they have only one functionality such as irrigation, the water supply of industrial and livestock facilities as well as high altitude watering troughs. In the end, it is important to mention that a large part of these micro-accumulations is counted informed accumulations (accumulations caused by anthropogenic actions in the area).

14.7 Institutional Responsibility for the Waters in the Republic of North Macedonia

Law on waters of the Republic of North Macedonia defines water as a property of the state and thus gives the right and obligation to manage with them and to preserve them in their natural condition and even improve. These responsibilities and obligations are implemented through appropriate governmental institutions. Competencies are divided into six ministries, Ministry of the environment and physical planning, Ministry of agriculture, forestry and water-economy, Ministry of the economy, Ministry of transport and communications, Ministry of education and science, Ministry of health and the Republic Institute for Health Protection (Spatial Plan of Republic of North Macedonia 2004; Water Strategy for Republic of North Macedonia 2009).

The subject of operation AD Water Management uses maintains and manages the irrigation and drainage systems as a whole, due to:

- water supply for irrigation;
- water supply to a utility company for water supply for human consumption (drinking water and other needs);
- water supply for industrial and technological (commercial) needs, including the production of electricity;
- arranging river beds;
- drainage of the land; and—discharge of discharged waters (Spatial Plan of Republic of North Macedonia 2004; Water Strategy for Republic of North Macedonia 2009).

The Ministry of Environment and physical planning with current restructuring should take responsibilities related to the protection, improvement and planning in water management. The Ministry of Economy has jurisdiction over-abstraction of water needed for the industry and energy production (production of electricity and heat). Their responsibilities, the Ministry achieves through its energy sector and relevant units in the sector (Spatial Plan of Republic of North Macedonia 2004; Water Strategy for Republic of North Macedonia 2009). The Ministry of transport and communications has responsibilities related to supply drinking water, collection and drainage of urban wastewater and responsibilities related by internal navigation (Spatial Plan of Republic of North Macedonia 2004; Water Strategy for Republic of North Macedonia 2009). The Ministry of education and science through the

Hydrobiological institute-Ohrid care for the physical and chemical composition of the water in natural and artificial lakes and the state of flora and fauna of aquatic life in them (Spatial Plan of Republic of North Macedonia 2004; Water Strategy for Republic of North Macedonia 2009).

The Ministry of agriculture, forestry and water economy manages with the water for agricultural purposes as well as infrastructural facilities such as dams, reservoirs, irrigation systems. The hydrometeorological service is part of the ministry, and he is responsible for monitoring the quantity and quality of surface water and groundwater. The Ministry of health implements control of the state of the water in terms of potential epidemics that can spread through water and control of the water as a kind of food. Responsibilities are implemented through two bodies in own composition—state sanitary and health inspectorate and food directorate (Spatial Plan of Republic of North Macedonia 2004; Water Strategy for Republic of North Macedonia 2009). Republic Institute for health protection has obligations in relation to communal hygienic in public facilities, quality control and hygienic-bacteriological correctness of the waters (Spatial Plan of Republic of North Macedonia 2004; Water Strategy for Republic of North Macedonia 2009). Within these institutions, there are departments, units, inspectorates and directorates with defined responsibilities in relation to water. There are four river basins in North North Macedonia, and currently, there are four departments in the establishment at the MEPP (Spatial Plan of Republic of North Macedonia 2004; Water Strategy for Republic of North Macedonia 2009).

These departments are responsible for:

- carrying out the basic analysis of river basin characteristics;
- preparation and implementation of the river basin management plans (RBMP);
- preparation of the Programme of measures;
- collecting the monitoring data, controlling the operators (drinking water supply utilities, irrigation operators, industry water suppliers, etc.);
- protection from the adverse effects of the water;
- protection of the water from pollution, preparation and updating of polluters cadastre;
- establishing and updating of the register of protected areas and
- international cooperation regarding the preparation of international river basins management plans, performing scientific research in the water field, etc. (Spatial Plan of Republic of North Macedonia 2004; Water Strategy for Republic of North Macedonia 2009).

14.8 Water Supply and Water Resources Demand

The water supply in the country is not solved especially According to Article 13 in the Water's Law the water supplying contains: Water use is the use of water covering the activities of storage, capture, abstraction, diversion of surface and ground waters:

- consumption by humans, irrigation, industrial, technologic, economic demands and for other purposes;
- to produce electricity and other power purposes;
- breeding of fish;
- navigation;
- sport, recreation, bathing, tourism and
- Accumulation, capture, extraction, use, transfer and other purposes.

Supplying the population with drinking water is an important priority for every country. Hence, the Census of Population, Households and Dwellings in 2002 (there was no new Census in the country), as a statistical survey which covers the whole population, is also used to collect data on the manner in which the households are supplied with drinking water, as well as on the existence of appropriate water supply installations in dwellings. Besides the geographical location of the state, there are 7.4% of the dwellings without water installation. According to the Census data from the total number of households:

- 86.7% are connected to the Public water pipeline
- 4.9% is supplied from Private air-compressed water tank in the dwelling
- 3.5% is supplied from the well
- 2.7% other ways
- 2.2% are connected to Public water pipeline located outside of the dwelling (Table 14.7)

The situation with the wastewater sewage system is even more urgent. The Census in 2002 shows the percentage of different types of sewage systems and solving of the problems with the wastewater in the dwellings. 59.9% of the dwellings are connected to the public sewage systems, 20.6% have their public tank, 12.2% have free wastewater discharge, and 7.4% are without any type of wastewater outflowing connection, which means that huge percentage of 40.1% have no connection to the public savage system. The responsibility for solving these problems belongs predominantly to Local-self Governments (Table 14.8).

The drinking water supply issue is not yet solved even in the XXI century. From the total number of 564296 households, 13.3% have not solved its water supply with the public pipeline, but in some older way, but with wells, air tanks and pipelines out of the dwellings (Table 14.9).

Table 14.7 Drinking water supply source in households

Total number of households		Public water pipeline	Private air compressed air tank	Pipeline out of the dwelling	Well	Other ways, outside of the dwelling
No	564296	489169	27772	12525	19786	15044
%	100	86.7	4.9	2.2	3.5	2.7

Source State Statistical Office

Table 14.8 Wastewater discharge installations according to Census 2002

Total number of dwelling		Public sewage system	Septic tank	Free wastewater discharge	No any installation
No	697529	417653	143353	85007	51516
%	100	59.9	20.5	12.2	7.4

Source State Statistical Office

Table 14.9 Water supply of industry and mining (m^3)

The volume of water abstracted and supplied own water supplies								
Year	Total	Groundwater	Springs	Surface water			Public water supply	Other
				Water courses	Reservoirs	Lakes		
2011	5869979	55265	480396	5061935	52171	220212	203126	233093
2012	5006246	65293	147494	2639871	1901038	252549	102695	5901
2013	2537780	25504	539968	959418	1012888	2	354580	2288
2014	3427825	17606	1654162	481822	1010409	263827	32283	2819
2015	4282042	3920	217847	1278812	812725	8112	32461	1363

Source State Statistical Office

Table 14.10 Water for the technical purpose (m^3)

Year	Total	Fresh water		Water recirculation system		Reused water	
		For technical purposes	Drinking water	All	Freshwater, added	After purifying	After cooling
2011	4953364	4798605	126976	29413	2033	181	225
2012	4923165	4368666	63481	551425	2844	2000	1158
2013	2437998	2101022	324282	12552	1075	1065	152
2014	3366116	3345818	8321	11957	30	0	50
2015	4275252	4255626	10230	14643	5572	126	199

Source State Statistical Office

The situation with the wastewater discharge is even worse than the water supply. Only 59.9% of the dwellings are connected to the public savage sewage system, and 19.6% are without installations and septic tanks, but the wastewater discharge is freely outflowing with a large possibility of deceases spreading. This situation is predominately existing in the Roma settlements in the urban areas, but also in the smaller villages, without enough infrastructure and mainly depopulated in the last 20/30 years (Table 14.10).

The water usage in industry and mining has a different origin. Predominantly is used from the water courses (streams, rivers and channels), reservoirs and springs. The amount used from natural lakes, public water supplies, underground water and

Table 14.11 Untreated wastewater outflowing from industry and mining (m^3)

Year	Total	Ground	Public sewer system	Water courses	Reservoirs	Lakes
2011	5062710	14835	123658	4884306	39911	0
2012	4808627	7551	113683	4237414	449979	0
2013	2326176	1016	253274	1226542	845342	2
2014	3331536	586	16832	3298540	15573	5
2015	4278699	691	16184	4261814	10	0

Source State Statistical Office

other sources is rare and less. It is necessary to avoid usage of high-quality water as a technology in the industry which has no needs for drinking water (food industry) (Table 14.11).

Water for technical usage is divided into freshwater and reused water. In the table amounts, freshwater is predominant then reused water. Hence, the amount of drinking water is much less used with a maximum in 2013 with 324282 million m^3 then fresh water with lower quality, which is only available for technical purposes (Table 14.12).

The main recipients of untreated wastewater from industry and mining in the Republic of North Macedonia are water courses (streams and channels), public sewer systems and artificial lakes (reservoirs). The wastewater inflow in the natural lakes was detected in 2013 and 2014.

The goal of the modern industry is production in the sustainable development of the environment. Compared with the untreated wastewater this amount is symbolic. There are larger companies and cities without reclining systems downstream from their rivers/channels (Table 14.13).

Additionally, the main processes for wastewater discharging are produced in factories, and much less amount for cooling water and sanitary water. With the production processes, the water is combined/mixed with different types of pollutants. Additionally in the table is missing the amount of hot water produced by thermopower plant REK Bitola and REK Oslomej.

Table 14.12 Outflowing of re-cleaned wastewater from industry and mining according to the recipient (m^3)

Year	Total	Ground	Public sewer system	Water courses	Reservoirs	Lakes
2011	77573	397	71986	5188	2	0
2012	92492	9	86567	5913	2	0
2013	230053	6	226398	3617	32	0
2014	12161	47	4533	6751	828	2
2015	16188	18	10524	5637	9	0

Source State Statistical Office

Table 14.13 Wastewater in industry and mining according to usage (m^3)

Year	Total	Production	Cooling water	Sanitary water	Other
2011	820679	657857	45957	82898	33967
2012	1045121	942314	68365	32778	2545
2013	559629	491402	40319	23446	4439
2014	3373151	3335607	30509	5040	1995
2015	4281081	4265027	10237	4042	1774

Source State Statistical Office

14.9 Climate Change Impacts on Water Resources

The climate change phenomenon has not avoided North Macedonia, due to the geographical location and hilly-mountain geomorphology, various climate factors. The recent study shows complementary climate change in water resources in the country with other Southeast European and Mediterranean studies with numerous case of significant downward trends in streamflow, predominantly identified in the eastern part. From 13 naturally regime streams, 4–5 are statistically significant downward trend in annual maximum, mean and minimum streamflow and 2–5 significant downward trends in seasonal streamflow data in all four seasons. This phenomenon is connected not with the significantly decreasing of the precipitation, but with evapotranspiration rising, made by significant upward trends in the air temperatures (Radevski et al. 2018). Those conclusions indicate decreasing of the total stream water resources, especially high-quality spring water, analysed in the above mentioned article.

The wider study for proves that climate change shifts timing of occurring of the European floods, the floods in the last 50 year has not significantly increased their magnitude, but change the period of occurrence with four significant regions of detected changes. In the Adriatic coastal area, there is a shift towards later floods (50% of the stations by more than 6 days), made by stronger Atlantic influence in the winter (Blöschl et al. 2017).

14.10 Agricultural Irrigation

The land in the country unirrigated until Federal Law of irrigation financing of North Macedonia? After 10 year period of building activities, in 1967 the irrigation area in the covered 42000 ha of agricultural land (three systems of irrigation—Bregalnica, Strumica and Tikvesh) and three systems for water drainage (Pelagonija, Struga Plain and Skopje Plain). These territories with other smaller areas cover around 70,000 ha, and after the construction of these ameliorative systems, the agricultural production was multiple increased from 4.5 times for vegetable, triple in tobacco production to 230 time more in sugar beet (Gashevski 1972).

The irrigation processes in the country started in the 1950s with outflowing of the largest country plains, which were in wide area wetlands. The Pelagonija Plain (Boshevski 1977) was first dried, and after that irrigated efficiently with canals, dams and creeks regulation. The water was supplied especially in the summer dry season with dams, underground water—wells and local springs. There were two main phases of irrigation of the largest plain in the country:

1. Drainage of the water (Crna Reka regulation and its tributaries) with the building of main and detail channel network and torrent control.
2. Irrigation, water supply for agricultural land with water during the dry summer season using water sources from accumulations, groundwater and other permanent water sources.

The water management of the Pelagonija is divided into four development phases:

- Study research work;
- Building of water management objects;
- Capacity building of institutions of water management;
- Exploitation and sustainability of the built hydro-technical objects.

14.11 Summary and Conclusions

With a total area of 25,713 km^2 Republic of North Macedonia is country located in the central part of the Balkan Peninsula. The relief is predominantly hilly-mountainous, with an altitude range of 54 m amsl to 2764 m amsl. This landscape results with very complex climate conditions with variations from basin to basin. The richest part of the country with precipitation are mountain ridges across the border with Albania (maximum 1400 mm per year), the central part of the country is driest with annual precipitation sum of 370 mm, east part have maximum average annual precipitation of 950 mm.

These precipitation conditions feature different river regime conditions. In rivers with the natural regime, there are two main types of stream regimes, moderate Mediterranean and continental. The larger area of the country is covered with continental river regime. In general, in both river regimes, there is a long summer period poor in precipitation, and most of the streams are periodical.

The phreatic wells are spatially distributed in all plains, but they are located on different depths (from 3–20 m). The artesian wells are located in the almost all plains (except Kocanska and Debar Basin) much deeper located on the depths of 50 m to the 450 m in Strumica Basin. The richest basins with artesian aquifers are Pelagonija and Strumica Basin.

The springs in the country have a different regime and flow, depending mainly from hydrogeological conditions (type of the rocks). The Karst Mountains in the western part are significant alimented areas for largest karst springs in the country. The aquifers in the eastern part are predominantly made by magmatic and metamorphic rocks with features of smaller springs below 5 l/s.

The total flow from the whole 1100 springs in the country published in Cadastre of Springs (1968) was 23 m^3/s. Ss. Naum spring is the largest in the country with average discharge 8 m^3/s, with a maximum flow of 11 m^3/s with more than 1/3 from the total discharge of all spring water in the country. The second largest spring area is 5 karst springs of Crna River with the total amount of 5 m^3/s, and the third is spring Rasche with average flow 4–4.5 m^3/s, (main water supply source for the city of Skopje). The surface waters in the country are distributed in generally in dendritic stream network, because of predominantly fluvial and denudation processes. The river basin is separated between Aegean basin, Adriatic basin and the Black Sea basin.

The largest basin is Aegean (22189 km^2), divided between river Vardar catchment with two right tributaries of Struma River (Strumica River and Lebnica River). The main river Vardar has a spring called Vrutok, the total length of the river in the country is 301 km. Bregalnica River is the largest left tributary of River Vardar. Its spring is located east far on Bulgarian border cote (1720 m). The stream length is 225 km and a total basin area of 4307 km^2. The average value of streamflow at the confluence point is 28 m^3/s. The larger two right tributaries are Treska and Crna Reka (average annual streamflow is 37 m^3/s., the total length of 207 km and catchment area of 5890 km^2). These rivers are streaming to the area rich in water especially in their spring area, with the average multiannual amount of precipitation larger than 900 mm.

The second largest basin is Adriatic, which is the whole spring area of river Crni Drim (two largest lakes Ohrid and Prespa and also Radika catchment with a total area of 3360 km^2. The smallest is Black Sea basin with spring area of river Binacka Morava called Tanushevska River, small stream with 44 km^2, located north far on Skopska Crna Gora Mountain.

From the basic river characteristics, there are three outflow points in the country. The largest outflow point is the river Vardar with the average multiannual flow of 145 m^3/s. The second largest is the river Crni Drim, and the third is the river Strumica average streamflow of 4.2 m^3/s. The Water management structure became importantly issue in the second half of 20th century. The main management body in the North Macedonia was Water Management Authority. Water division regions are determined according to the North Macedonian Water Strategy, divided into 16 different areas (12 in Aegean Basin, and 4 in Adreatic basin).

Today, in the Republic of North Macedonia there are 318 accumulations, of which 206 dams are built for their functional purpose (water supply, irrigation, exploitation of hydroelectric potential, fishing, etc.), but there are and 112 artificial lakes, whose origin is a consequence of human activities in the landscape (most common exploitation of natural resources). The southernmost accumulation is "Kalkovec", the northernmost is "Otoshnitsa", the most western is Shpilje and the most eastern is the "Drazevo 5". The artificial reservoirs are mostly located in two elevation zones: the first group at an altitude of 201 m to 400 m (total number of

105) and the second group of 601–800 m above sea level (91 lakes). There are more purposes for constructing artificial lakes, in the case of North Macedonia are built for: irrigation (134 accumulations), recreation fishing (43 accumulations), watering trough (35 accumulations), fishing farms (28 accumulations), recreation (27 accumulations), recreation (27 accumulations), retention (15 accumulations), hydropower (9 accumulations), water supply (8 accumulations), dumping mining waste (5 accumulations). First artificial lake for hydropower purposes is Matka; total installed power from all accumulations is 428.170 KWA. The largest artificial lake in the Republic of North Macedonia, Kozjak, is located at the altitude of 471 m in the middle course of the river Treska, i.e. 25 km upstream from the inflow in the river Vardar. Its main purpose is the production of electricity, recreational fishing, irrigation and retention. Accumulation Kozjak accumulates 550,000,000 m^3; it is 33 km long, maximum width is 400 m and covers an area of 13.5 km^2. Total power from installed generators is 80 MW, which generates 150 GWh per year. Located in the western parts of the Republic of North Macedonia, near city of Debar is a second largest artificial lake. It is built on the river Crn Drim, at an altitude of 587 m. Its main purpose is to utilize hydropower potential and irrigation of the Debarsko field. This artificial accumulation drains the waters in the drainage area of 3.941 km^2. In terms of its basic morphometric characteristics, it can be noted that it is 21 km long, the width is 1.8 km, and the covers an area of 13.2 km^2. This lake irrigates 1980 ha farmland.

Tikves Lake is located in the southern part of the Republic of North Macedonia at an altitude of 269 m. The purpose of this accumulation is the production of electricity and irrigation of the Tikves field. Annually through the dam flows 1188,000,000 m^3 of water. The artificial lake Tikves accumulates 475 million cubic meters, of which 240 million cubic meters for the production of electricity and 120 million cubic meters for irrigation. The length of the reservoir is 28 km, the width is 300–700 m, while covers an area of 14 km^2. Total installed generators capacity is 88 MW with the average annual production of electricity 207 GWh.

Small accumulations with a capacity below 1 million cubic meters water, in the country there are 128 accumulations. Most of the small accumulations are scattered all around the country, while in the Region of Pelagonia these small accumulations are more concentrated. With area below 0.5 m^2, are classified in the group of micro accumulations. A total number of micro artificial lakes in the territory of the Republic of North Macedonia is 169. They are scattered around the country. Even if their capacity is very small, they can be very significant in the process of the development. In the most cases, they have only one functionality such as irrigation, the water supply of industrial and livestock facilities as well as high altitude watering troughs. Large part of these micro-accumulations are counted informed accumulations (accumulations caused by anthropogenic actions in the area).

Supplying the population with drinking water is an important priority for every country. Besides the geographical location of the state, there are 7.4% of the dwellings without water installation. According to the Census data from the total number of households: 86.7% are connected to Public water pipeline, 4.9% is supplied from Private air-compressed water tank in the dwelling, 3.5% is supplied from the well, 2.7% other ways, 2.2% are connected to Public water pipeline located outside of the dwelling. The situation with the wastewater sewage system is even more urgent, 59.9% of the dwellings are connected to the public sewage systems, and 40.1% have no connection to the public savage system.

The drinking water supply issue is not yet solved even in the XXI century. From the total number of 564296 households, 13.3% have not solved its water supply with the public pipeline, but in some older way, with wells, air tanks and pipelines out of the dwellings. The climate change phenomenon has not avoided North Macedonia, due to the geographical location and hilly-mountain geomorphology, various climate factors. The recent study shows complementary climate change in water resources in the country. From 13 naturally regime streams, 4–5 are statistically significant downward trend in annual maximum, mean and minimum streamflow and 2–5 significant downward trends in seasonal streamflow data in all four seasons. This phenomenon is connected with evapotranspiration rising, made by significant upward trends in the air temperatures. In the Republic of North Macedonia, there are three systems of irrigation (Bregalnica, Strumica and Tikvesh) and three systems for water drainage (Pelagonija, Struga Plain and Skopje Plain). These territories with other smaller areas cover around 70,000 ha, and after the construction of these ameliorative systems, the agricultural production was multiple increased from 4.5 times for vegetable, triple in tobacco production to 230 time more in sugar beet.

14.12 Recommendations

The basic recommendations in the country water management are complementary with the Organization for Economic Cooperation and Development (OECD), where main topics of managing of water quantity, improving water quality, success in managing of water risks and disasters, ensuring good water governance, sustainable financing and pricing of water services (OECD 2003). The main topics of this problem taking in consideration that North Macedonia is country in development are:

1. Improving the knowledge about the present conditions of water bodies;
2. Water quantity and quality monitoring improvement (there is decreasing of working gauge stations in meteorological, hydrological variables in lack of government funds and it is also necessary to develop more water quality stations);
3. Open data sources for the scientist in scope of obtaining new scientific results about water objects without administrative barriers, which will be useful for the managing authorities;
4. Higher economic governance and water sector funding with high quality skilled administration;

5. Strong cooperation with scientific organizations in development of scientific new strategy about water management according to new population distribution in the country (population transfer and disappearing of more than 200 villages as a result of migration in the western countries and larger country cities (Skopje, Bitola, Kumanovo and Tetovo);
6. A capital projects need to be prepared and implemented as: ameliorative channels maintenance and new channel network in larger not covered agricultural regions/plains, new dams building especially Chebren and Galishte dam buildings on Crna River;
7. Wastewater treatment improving with water treatment plants building downstream the larger pollutants;
8. Employment of adequate professional human resources in the Ministry of Agriculture, Forestry and Water Management and no persons without any degree and skills in water problems.

These measures are crucial for improving the system of water resources management in North Macedonia, which, unfortunately, mostly maintain only partially of the capacities built during the time of Yugoslavia, and the construction of new hydro-technical facilities is stagnating considering the economic situation of the country.

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Chapter 15
Water Quality and Pollution Status of the Main Rivers in the Republic of North Macedonia

Olgica Dimitrovska, Ivan Radevski and Svemir Gorin

Abstract In this paper, the first analytic emphasis will be on the main pressuring of the quality of the water resources in the Republic of North Macedonia, i.e. the pointing and diffusive sources of pollution as a result of the activities of the households, the industry and the agriculture. After that the emphasis of the analytics will be on the water quality through the indicators: Oxygen consuming substances in rivers (BOD_5 and total ammonium) and Nutrients in freshwater (nitrate, nitrite and orthophosphate). The analysis will be taking into account the average annual concentrations of the mentioned parameters for the main rivers Vardar, Bregalnica and Crna Reka, for the period 2001–2015. In our country the quality of the watercourses is of worse quality downstream from the cities, mostly because from the lack of waste waters treatment. The regression analysis points to the fact that there are certain variations of the concentrations in the parameters. In Crna River and Vardar, it is recorded a moderate eutrophic status of the waters relative to the level of BOD_5. These results reflect the situation, above all, of the small percentage of treatment of urban and industrial wastewater, as well as the inadequate regime for the protection of river basins. This essay aims to show the status of the quality of the major watercourses in the Republic of North Macedonia and to indicate the necessary measures to avoid further deterioration of the water quality and thus to achieve a good ecological status or potential of the waters.

Keyword Measures · Protection · Pollution · River Wastewater

O. Dimitrovska (✉) · I. Radevski · S. Gorin
Faculty of Natural Sciences and Mathematics, Institute of Geography, Ss. Cyril and Methodius University, Skopje, Republic of North Macedonia
e-mail: olgica.dimitrovska@gmail.com

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15.1 Introduction

Water is the most vital resources for all kinds of life on this planet. Rivers are vital and vulnerable freshwater systems and are essential for the sustenance of all life. However, the declining quality of river water in these systems threatens their sustainability and is, therefore, a cause for concern (Balkhande and Kulkarni 2013). Rivers are waterways of strategic importance across the world, providing main water resources for domestic, industrial, and agricultural purposes (Ngwenya 2006). According to Ljeshevich "As a result of the development of the urbanization and industrialization, negative consequences are arising from the natural resources and the environment" (Ljeshevich 2005; Dimitrovska et al. 2012). The Republic of North Macedonia covers approximately 2 per cent (6.4 billion m^3) of the country with some 35 rivers, and 53 natural and artificial lakes indicate sufficient water resources, which are however unequally distributed. Water resources depend mainly on the appearance, duration and intensity of precipitation (MOEPP 2010). The use, protection and conservation of water resources are therefore of utmost importance. The major water users in the Republic of North Macedonia are agriculture, industry, population (drinking water supply) and energy production. According to the total water demands by the user, currently the major water consumer is the irrigation sector with 44 per cent, followed by nature with 31 per cent, then industry with 14 per cent, and drinking water supply by population and tourists with 11 per cent (UNECE 2011). The increased water consumption in the Republic of North Macedonia has led to an increase in the amount of wastewaters that pollute the water flows to a greater extent, primarily due to people's neglect of the natural resources and the absence of appropriate waste management and treatment mechanisms both on a local and national level. The main sources of pollution of the waters in the Republic of North Macedonia are: industrial and mining wastewaters, wastewaters from households and agriculture (Dimitrovska et al. 2012). The pollution is especially serious in the urban settlements with a greater number of inhabitants and with developed industry. The inadequate sanitary urban infrastructure and the lack of control of the pollution where the majority of the urban and industrial waters are not treated, both lead to worsening of the condition (MOEPP 2010). However, even though the condition of the quality of the surface waters in certain regions is substandard, in the Republic of North Macedonia appropriate measures are being undertaken to lower or even stop the pollution of the waters with which a better ecological status or potential could be achieved (Dimitrovska et al. 2012). The evaluation of waters quality was conducted in comparison with other catchment basins at national or international level (Cirtina et al. 2015; Mebirouk et al. 2017; Romanescu et al. 2013, 2014, 2015; Van Leevwen 2016). In this paper an analysis will be made based on the sources of pollution of the water flows in the Republic of North Macedonia in the period from 2001 to 2015, and at the same time the quality of the water of the main rivers (Vardar, Bregalnica and Crna Reka) will be made for the same timeline.

15.2 Data and Methods

For the purposes of this chapter, the emphasis of the analysis is on the data and information collected primarily from state institutions and their publications. The main data sources were obtained from the Ministry of Environment and Physical Planning and the State Statistical Office of the Republic of North Macedonia. In order to complement the research, more official documents from the European Union related to water quality were used. Through the method of field observation, on a couple of occasions visits were made on the parts of the area being researched in order to obtain data directly from the source in terms of the pollution of the watercourses. With the help of the mathematical-statistical, analytical and synthetic comparative method, the whole database was processed where the data obtained show the condition and the trend of polluting and contaminating the bigger watercourses in the Republic of North Macedonia. The graphic method is used in combination with the mathematical-statistical method for presenting the obtained data.

15.3 Study Area

The Republic of North Macedonia is located in South-East Europe, in the center of the Balkan Peninsula. According to the geographical position, it is a central Balkan country that borders with four countries: Bulgaria to the east, Serbia to the north, Albania to the west and Greece to the south (Dimitrovska et al. 2012) (Fig. 15.1). The Republic of North Macedonia has an area of 25.713 km^2. The land relief is mainly hilly and mountainous. The average altitude of the terrain is 850 m above the sea level. More than 30 per cent of the land area is situated above 1.000 m, and there are 16 mountain peaks higher than 2.000 m. The highest point is the Golem Korab peak (2.753 m) situated in the north-western part of the country on the Albanian border, while the lowest point is situated on the Vardar River (44 m) (UNECE 2011). The Republic of North Macedonia is dominated by a sub-Mediterranean climate with characteristic warm and dry summers, and cold and humid winters. The mean annual temperatures decrease from the north to the south of the country. The mean annual precipitation on mountains is approximately 1.000–1.500 mm, and in the basins, it is 600–700 mm (SSO 2017). About two per cent of the land area is covered by water. The country has 35 large and small rivers, 3 natural lakes and 50 artificial lakes. The rivers flow in three different areas of river basins: Aegean river basin (87% from the overall territory of the Republic of North Macedonia), Adriatic river basin and the Black Sea basin. The biggest river is the Vardar with, 388 km (Dimitrovska et al. 2012) (of which 301 in the RM) "where its flow gathers the major part of the area of the country (80%) and is a part of the Aegean flow area" (MOEPP 2010). Larger confluence of Vardar are Treska, Pcinja, Bregalnica and Crna Reka. According to the last Census of Population, Households and Dwellings of 2002, the total population in the Republic of North Macedonia is 2.022.547 inhabitants. According to the latest population estimates (as at 31.12.2016) the total population is 2.073.702 inhabitants (SSO 2017). The territorial distribution of the population is uneven. Some 67% of the population lives in urban areas, mainly in the five largest cities: in the capital Skopje, in Bitola, in Kumanovo, in Tetovo and Prilep. In industry, the most significant sectors are the food and the tobacco industry, as well as the manufacture of iron and steel (SSO 2017).

The Vardar is the biggest and most significant river in North Macedonia with an inflow size of 20.606 km^2, occupies approximately 80.14% of the total territory of the Republic of North Macedonia, and about 85.98% of the total population of the state lives in that area (EUOPRD 2017). The source of the river is located at the village of Vrutok which is made of spring on an elevation of 683 m and leaves the territory of North Macedonia at the city of Gevgelija at an elevation of 44 m. The length of the river is 301 km, while the estuary into the Aegean Sea has a total length of 390 km (Petrushevski and Markoski 2014). The average annual flow is gradually increased from the source towards the estuary, that is, 25 m^3/s in Polog, 63 m^3/s in Skopje and 145 m^3/s in Gevgelija respectively at the exit of our country (MOEPP 2010). Its valley is composite and is consisted of 5 valleys (Poloshka, Skopska, Veleshka, Tikveshka and Valandovsko-Gevgeliska) and 4 gorges between the valleys (Vardarski Derven, Taorska, Veleshka and Demir Kapiska) (Gashevski 1978). It has remarkable international, regional and local significance, since it starts from, or gravitates to all essential roads in the country. It is particularly important that it connects to the North with the valley of the river Morava and then continues with the Danube and Central Europe, and in the South with Thessaloniki and the Eastern Mediterranean. The valley is also important because through it from the South we have the penetrating influences of the Mediterranean Sea and from the North the moderate-continental climate. This further influences the overall climate of the Republic of North Macedonia. The larger tributaries are the rivers Lepenec, Pchinja and Bregalnica from the left and Treska, Topolka, Babuna, Crna Reka on the right side. The capital and largest city of the Republic of North Macedonia and several big industrial cities with a total population about 800.000 are located in this area: Gostivar (83.557 inhabitants), Tetovo (91.431 inhabitants) Skopje (544.086 inhabitants), Veles (54.630) and Gevgelija (22.764 inhabitants) (SSO 2016). Water is abstracted from the Vardar for irrigation (63%), fish ponds (11%), drinking water (12%), municipal and industrial uses (15%), agriculture, and there are hydroelectric power stations at several reservoirs in the river basin (INWEB 2004).

Its biggest tributary the Vardar River from the west is **Crna Reka**. The source of the river is at the village of Zeleznec in the South-Eastern part of the Ilinska mountain at an elevation level of 769 m and at the place called Stobi at an elevation of 129 m it flows into the river Vardar with a total length of 207 km (Vasileski and Radevski 2011). The total catchment area is 5.890 km^2 of which 5.130 km^2 are in the Republic of North Macedonia (Gashevski 1978). According to the catchment area and the amount of water it inflows into Vardar (average annual flow of 29.3 m^3/s), it is the largest of its tributaries. Crna Reka flows through four

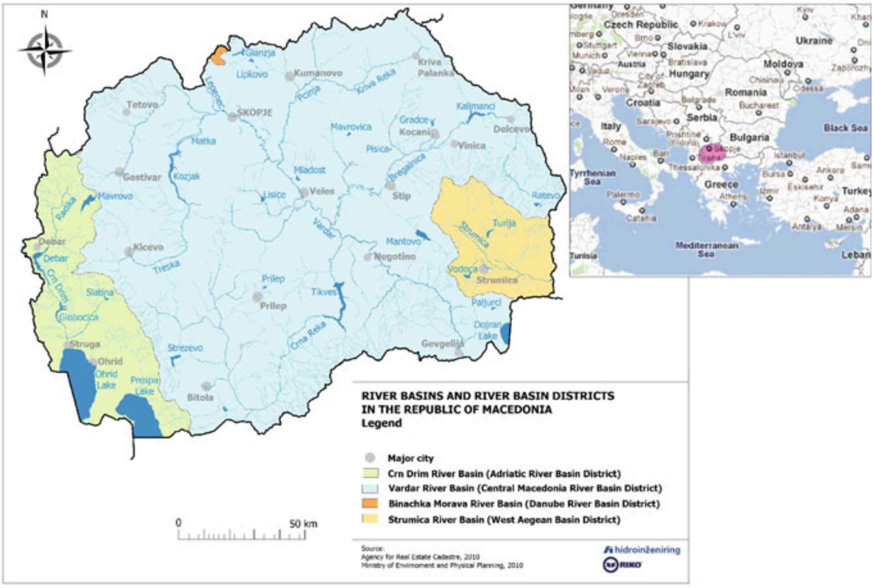

Fig. 15.1 River basin and river basin districts in the Republic of North Macedonia

spatially-morphologically diverse areas. In the upper part of the valley there is a predominantly ravenous character with several smaller erosive extensions, then flows through the spacious Pelagonia Basin where it has a typical plain character. The third part of the valley constitutes the very attractive Skocivirska Klisura where, after the exit from it flows through the Tikves Basin (Gashevski 1978). The larger tributaries are the rivers: Shemnica, Dragor, Eleska from the right and Blato and Raec on the left.

The climate zones are cold continental (60% of the area), continental-submediterranean (20%), and foothills continental mountainous (20%). There are four reservoirs: Strezevo, on the Shemnica River; Prilep, on the Oreovachka River; Suvodol, on the Skochivirska River, and Tikvesh (Lake Tikvesh) on Crna Reka. The catchment area includes twenty municipalities, with 338 settlements (urban: 3, rural: 335), and a total of 232.272 inhabitants (Spirkovski et al. 2007).

The river **Bregalnica** is the largest left tributary of the river Vardar, i.e. with its length of 225 km is the second longest in the Republic of North Macedonia. Its source starts from the Maleshevski Mountains on an elevation level of 1.720 m and at Gradsko to a level of 137 m it flows into Vardar (Gashevski 1978). The total drainage area is 4.344 km^2 with an average annual flow of 12.2 m^3/s (MOEPP 2010). The valley of the river Bregalnica has a typically composite character, that is, alternating between the ravine and the flatland sections. Between Berovska and Delchevska Kotlina (Pijanec) is the Razlovska Klisura and immediately after Delchevo begins the imposing Istibanjska Ravine. Further on it flows through the Kocani and Ovche Pole valleys. Downstream from the town of Shtip to the estuary in the river Vardar, the river Bregalnica runs through a ravine where the riverbed is embedded in young paleogene sediments (Gashevski 1978). The largest tributaries of Bregalnica are the rivers Kamenicka, Orizarska, Kochanska, Zletovska and Svetinikolska from the right and Ratevska, Zrnovska and Kriva Lakavica on the left.

The climate in the Bregalnica catchment is relatively arid, falling predominantly into the modified-continental climate type. There are four larger artificial accumulations in the inflow; Ratevo on the river Ratevska, Kalimanci on Bregalnica, Mantovo on Kriva Lakavica and Knezevsko lake on the river Zletovska. The catchment area includes fifteen municipalities, with 309 settlements (urban: 10, rural: 299), and a total of 205.618 inhabitants (MOEPP 2016).

15.4 Water Use and Wastewater

Law on Waters (Official Gazette of RM 2008) provides in Article 13 the definition of water use. Water use is use of water covering the activities of storage, capture, abstraction, diversion of surface and ground waters: consumption by humans, irrigation, industrial, technological, economic needs and for other purposes; to produce electricity and other power purposes; breeding of fish; shipping-navigation; for sport, recreation, bathing, tourism and accumulation, capture, extraction, use, transfer and other purposes. The major water users are population (drinking water supply), industry and mining, agriculture and energy production.

15.4.1 Drinking Water Supply

Supplying the population with drinking water is an essential priority for every country. Hence, the Census of Population, Households and Dwellings, as a statistical survey which covers the whole population, is also used to collect data on the manner in which the households are supplied with drinking water, as well as on the existence of appropriate water supply installations in dwellings. According to the data from the last census it can be noted that 86.69% of the total number of individual households are supplied with drinking water from public water pipeline, which represents a statistically high indicator (Table 15.1). Nevertheless, the mere fact that at the beginning of the 21st century, in the heart of Europe, there are still households drinking water which is neither biologically nor chemically examined, represents a worrying indicator (SSO 2017). The percentage of connections to public water supply systems in the municipalities-urban areas is much higher than the average and higher compared to rural areas. It varies from 82 per cent (Berovo, Kumanovo) to 100 per cent Skopje-Center municipality. Regarding rural areas, the percentage of the connected dwellings to the public water supply systems is very different and varies from 10 per cent up to 100 per cent (MOEPP 2010).

Table 15.1 Drinking water supply system in households

Total number of households	Public water pipeline, in the dwelling	Private air-compressed water tank, in the dwelling	Public water pipeline, outside the dwelling	Well	Other ways (outside the dwelling)
564.296	489.169	27.772	12.525	19.786	15.044
100%	86.69	4.92	2.22	3.51	2.67

Source State Statistical Office 2017

In the Republic of North Macedonia, there are mainly local water supply systems for cities, towns and villages. Many of them, initially constructed for the city or town, are extended to meet the water demands of the local rural areas. There are also regional water supply systems. For drinking water supply springs, groundwater and surface water or combined resource are used. Drinking water consumption varies from 300–400 l/capita/day in urban areas (Skopje even 500 l/capita/day), which is above the average of most European countries. In rural areas, demand is lower by about 200 l/capita/day (UNECE 2011).

15.4.2 Industry and Mining

Water supply in industry and mining includes all water quantities directly abstracted and supplied by business entities. According to the statistical data (SSO 2009, 2013, 2017), the amounts of water for the industry and mining (Table 15.2) in the majority (from 85.4% in 2004 to 99.2% in 2015) are provided from own water supplies, i.e. from ground and spring waters as well as from surface waters too (water courses, reservoirs and lakes). From all of them, the largest quantities of water are the ones of the reservoirs (around 70%), from the lakes (around 15%) and the least from the water courses (about 5%).

The largest consumers are the chemical industry, food processing, non-ferrous metal production, and the textile fiber and fabric industry. Here it is important to be noted that the varying of the water consumption from the industry and the mining industry as well is a result of the economic difficulties in our country. Some factories and mines are already closed, some work with reduced capacity and others have entirely changed its production. The used waters for technological applications from the industry and mining are quantities of water used or spent during the technological processes for example during production and cooling.

Regarding the used waters for technological applications, an oscillatory trend can be noticed in the period 2001–2015 where a particular spike is noticed in 2010 (Table 15.3). This variability of data above all is a result of the discontinuity in the industrial processes. In the period 2001–2015, for technological applications fresh waters (95%) were mostly used.

Table 15.2 Water supplied to industry and mining (thousands m^3)

	The volume of water abstracted and supplied			
	Total	Own water supplies (ground water, springs, surface water)	Public water supply	Other
2001	1.731.822	1.656.322	51.756	23.744
2002	1.633.626	1.567.059	50.046	16.521
2003	2.436.652	2.361.720	48.196	26.736
2004	4.053.069	3.462.649	563.684	26.736
2005	1.930.859	1.654.216	251.057	25.586
2006	1.841.649	1.639.116	189.585	12.948
2007	3.067.186	2.980.002	85.212	1.972
2008	1.994.711	1.922.116	68.452	4.143
2009	4.971.865	4.700.119	36.162	235.584
2010	6.920.554	6.368.589	516.497	35.468
2011	6.306.198	5.869.979	203.126	233.093
2012	5.114.842	5.006.246	102.695	5.901
2013	2.894.648	2.537.780	354.580	2.288
2014	3.462.927	3.427.825	32.283	2.819
2015	4.315.866	4.282.042	32.461	1.363

Source State Statistical Office (2009, 2013, 2017)

15.4.3 Agriculture

The favourable climate and pedological conditions in the Republic of North Macedonia create the basis for intensive agricultural production of specific highly cost-effective crops like wheat, vineyards, vegetable and fruits. Due to uneven distribution of precipitation in time and space, irrigation in our country is a necessary condition for successful agricultural production.

The arable agricultural area in the Republic of North Macedonia accounts for approximately 667.000 ha. If entirely constructed, irrigation schemes could irrigate around 400.000 ha, or 60% of the total arable land. So far, 106 smaller and larger irrigation schemes have been built covering an area of 163.693 ha of fertile arable land, i.e. 49.9% of the area that may be irrigated. Actual possible area for irrigation is about 126.600 ha (Fig. 15.2).

The irrigation schemes are mainly constructed in the period between 1958 and 1980, which means that some of them are under operation for more than 40 years. Out of the total area under irrigation, 61% is irrigated by sprinkling, while 39% by another type of surface irrigation (MOEPP 2010). Water for irrigation is mostly taken from reservoirs (75%), with the remainder coming from wells and rivers. Around 15.000 ha are irrigated with water from rivers, the main resource being the Vardar River (UNECE 2011).

Table 15.3 Water used for production purposes (thousands m^3)

	Total	Fresh water	Recycled water	Water used repeatedly
2001	1.645.595	1.642.017	3.557	353
2002	1.554.614	1.552.740	1.971	67
2003	2.350.453	2.348.620	74.884	265
2004	3.669.675	3.606.928	2.471	376
2005	1.622.325	1.622.325	0	0
2006	1.599.739	1.599.670	0	106
2007	2.960.540	2.952.070	9.782	1.108
2008	1.906.480	1.871.139	15.902	45.553
2009	4.398.217	4.388.573	4.402	6.516
2010	6.251.678	6.235.724	38.030	0
2011	4.953.364	4.925.581	31.446	406
2012	4.923.165	4.432.147	554.269	3.158
2013	2.437.998	2.425.304	13.627	1.217
2014	3.366.116	3.354.139	11.987	50
2015	4.275.252	4.265.856	20.215	325

Source State Statistical Office (2009, 2013, 2017)

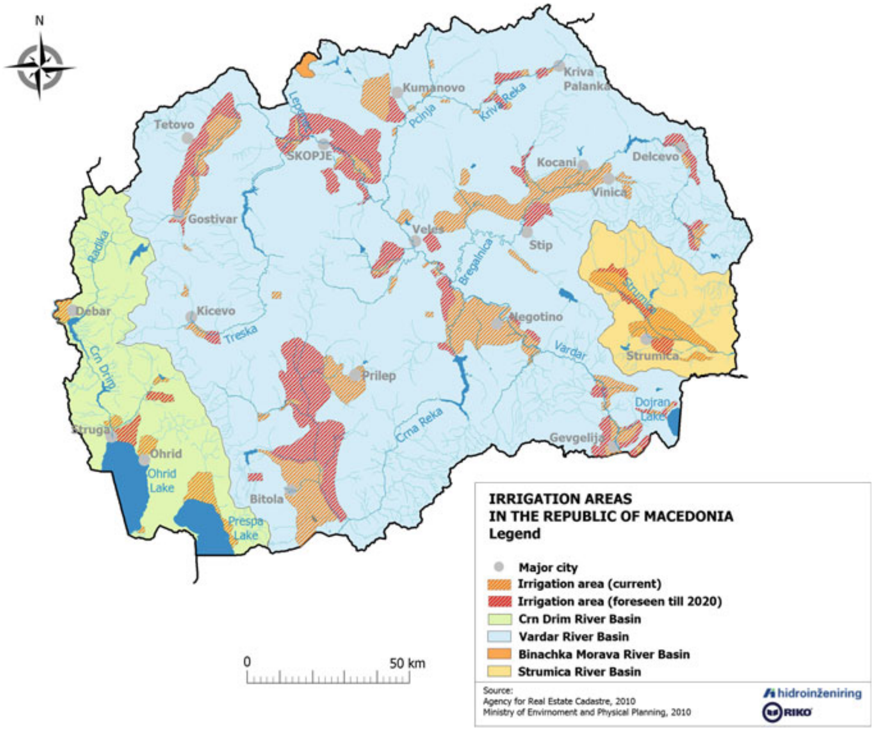

Fig. 15.2 Irrigation areas in the Republic of North Macedonia

15.4.4 Reservoirs

The territory of the Republic of North Macedonia mainly is characterized by mountains and lowland areas, which generally gravitate around major watercourses. Such configuration contributes to significant energy potential in the rivers, but also for their quick leaking. That means space is ideal for the construction of dams and creation of small and large reservoirs which allowing regulation on rivers and multipurpose optimal utilization of waters (MOEPP 2010).

In the Republic of North Macedonia, there are 24 large reservoirs and 170 small reservoirs (Fig. 15.3). They all have a specific purpose. The big reservoirs mostly have a multifunctional purpose (electricity production, irrigation, tourism and recreational activities, fish farming, etc.), and the smaller one is with the mono-functional purpose (Markoski et al. 2014).

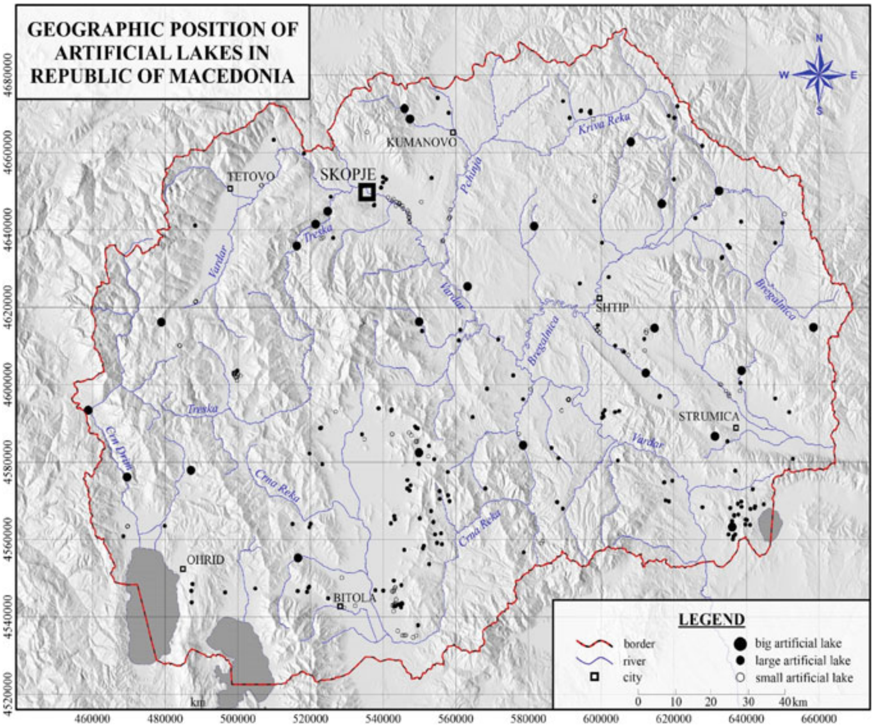

Fig. 15.3 The geographic position of artificial lakes in the Republic of North Macedonia *Source* Markoski et al. 2014

15.4.5 Wastewater

Wastewater is any water that has been affected by human use. Wastewater is "used water from any combination of domestic, industrial, commercial or agricultural activities, surface runoff or stormwater, and any sewer inflow or sewer infiltration" (Tilley et al. 2014). Therefore, wastewater is a byproduct of domestic, industrial, commercial or agricultural activities. Wastewater is one of the most dangerous pollutants of surface water in the Republic of North Macedonia.

15.4.5.1 Wastewater from Households

The wastewaters from the households in our country, if not being treated, present a significant impact on the quality of the surface waters, mainly because of the deposits of organic materials and nutrients, as well as dangerous substances. The wastewaters from the settlements should be treated inappropriate treatment stations before being discharged (Analytica 2009). Generally, existing sewage systems in major urban areas are designed to collect and convey both, wastewater and precipitation water. Only 12 cities have constructed separate sewage systems. The city of Skopje has constructed a separate system for wastewater (56%) and precipitation water (18%). Usually, collectors for precipitation water discharge water into the closest recipient, while wastewater is discharged downstream from the urban areas (MOEPP 2010).

About 60% of the discharged sewage (Table 15.4) is connected to the public sewage system, while 40% of sewage from households is not connected (21% with a septic tank, 12% free wastewater discharge and 7% no installation). The data that as many as 40% of the total number of dwellings are not equipped with installations for discharging wastewater from the households into public sewage system show that little care is taken in the Republic of North Macedonia for protection of the environment from household wastewater.

The types of treatment according to the Directive for treatment of the urban wastewaters are taken as representative indicators for the level of treating and the potential improvement of the aquatic environment. With the primary (mechanical) treatment parts of the suspended solid particles are removed, while the secondary (biological) treatment uses aerobic and anaerobic micro-organisms for decomposition of most organic matter and preserving parts of the nutrients (about 20–30%)

Table 15.4 Dwellings according to wastewater discharge installations, Census 2002

	Total number of dwellings	Public sewage system	Septic tank	Free wastewater discharge	No installation
Absolute numbers	697.529	417.653	143.353	85.007	51.516
%	100.0	59.88	20.55	12.19	7.38

Source State Statistical Office 2017

(Dimitrovska et al. 2012). The tertiary (advanced) treatment more efficiently removes the organic matter. Generally, this includes preserving of the phosphorous, and in some cases removing of the nitrogen. The primary treatment on its own does not remove the ammonium, while the secondary (biological) treatment removes up to 75% (Dimitrovska et al. 2012; EC 1991).

Regarding the treatment of the wastewaters, the situation is more than concern about the fact that only a small part of the wastewater from the households is being purified using either mechanical (8%), biological (7%) or any other treatment (0.5%). Despite the rising trend, the current state is unsatisfactory with regard to EU requirements (MOEPP 2018c).

Regarding the urban wastewater quantities, there is no monitoring of the discharged wastewater from municipal sewage systems. There is no data on the urban wastewater quality, due to not existing systematic monitoring. In the Law on Waters (Article 150), there are provisions that any wastewater producer must install, operate and maintain measuring devices, as well must provide wastewater quality analysis; in practice the law is not respected. Only the laboratory of the Water Supply and Sewage Utility in Skopje (Centre for sanitation control and supervision) has equipment for performing analyses. The wastewater quality is monitored at six locations where the main sewage pipes discharge the wastewater into the river Vardar (MOEPP 2010). At the moment, a full treatment of wastewater is provided only for the urban municipalities of Kumanovo and for the municipalities Struga and Ohrid trough one joint treatment plant where wastewater treatment plants are operational. There are several small size wastewater treatment plants (Table 15.5) located in rural municipalities (smaller towns or villages), which usually provide a single solution for treatment of the wastewater of smaller settlements (Ilinden, Dolneni, Krivogastani, Cucer Sandevo, Makedonski Brod, Resen, Dojran and Berovo).

All these facts illustrate that most of the municipalities, especially the rural ones, have neither public sewage collection systems nor facilities for treatment and disposal of wastewater. Due to this, most of the raw or untreated sewage is discharged into streams, rivers and lakes and it creates a serious threat to the environment and public health (MOF 2018). Taking into consideration all the existing treatment plants, in operation or close to commissioning, the total rate of population served with wastewater treatment would be approximately 20%. However, especially most bigger cities like Skopje, Bitola, Prilep, Strumica, Tetovo, Gostivar, Veles and Stip have no wastewater treatment plant. Due to their high discharge of organic and trophic material, they cause significant pollution in the rivers, which has a terrible impact on the aquatic ecosystem, with its aquatic communities such as fish fauna, macroinvertebrates and macrophytes. Sewage treatment plans have top priority, both on the local and national level (UNECE 2011).

In the meantime, there were built and put into use the following wastewater purification stations: Strumica (53.000 p.e.[1]), Kichevo (32.000 p.e), Gevgelija

[1]According to the UWWT, p.e. (population equivalent) means the organic biodegradable load having a five-day biochemical oxygen demand (BOD_5) of 60 g of oxygen per day.

Table 15.5 Wastewater treatment plants in Republic of North Macedonia

Location/City/ Settlement	Population equivalent (p.e.)	Condition	Treatment
Village Kucicino, Municipality of Chesinovo—Oblesevo	700 p.e	Under construction	Wetland Biological treatment and treatment of the sludge
Karbinci	1.100 p.e	Under construction	Wetland Biological treatment and treatment of the sludge
Ilinden (two WWTPs for the settlements Ilinden and Kadino)	1.250 p.e.	Operational	Biological treatment
Rankovce (for the settlements Petralica—Ginovce)	1.500 p.e	Constructed in 2008. Not operational yet due to lack of households connected	Mechanical, biological treatment and sludge treatment
Dolneni	3.200 p.e	Operational	Biological treatment
Krivogastani	3.500 p.e	Operational	Lagoon system with mechanical and biological treatment, treatment of the sludge and its use for agriculture purposes
Cucer Sandevo (for the settlements Brazda, Gluvo and Mirkovci)	The plant was in initial phase designed for 3.000 p.e., with the possibility for extension of the plant to 9.000 p.e	Operational	The mechanical pre-treatment, trickling filters and digestion of the settled sludge (Imhoff tanks) were constructed. Drying of sludge was solved by drying sludge beds.
Makedonski Brod	5.000 p.e	Operational	Mechanical treatment, biological treatment and treatment of drying and stabilization of the sediment. (sludge treatment in drying bed)
Saraj	8.500 p.e	Construction was finished in 2015, WWTP should be a takeover by the Saraj Municipality, and Municipality will be final user of the plant. It is not still in function because of administrative obstacles	Mechanical and biological secondary treatment with trickling filters, recipient Treska River

(continued)

Table 15.5 (continued)

Location/City/ Settlement	Population equivalent (p.e.)	Condition	Treatment
Resen (located in settlement Ezerani)	12.000 p.e	Operational	Two Phases: mechanical and biological treatment (sludge treatment in drying bed)
Dojran (located in settlement Nov Dojran)	12.000 p.e	Operational	Two Phases: mechanical and biological treatment
Berovo	14.000 p.e	Operational	Two Phases: mechanical and biological treatment
Sveti Nikole	17.500 p.e	Under reconstruction	Mechanical and biological secondary treatment (trickling filters)
GjorcePetrov (located in settlement Volkovo)	20.000 p.e	At the final phase of construction	Mechanical and Biological Wastewater Treatment will be applied, and the plant is designed for fully automatic operation.
Gevgelija	15.000 p.e	Under construction	Mechanical and biological treatment, and treatment of the sludge
Kumanovo	100.000 p.e	Operational	Mechanical treatment, degreasing method, aerobic treatment and sedimentation
Ohrid and Struga (located in settle-ment Vranishte)	120.000 p.e	Operational	Mechanical and biological treatment of wastewater
Prilep	95.000 p.e	Under construction	Mechanical treatment, biological treatment and treatment of drying and stabilization of the sediment (according to the EU WWT Directive)

Source Ministry of Finance

(32.000 p.e) and Radovish (25.000 p.e). The following cities have received approval from the Ministry of environmental and physical planning for building purification stations: Veles (53.000 p.e), Shtip (53.000 p.e), Kochani (50.000 p.e), Tetovo (95.000 p.e) and Bitola (112.000 p.e). In its final stages of completion is the preparation of the technical documentation for the biggest agglomeration in our country, Skopje (650.000 p.e).

Under the Urban Wastewater Treatment Directive, the EU Member States are required to provide connection to wastewater collection systems in all agglomerations exceeding 2.000 population equivalent. The secondary treatment-the biological treatment must be provided for all agglomerations that are larger than 2.000 population equivalent which discharges wastewaters directly in the fresh waters-recipient. Special requests with different terms or deadlines for fulfilling in dependence on the sensitivity of the recipient waters are being established for agglomerations with more than 10.000 population equivalent (Dimitrovska 2010). In accordance with the Urban Waste Water Treatment Directive in the Republic of North Macedonia, a total of 118 agglomerations are defined, two of which are over 100.000 p.e., 28 in size from 10.000–100.000 p.e. and the remaining 88 are from 2.000 to 10.000 p.e. It has been established that 30 agglomerations may be subject to requirements for reducing nutrients. The largest agglomeration is Skopje, which is about 31.5% of the total wastewater generated in the agglomerations above 2.000 p.e. and about 37% of the total sewage in agglomerations over 10.000 p.e. (EUOPRD 2017).

15.4.5.2 Wastewater from Industry and Mining

The wastewaters from the industry and mining are the result of their usage in the technological processes for production, cooling systems (most often are being discharged without previously being cooled), from sanitary facilities and other sources. Major quantities of wastewaters in analyzed period 2001–2015 were created during the production processes (83.7%), form cooling (8.3%), from sanitary waters (5.2%) and 2.8% from other waters (SSO 2009, 2013, 2017). In our country, a big problem appears from the discharging of untreated wastewaters from the industry and mining in specific recipients (soil, sewer, watercourses, reservoirs and lakes) (Fig. 15.4). In the analyzed period certain changes regarding the recipients of these wastewaters can be noticed (Table 15.6).

The highest percentage, (on average for the whole period of 79.3%) is discharged into watercourses where the lowest values (33.6%) occur in 2005 and the highest (99.6%) in 2015. Furthermore, with a higher percentage, (on average for the entire period of 11.7%), they are discharged into the reservoirs where the highest values occur in 2005 (62.9%), 2009 (30.4%) and 2013 (36.6%). Smaller quantities are released in the public sewage system (on average for the entire period of 4.7%), where the highest values occurred in 2004 (15.8%), 2009 (13.1%) and 2013 (10.9%). The remaining part of the untreated wastewater is discharged into the soil

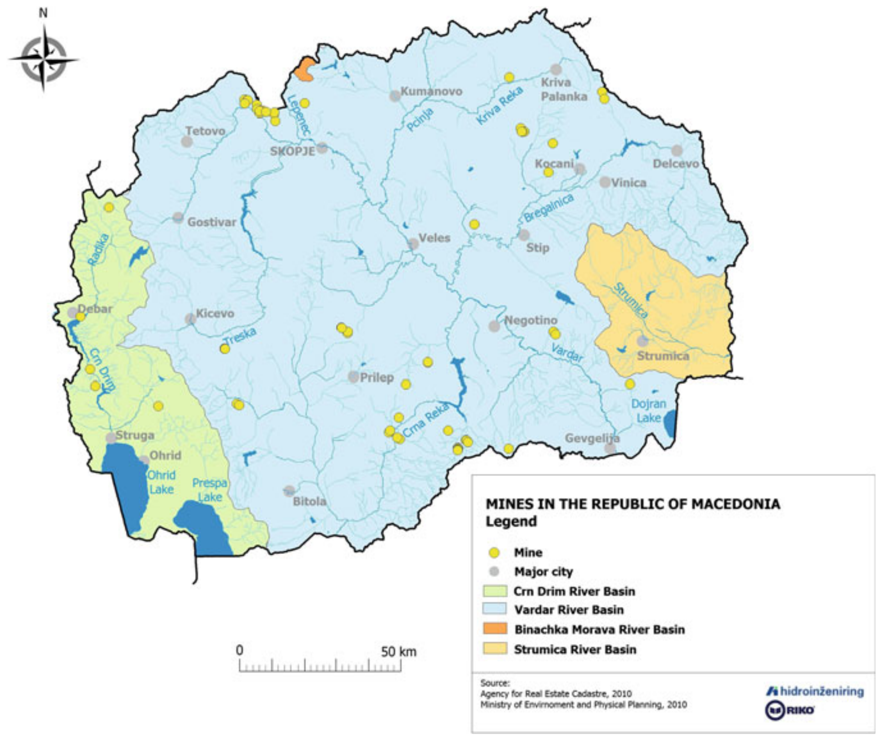

Fig. 15.4 Mines in the Republic of North Macedonia

and the lakes. From 2004 to 2012, as in 2015, there is no discharge of unpurified wastewater from the industries and the mining into the lakes.

This slight change is a result of the changes in the industrial production and in the mining wherein the given period, a part of the industrial objects and mines were not operational, and the newly built smaller industrial objects are connected to the public sewer systems. In the Republic of North Macedonia, only around 3–4% of the total wastewater quantity from industry and mining are treated. The public sewage system is the main recipient of treated wastewater (Fig. 15.5). In 2015, approximately 34.8% of the total wastewater quantities were discharged in watercourses, 65.0% in the public sewage system, and the rest in water reservoirs and soil (SSO 2017).

We need to emphasize that the percentage of treatment of the wastewaters is quite small and unsatisfactory and there is a problem with the technical correctness of the treatment facilities which in great part are obsolete. Given the fact that most of the wastewater that comes from the industry and mining is being discharged without treatment, it is necessary to major efforts to be made for the improvement of the condition in terms of building new facilities that currently show no tendency to rise.

Table 15.6 Discharge of unpurified wastewaters from industry and mining, by the recipient (thousands m^3)

	Total	Ground	Public sewage system	Water Courses	Reservoirs	Lakes
2001	1.649 597	2.320	34.730	1.179.742	18.431	414.374
2002	1.557 107	1.986	33.303	1.501.239	20.005	574
2003	2.353 371	2.317	90.995	2.236.985	22.742	332
2004	3.531 724	112.685	559.090	2.847.634	12.315	0
2005	1.551 604	27.705	30.226	517.528	976.145	0
2006	1.622 382	28.931	80.519	1.461.068	51.864	0
2007	2.956 200	14.765	96.066	2.279.218	566.153	0
2008	1.811 694	5.389	162.879	1.092.451	550.975	0
2009	4.830.669	11.280	634.434	2.783.655	1.401.300	0
2010	6.221 267	19.715	449.584	5.742.362	9.605	0
2011	5.062 710	14.835	123.658	4.884.306	39.911	0
2012	4.808 627	7.551	113.683	4.237.414	449.979	0
2013	2.326.176	1.016	253.274	1.226.542	845.342	2
2014	3.331.536	586	16.832	3.298.540	15.573	5
2015	4.278.699	691	16.184	4.261.814	10	0

Source State Statistical Office (2009, 2013, 2017)

15.4.5.3 Impact from Agriculture

Major agricultural contributors to water pollution (and the main targets for water pollution control) are nutrients, pesticides, salts, sediments, organic carbon, pathogens, metals and drug residues. The importance of different forms of agricultural pollution varies with individual situations, and adverse impacts such as eutrophication[2] (which may include sediments, nutrients and organic matter) arise from combinations of stressors (FAO, IWMI 2017).

The use of mineral fertilizers in agriculture in the Republic of North Macedonia in recent years shows a downward trend, which is undoubtedly due to the reduced agricultural activity, where nitrogen fertilizers are still most used, and mixed, phosphoric and potassium fertilizers are also of a smaller percentage (MOEPP 2018a). In crop production, water pollution from nutrients occurs when fertilizers are applied at a higher rate than they are fixed by soil particles or exported from the soil profile (e.g. by plant uptake or when they are washed off the soil surface before plants can take them up). Excess nitrogen and phosphates can leach into groundwater or move via surface runoff into waterways. Phosphate is not as soluble as nitrate and ammonia and tends to get adsorbed onto soil particles and enter water

[2]According to the UWWT, 'eutrophication' means the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned.

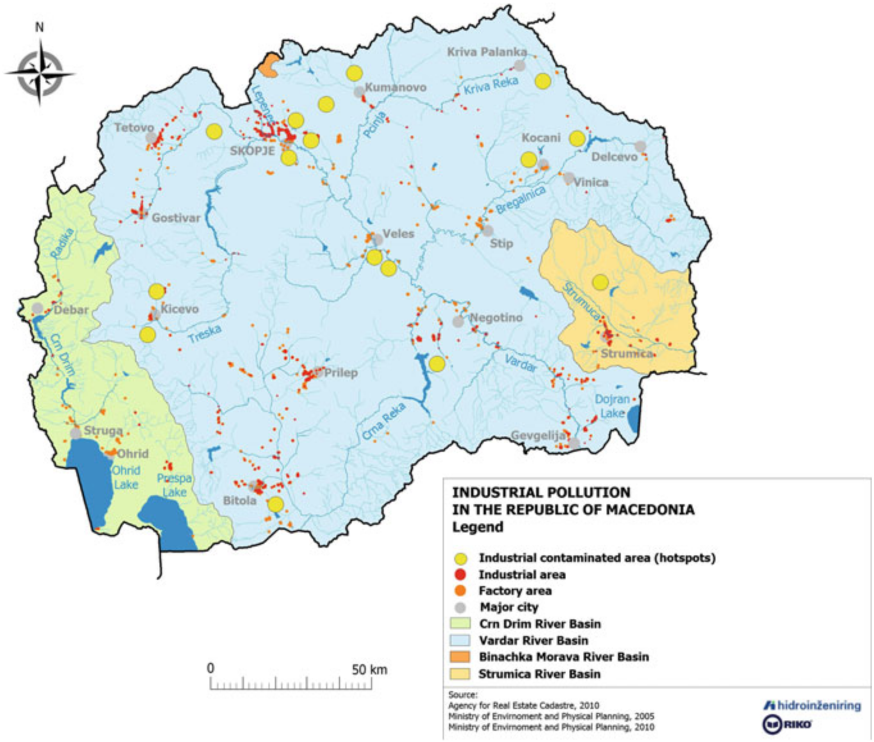

Fig. 15.5 Industrial pollution in the Republic of North Macedonia

bodies through soil erosion (FAO, IWMI 2017). Of the pesticides, the most commonly used are the fungicides (68.4%), with insecticides (21.0%) and herbicides (10.6%) with a lower percentage, and there has been a decreasing trend in recent years in relation to their use (MOEPP 2018b). When improperly selected and managed, they can pollute water resources with carcinogens and other toxic substances that can affect humans (FAO, IWMI 2017).

The large water pollution comes from the washing of some substances from the agricultural land treated with fertilizers and pesticides. The harmful and toxic substances, but also part of the plant nutrients, are washed out from the soil by dissolving into the water that comes from the rains or the one which is used for irrigation and then flows out into the rivers. The nutrients when they come to the rivers, the lakes and the irrigation canals, especially nitrogen and phosphorus, can cause eutrophication. The damage from the eutrophication is double, on one hand the large mass of plants in the water can prevent or hinder the use of water for production, fishing, bathing and irrigation. On the other hand, the plants in the water consume oxygen more than what is complemented where extinction occurs and the decay of plants and algae where the water receives unpleasant smell and taste. All these changes reflect the water quality by reducing its usefulness (Dimovski 1994).

15.5 Water Quality and Pollution Status of the Rivers

The monitoring of the quality of the surface waters is being done by the Hydro-Meteorological administration of the Republic of North Macedonia. The River Monitoring System Project in North Macedonia (RIMSYS) is a collaborative project undertaken by Switzerland and North Macedonia. The objectives of RIMSYS includes the long-term assessment of water quality and discharges as well as the establishment of an effective forecasting and alarm system. The monitoring comprises of 20 measuring stations located on the rivers, lakes and accumulations (Fig. 15.6).

The classification of the surface waters is performed in accordance with the bylaws: Ordinance on water classification (Official Gazette of RM 1999) and an Ordinance for categorization of watercourses, lakes, accumulations and underground waters (Official Gazette of RM 1999). "According to this classification, today there are five classes of waters, where the quality of the first (I) class is the best, and the quality of the fifth (V) class is the worst" (Dimitrovska et al. 2012). In the meantime, according to the Water Framework Directive and the Law on waters (2008), a new Decree on the classification of surface waters has been adopted

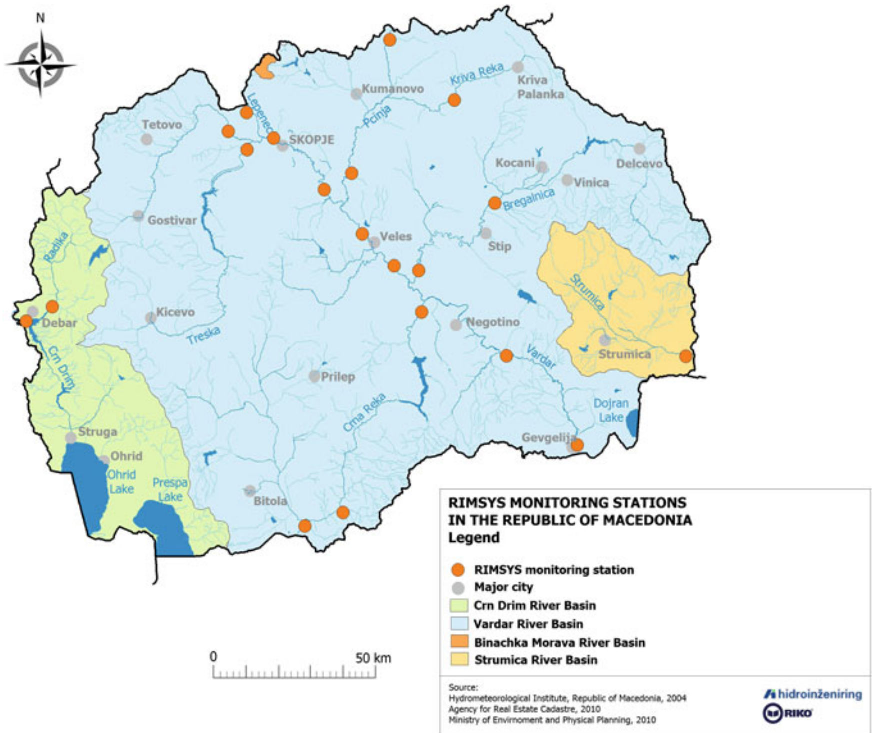

Fig. 15.6 RIMSYS monitoring stations in the Republic of North Macedonia

(Official Gazette of RM 2016), which will apply from 1 January 2019. It defines five classes of water quality: high, good, moderate, insufficient and bad ecological status. The lowest two classes, "insufficient" and "bad" are comparable to "lead at risk of eutrophication or subject to eutrophication".

The pollution of surface watercourses in the Republic of North Macedonia is most often transmitted through indicators (MOEPP 2015) which are defined in accordance with the basic group of indicators (CSI) of the European Environmental Agency: Oxygen consuming substances in rivers—MK NI 019 (BOD_5 and total ammonium) and Nutrients in freshwater—MK NI 020 (nitrate, nitrite and orthophosphate). The analysis will be taking into account the average annual concentrations of the mentioned parameters for the main rivers Vardar, Bregalnica and Crna Reka, for the period 2001–2015.

Biochemical oxygen demand (BOD) and ammonium are key indicators of organic pollution in water. BOD shows how much-dissolved oxygen is needed for the decomposition of organic matter present in water. Concentrations of these parameters frequently increase as a result of organic pollution caused by discharges from wastewater treatment plants, industrial effluents and agricultural run-off. Severe organic pollution may lead to rapid de-oxygenation of river water, a high concentration of ammonia and disappearance of fish and aquatic invertebrates. The most important sources of organic waste load are household wastewater; industries, such as paper or food processing; and silage effluents and manure from agriculture. (UNECE 2017).

The key indicator for the status of oxygenation of the water bodies is the biochemical oxygen demand (BOD), which represents oxygen demand as a result of the organisms in the water that consume the organic substance which can be oxygenated. The average annual concentration of BOD within 5 or 7-day incubation (BOD_5/BOD_7) is expressed in mgO_2/L (SSO 2017).

From the Fig. 15.7, can be noticed that in the analyzed period there is a high concentration of BOD_5 in specific measurement points in the rivers the Vardar and Crna Reka that for the period 2001–2015 mostly correspond to water quality for III and IV class. Higher concentrations of BOD_5 in the river Vardar are registered in 2001, 2002, 2004 and 2008 and the Crna Reka in 2004, 2007 and 2008. In the river Bregalnica, there is a trend for increasing of the amounts of BOD_5 starting from 2003 where for the period 2004–2009 the concentrations correspond to water quality for III and IV class. According to the new Decree for classification of surface waters, in relation to the concentrations of BOD_5, the river Vardar in the initial period of analysis is continuously in an insufficient/bad ecological status, while from 2010–2015 it is in a moderate/insufficient ecological condition. The river Bregalnica is mostly in a good/moderate ecological condition with occasional deterioration in the quality of a moderate/insufficient ecological condition. Crna Reka in the period 2001–2008 is continuous with insufficient/bad ecological status and the next period varies from moderate/insufficient to good/moderate ecological state.

As to the concentrations of total ammonium in the rivers expressed in mgN/l, in the analyzed period stable trend was tracked up to 2008, followed by decrease in

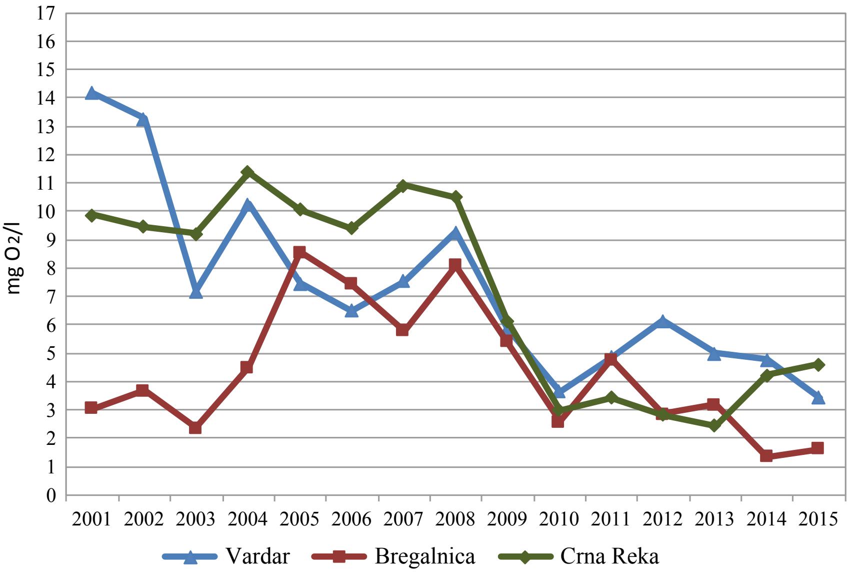

Fig. 15.7 BOD$_5$ concentration in rivers *Source* State Statistical Office (2009, 2013, 2017)

ammonium concentrations in the period from 2009 to 2010, while the remained period which is subject of analysis was characterized by a slight increase (Fig. 15.8). As far as ammonium concentrations in rivers are concerned, there are significant variations every year. Higher concentrations of ammonium are registered in Crna River and the Vardar in 2001 corresponding to the water quality of III and IV class. According to the new Decree on classification of surface waters, in relation to the concentrations of total ammonium, the river Vardar in the whole considered period is in good/moderate ecological condition, while the river Bregalnica is better, and it is predominantly in high/good ecological condition, except in 2001 and 2003 where it is in good/moderate ecological condition. Crna Reka in the period 2001–2008 is of poorer quality where it is in moderate/insufficient ecological condition and from 2009–2015 it has a good/moderate ecological status.

"In the Republic of North Macedonia, there is a variable trend in the concentrations of BOD$_5$ and the concentrations of ammonium in the rivers, during the period under review" (http://www.moepp.gov.mk/?page_id=4436&lang=en). There was a stable trend in BOD$_5$ and concentrations of ammonium in the rivers in the Republic of North Macedonia in the period 2001 to 2008. The decrease in BOD$_5$ concentrations and ammonium concentrations were tracked in 2009 and 2010, followed by a slight increase of concentrations in the river of Vardar. "These results could reflect the status of inefficient treatment of urban and industrial wastewaters in the country, as well as the inadequate protection of river basins" (https://www.eea.europa.eu/soer/countries/mk/freshwater-state-and-impacts-macedon).

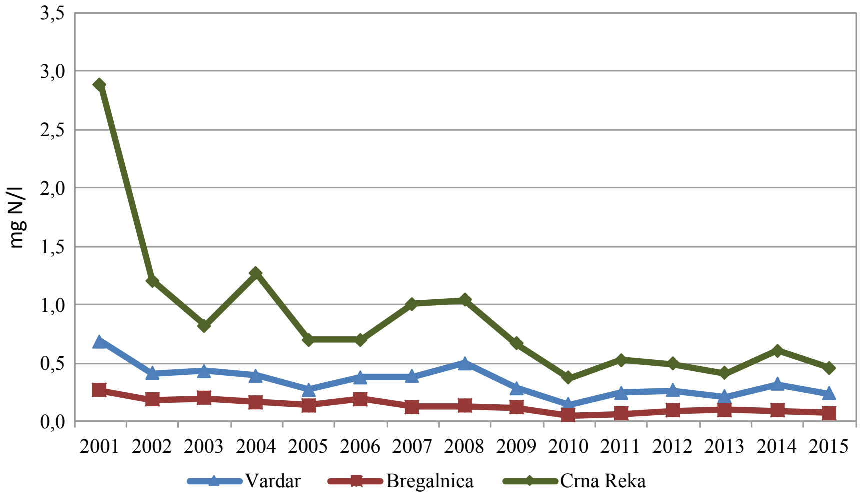

Fig. 15.8 Total ammonium in rivers *Source* State Statistical Office (2009, 2013, 2017)

Nutrients in freshwater is an indicator which follows the changes of the concentrations of nutrients (nitrates, nitrites and orthophosphates) in the rivers. The concentration of nitrate is expressed as mg NO_3/L, nitrite as mgNO_2/L and orthophosphate as mgP/L. Large inputs of nutrients to freshwater bodies from the urban, industrial and agricultural point and fugitive sources can lead to eutrophication of water bodies. This causes ecological changes that can result in a loss of plant and fish species (reduction in ecological status) and have negative impacts on the use of water from these water bodies for human consumption and other purposes. The indicator can be used to illustrate current geographical variations in nutrient concentrations and long-term trends (UNECE 2018).

Nitrates are the measurement of the most oxidized and stable form of nitrogen in a water body. It is the principle form of combined nitrogen found in natural waters and results from the complete oxidation of nitrogen compounds. Nitrate is the primary form of nitrogen used by plants as a nutrient to stimulate growth. Excessive amounts of nitrogen may result in phytoplankton or macrophyte proliferations (EPA 2018).

The average annual concentrations of nitrates for the whole analyzed period of the main watercourses are relatively stable (Fig. 15.9). Only in 2003, higher concentrations are registered in the river Bregalnica. The concentration of this parameter with higher values appears in the river Vardar in regard to other rivers, but still, the concentrations of nitrates in all the rivers are in accordance with the Regulation for categorization of the waters in the Republic of North Macedonia.

According to the new Decree on the classification of surface waters, in relation to the nitrate concentrations, the river Vardar is in a good/moderate ecological

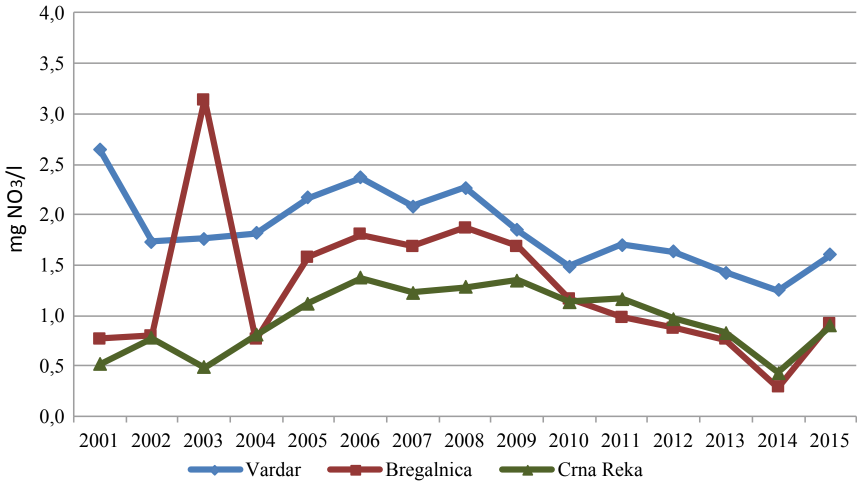

Fig. 15.9 Nitrates in rivers *Source* State Statistical Office (2009, 2013, 2017)

condition throughout the analyzed period. Only in 2003, the river Bregalnica was of worse quality, i.e. it was moderately/insufficiently ecological condition, from 2005–2010 it had a good/moderate ecological status, and in the past few years, it has a better quality, i.e. with a high/good ecological status. Also, in Crna Reka, there were also variations in its quality in the period of 2001–2004 and 2012–2015 with a high/good ecological status, and from 2005 to 2011, it is with a slightly lower quality, i.e. with a good/moderate ecological status.

Nitrites is an intermediate in the oxidation of ammonia to nitrate. Many effluents, including sewage, are rich in ammonia, which in turn can lead to increased nitrite concentrations in receiving waters. Therefore high levels of nitrite in river waters may indicate pollution. This form of nitrogen can be used as a source of nutrients for plants, and its presence encourages plant proliferation. Nitrite is also toxic to aquatic life at relatively low concentrations. In unpolluted waters, nitrite levels are generally low (< 0.01 mg/L N) (EPA 2018).

The average annual concentrations of nitrites in the whole analyzed period have high values in all the rivers and correspond to water quality for III and IV class (Fig. 15.10). The highest concentrations are noticed in the river Vardar in 2001 and 2003. The concentrations of nitrites have a trend of decline in the period 2003–2015 but still, correspond to water quality for III and IV class. According to the new Decree on Classification of Surface Waters, related to the nitrite concentrations the river Vardar is characterized by worse quality compared to other rivers, i.e. from 2001–2003 with moderate/insufficient ecological status and in the remaining period it has a good/moderate ecological status. The river Bregalnica is almost in the entire considered period with a high/good ecological status except in 2003, 2006 and 2014 when it is in a good/moderate ecological condition. The situation with Crna Reka is

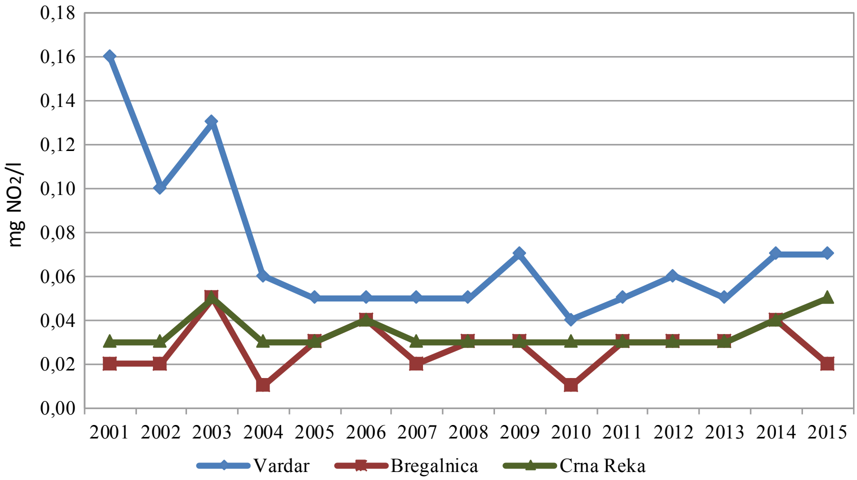

Fig. 15.10 Nitrites in rivers *Source* State Statistical Office (2009, 2013, 2017)

similar, where it is usually of high/good ecological status except in 2003, 2006, 2014 and 2015 when it is in good/moderate ecological condition.

Orthophosphate forms are produced by natural processes, but significant man-influenced sources include: partially treated and untreated sewage, runoff from agricultural sites, and application of some lawn fertilizers. Orthophosphate is readily available to the biological community and typically found in deficient concentrations in unpolluted waters (EPA 2018). In the analyzed period, a slight drop was recorded in the mean annual concentrations of orthophosphates in all three rivers. An exception was recorded in the period from 2013 to 2015 when an insignificant increase in orthophosphates concentrations was recorded in all three rivers. (Figure 15.11).

Higher concentration levels of orthophosphates are noticed on the river Vardar, which in the period of 2005–2012 are significantly reduced, while in 2013 and 2014 a slight increase is noticed. The orthophosphate concentrations in the rivers Bregalnica and Crna Reka in the period between 2004 and 2015 show a minor downward trend. According to the new Decree on the classification of surface waters, in relation to the concentrations of orthophosphates in all rivers in the whole considered period, it is usually found out that there is insufficient/bad ecological status.

In the analyzed period, a slight drop was recorded in the mean annual concentrations of nutrients in all three rivers. An exception was recorded in the period from 2013 to 2015 when an insignificant increase in orthophosphates and nitrates concentrations were recorded in all three rivers. The trend of lowering of the pollution which is shown for the major watercourses is positive in regard to the water quality, but unfortunately, this trend is a result of the lowered intensity of industrial activity, and not as a result of the undertaken measurements for protection of the surface

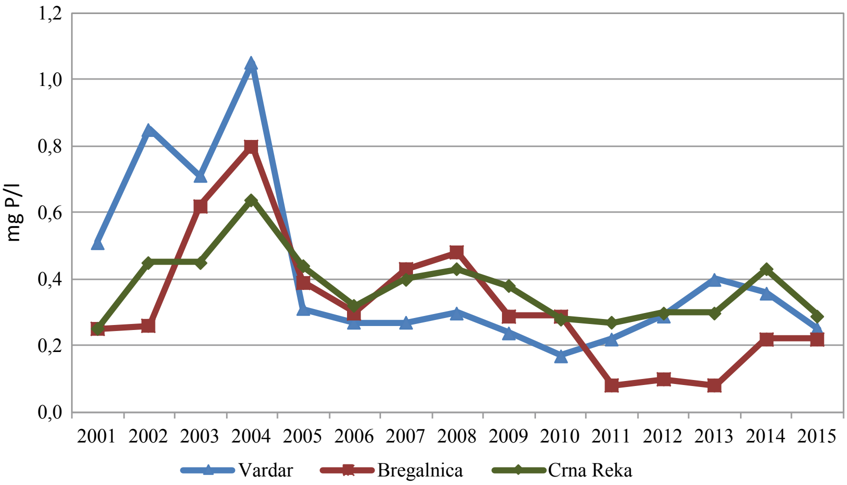

Fig. 15.11 Orthophosphates in rivers *Source* State Statistical Office (2009, 2013, 2017)

waters. In addition to this, we can add the fact that certain smaller confluents are being turned into collectors of wastewaters that emanate from the discharges of the major polluters. The quality of the surface water is better in areas with low population density and areas without industry (Dimitrovska et al. 2012).

15.6 Conclusions

The waters in the major rivers in the Republic of North Macedonia are seriously endangered by various sources of pollution, but the main point sources are household waste, industry and mining. The problematic sources of pollution such as agriculture and wastewater from the dispersed population are also a problem. The data that as many as 40% of the total number of dwellings are not equipped with installations for discharging wastewater from the households into public sewage system show that little care is taken in the Republic of North Macedonia for protection of the environment from household wastewater. Regarding the treatment of the wastewaters, the situation is more than concern about the fact that only a small part of the wastewater from the households is being purified using either mechanical, biological or any other treatment. Despite the rising trend, the current state is unsatisfactory with regard to EU requirements. Therefore, the introduction of regular treatment of wastewaters in the country is a top priority, both at local and national levels. Regarding the urban wastewater quantities, there is no monitoring of the discharged wastewater from municipal sewage systems. There is no data on the urban wastewater quality, due to not existing systematic monitoring. In the Law on Waters (Article 150), there are provisions that any wastewater producer must install, operate and maintain measuring devices, as well must provide wastewater quality analysis; in practice, the law is not respected. Only the laboratory of the Water Supply and Sewage Utility in Skopje (Centre for sanitation control and supervision) has equipment for performing analyses.

The wastewater quality is monitored at six locations where the main sewage pipes discharge the wastewater into river Vardar. At the moment, a full treatment of wastewater is provided only for the urban municipalities of Kumanovo and for the municipalities Struga and Ohrid trough one joint treatment plant where wastewater treatment plants are operational. There are several small size wastewater treatment plants located in rural municipalities (smaller towns or villages), which usually provide a single solution for treatment of the wastewater of smaller settlements. In the meantime, wastewater treatment plants have been built and put into operation in Strumica, Kicevo, Gevgelija and Radovis. The following cities have received consents for the construction of water treatment plants by the Ministry of Environment and Physical Planning: Veles, Shtip, Kocani, Tetovo and Bitola. At its final stage is the preparation of the technical documentation for the largest agglomeration in the Republic of North Macedonia, Skopje.

In the Republic of North Macedonia, a big problem appears from the discharging of untreated wastewaters from the industry and mining in certain recipients (soil, sewer, watercourses, accumulations and lakes). The largest percentage is discharged into the watercourses, then into the reservoirs, the public sewage system, and the least are discharged into the soil and the lakes. In the Republic of North Macedonia, only around 3–4% of the total wastewater quantity from industry and mining are treated. It is important to point out that the treatment of wastewater greatly depends on the technical functionality of the treatment facilities, and the construction of new facilities shows no significant upward tendency, which, of course, indicates that it is necessary to make further efforts for improving the situation in this sphere. The diffuse sources of water pollution from agriculture are nitrate fertilizers and pesticides. These diffuse sources cannot be precisely located due to the large area of contamination and are spread diffusely in space and time. Due to the reduced agricultural activity in our country there is a trend of reduction of the total quantity of used mineral fertilizers and pesticides. However, although they are used in smaller quantities, they certainly have a great impact on the quality of the rivers. Large water pollution comes from the washing of some substances from agricultural land treated with fertilizers and pesticides. The irrigation process increases the risk of the presence of nitrates and pesticides in rivers whose presence most often causes eutrophication.

The concentrations of BOD_5 and concentration of ammonium in the analysed period show a variable trend.. There was a stable trend in BOD_5 and concentrations of ammonium in the rivers in the Republic of North Macedonia in the period 2001 to 2008. The decrease in BOD_5 concentrations and ammonium concentrations were tracked in 2009 and 2010, followed by a slight increase of concentrations in the river of Vardar. These results reflect the situation, above all, of the small percentage of treatment of urban and industrial wastewater, as well as the inadequate regime for the protection of river basins.. In the analyzed period, a slight drop was recorded in the mean annual concentrations of nutrients in all three rivers. An exception was recorded in the period from 2013 to 2015 when an insignificant increase in orthophosphates and nitrates concentrations were recorded in all three rivers. According to the pressures in the rivers, there is a higher concentration of the analyzed parameters causing eutrophication and result in a worse ecological state. It is necessary to avoid further deterioration of the status of the waters in the analyzed rivers, which would contribute to achieving a good ecological status.. Sufficient water of good quality is essential for public health, the industry and agriculture. Hence, protecting water resources from undue pressure by human activities serves a sustainable economic development. It is also a prerequisite for preserving ecosystems which all depend on water. To achieve this aim, integrated water resources management at the river basin scale is the core approach of the North Macedonian Water Law and the EU Water Framework Directive. In the process of accession to the EU, the Republic of North Macedonia is making great efforts to fully harmonize the national legislation with the relevant environmental protection directives. In this context, waste water management and treatment plays a key role in achieving one of the basic objectives of the Water Framework Directive for the qualitative protection of water bodies. For this purpose, the project “Development of a national study for waters”, financed by IPA, is currently being worked out. The main objective of the project is to protect the environment from the negative impacts of urban wastewaters by collecting and purifying them before being omitted, ensuring safe drinking water supply and increasing the management capacity in the water sector.

15.7 Recommendations

Taking into consideration the main pressures on the water quality in the major watercourses in the Republic of North Macedonia, it is necessary to define the appropriate measures that would improve their ecological status. The main measures are as follows:

- To increase the percentage of the population connected to sewer systems
- To provide a high percentage of purification of the urban waste waters
- To provide a strict level of control and prevention from polluting and contaminating the watercourses from the industry
- To do a controlled use of the mineral fertilizers and pesticides.

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Part VIII
Water Resource Management in Greece

Chapter 16
Agricultural Water Management in Greece

Nicholas Dercas

Abstract The dry-warm climate of Greece, with wet winters and dry summers, leads to the need for irrigation in many crops in order to achieve satisfactory production and income. In the country ~3,500,000 hectares are cultivated, about 1,400,000 hectares of which are irrigated in the framework of collective irrigation networks and private boreholes. The irrigated surface of collective works is ~600,000 ha, and the respective surface of private systems is ~800,000 ha. Agriculture consumes 80–85% of the annual water resources used. In private systems, the methods of water application are sprinkling irrigation and micro-irrigation. Private systems are based on boreholes drilled by the farmers. Since there are several illegal boreholes in addition to legal ones, we are led to situations of over-pumping and high pressure in aquifers. Given that Greece is a coastal country (~16.500 km of coastline), the phenomenon of sea intrusion is intense and it is the biggest problem caused by agriculture to the environment (even greater than that of agrochemicals). The institutional framework for land reclamation projects has undergone significant changes over the last 60 years. Initially, there was a 'pyramid' management structure where the central administration controlled the planning, design, implementation and management of the projects, since the Agencies set up to manage the projects (GOEB and TOEB, acronyms in Greek) were under the direct supervision of the Ministry of Agriculture through the Land Reclamation Service (YEB, acronym in Greek). Over time, many responsibilities of the Ministry of Agriculture have been transferred to Prefectures, Local Authorities, and Regions, with the result that management Agencies do not have the technical support they had at the beginning. This fact, coupled with the poor financial status of management agencies (irrigators often did not pay their water debts), led to problems of operation, maintenance and general management of the projects. Also, management agencies have little and not properly trained staff. The problem is not only due to the lack of know-how but rather to poor coordination, as many actors are involved without even having the structure and the staff to carry out their responsibilities. In addition, a very important

N. Dercas (✉)
Water Resources Sector, Department of Natural Resources Management and Agricultural Engineering, Agricultural University of Athens, 75 Iera Odos Str, 11855 Athens, Greece
e-mail: ndercas1@aua.gr

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issue consists of the successive changes of the institutional framework. Proposals are being made to address the problems of design, operation, maintenance and the need to re-create an Organization/Company that can support management agencies and help to improve the situation.

Keywords Greece · Agriculture · Water · Management · Irrigation

16.1 Introduction

Water management is a sector of utmost importance since water is essential to the existence of life. In Greece, with a subtropical Mediterranean climate, meaning winter rains and high-temperature droughts in the summer, irrigation is indispensable for spring crops to grow and prosper. Due to the topographical configuration of the country, there are several climatic differences among its regions. Eastern Greece has a drier climate than Northern and Western Greece, the average annual rainfall varies from 400 to 1400 mm, (Alexandris 2018) of which a very small percentage corresponds to the dry season (May–September); larger rainfall occurs northwest (see Fig. 16.1); the average annual temperature varies between 20 and 12.5 °C, and the average annual evapotranspiration height varies between 1100 mm and 1600 mm (Tsakiris 1991).

Agriculture is the largest water consumer in Greece and at the same time the largest water polluter. The total annual water resources capacity of the country is estimated at 70 * 10^9 m^3, including that coming from neighboring countries (14 * 10^9 m^3). Of this, 5.5 * 10^9 m^3 (4.7 * 10^9 m^3, for agriculture, 85%) are consumed annually, and an increase in annual consumption of more than 3% is estimated (Greek Ministry of Development 2003).

The problems encountered in the management of irrigation water are considerable: low infrastructure maintenance, large water application and losses, over-exploitation and salinization of underground aquifers. In order to harmonize the national legislation with EU Directive 2000/60, Law 3199/2003 was adopted (Gov. Gazette Vol A, 280/09.12.2003). This law introduces a new organizational structure for the integrated management of water resources at the level of the hydrological basin. Directive 2000/60 also requires the cost of water services, including environmental and natural resource costs, to be recovered in accordance with the ‘polluter pays’ principle.

16.2 Development of Irrigation

In Greece, the cultivated land amounts to ~3.500.000 ha of which ~1.400.000 ha are irrigated. Of these irrigated areas, 65% concern arable crops, 24% tree crops, 8% horticultural crops and 3% vines (Hellenic Statistics Service 2001) (Fig. 16.2).

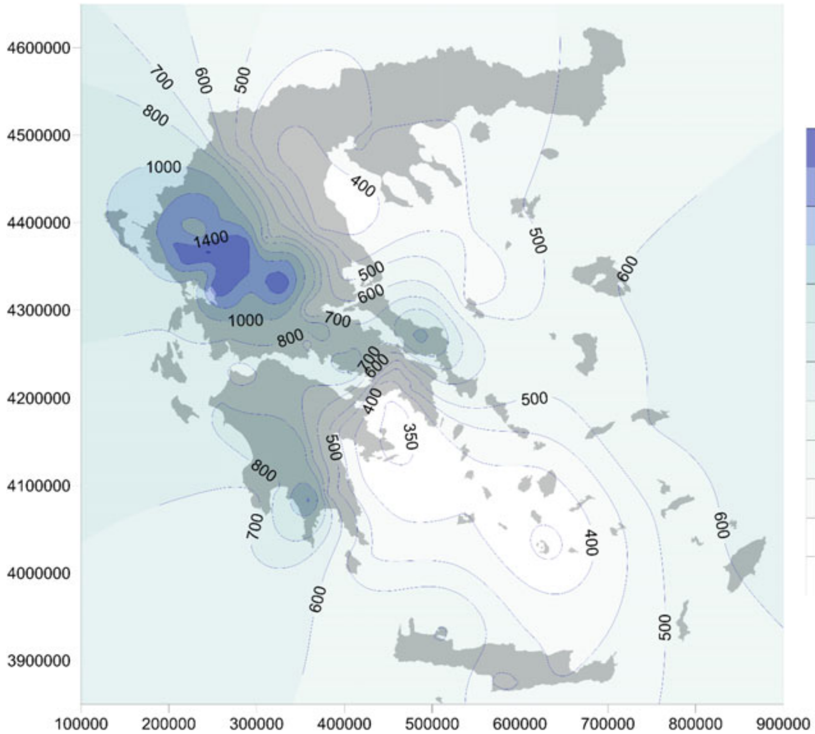

Fig. 16.1 Spatial annual rainfall allocation (Alexandris 2018)

The chart below shows the variation of irrigated agricultural land from the early 20th century to the present time (Fig. 16.3). The evolution of irrigation has been both quantitative and qualitative, as irrigation techniques at the end of 20th and the beginning of the 21st century are totally different from the ones applied in the early 20th century: up to the end of the '60s, surface irrigation methods were applied

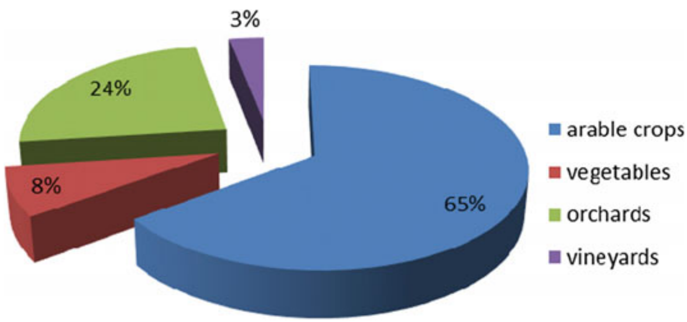

Fig. 16.2 The main irrigated crops in Greece (Hellenic Statistics Service 2001)

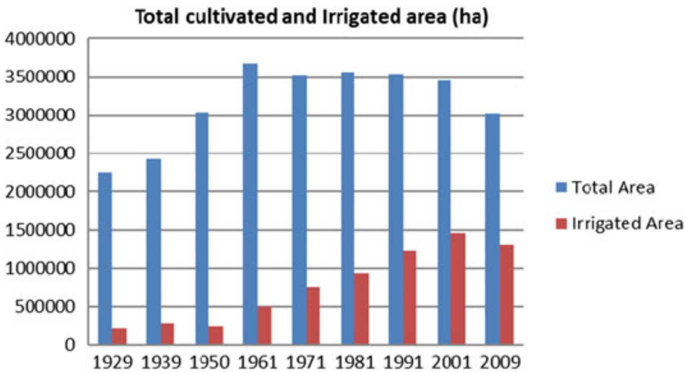

Fig. 16.3 Evolution of irrigations in Greece

(furrow, border, basin). During the 60s, a small number of collective networks were constructed using pipelines for distribution and sprinkler application to the field. These networks were designed in order to assess their effectiveness under Greek conditions and to urge for the acceptance of Greek farmers.

Since 1970 there has been a substantial shift, and the overwhelming majority of the networks that were constructed were pressurized pipeline systems and sprinkler application in the field. New micro-irrigation systems, mainly drip irrigation, were gradually introduced into these networks. This system, due to high installation costs, was used in high-yield crops such as flower gardens and greenhouses. Subsequently, with the production of the components on a large scale, their cost was significantly reduced, and micro-irrigation could be applied in other crops (orchards, vineyards, cotton, sugar beet and other).

The shift from surface (moving by gravity) to piped (moving by pressure) networks was followed by a change of the distribution system from rotation to on-demand system, which is popular to the farmers because it gives them freedom and ability to plan their irrigation.

Collective irrigation projects, where irrigation was originally developed, were constructed by the Greek State and accounted for 44% of the total irrigated area (Karamanos et al. 2004). The remaining 56% is irrigated by private works, which were constructed by Greek farmers to irrigate their parcels.

As mentioned above, agriculture is the largest user of water in Greece. Table 16.1 below shows the percentages used for irrigation per water region. It is noted that Greece is divided into 14 Water districts (Fig. 16.4). It is clear that the rates are high, with East Macedonia and Thessaly (the largest plain in the country) having the highest percentage (~0.92%). The smallest percentage is Attica with 0.14% due to the large urban center of Athens.

The sources of supply for collective irrigation networks are rivers and springs (42%), artificial lakes (25%), boreholes and wells (24%), natural lakes (5%) and drainage ditches (4%) with a constant trend to increase artificial water collections. The sources of supply for private irrigation systems are boreholes and wells (82%),

Table 16.1 Irrigation share from total water resources consumption per water district

Water district	Irrigation share from total water resources consumption
West Macedonia (Gov. Gazette Vol B, 181/31.01.2014a)	0.79
Central Macedonia (Gov. Gazette Vol B, 182/31.01.2014b)	0.86
East Macedonia (Gov. Gazette, Vol B, 2291/13.09.2013c)	0.92
Crete (Gov. Gazette Vol B, 570/8.04.2015a)	0.82
Attica (Gov. Gazette Vol B, 1004/24.04.2013d)	0.14
East Central Greece (Gov. Gazette Vol B, 1004/24.04.2013d)	0.90
West Central Greece (Gov. Gazette Vol B, 2562/25.09.2014c)	0.89
Thessaly (Gov. Gazette Vol B, 2561/25.09.2014d)	0.92
Epirus (Gov. Gazette Vol B, 2292/13.09.2013a)	0.82
Thrace (Gov. Gazette Vol B, 2290/13.09.2013b)	0.55
Aegean Islands (Gov. Gazette Vol B, 2019/17.09.2015b)	0.64
North Peloponnese (Gov. Gazette Vol B, 1004/24.04.2013c)	0.83
East Peloponnese (Gov. Gazette Vol B, 1004/24.04.2013d)	0.89
West Peloponnese (Gov. Gazette Vol B, 1004/24.04.2013d)	0.77

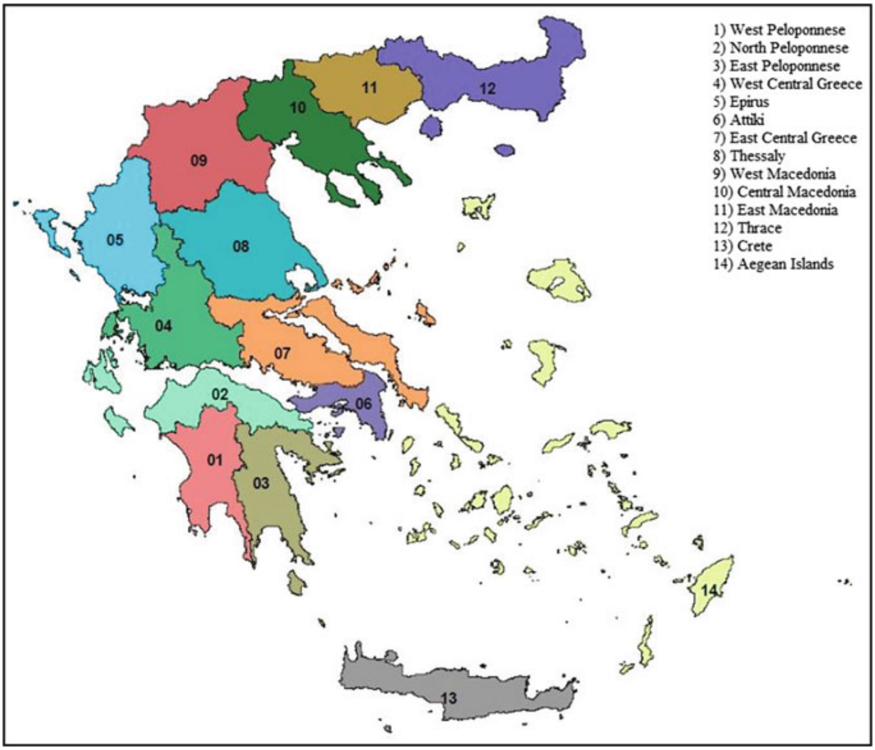

Fig. 16.4 The Water districts of Greece (http://wfd.opengov.gr)

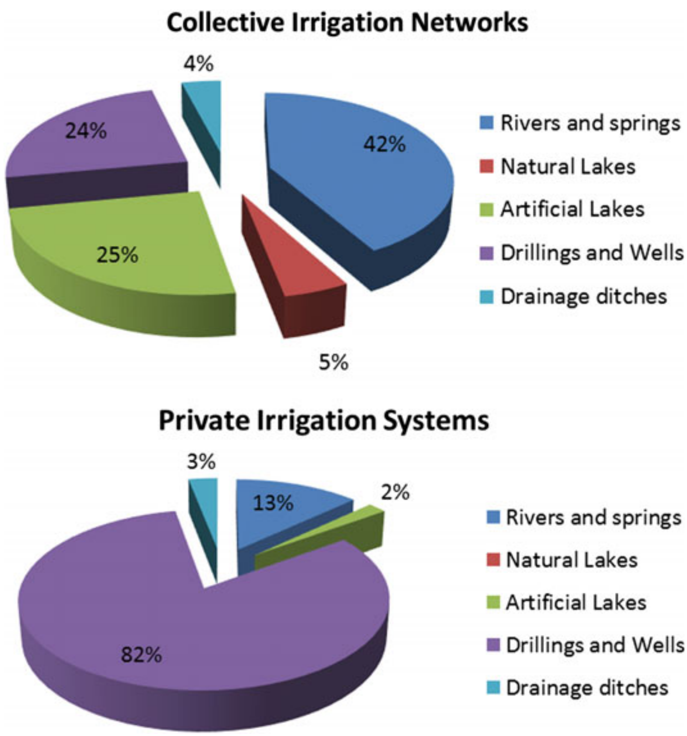

Fig. 16.5 Sources of supply of collective irrigation networks and private irrigation systems (based on data from Karamanos et al. 2004)

rivers and springs (13%), artificial lakes (2%) and drainage ditches (3%) (Karamanos et al. 2004) (Fig. 16.5).

Figure 16.6 presents the type of conduits (open channels and pipelines) used in the collective networks and the private irrigation systems. The high level of pipelines used in the private systems is due to the fact that the farmers are in charge of the entire financial cost and for this reason they use an efficient system for the supply and distribution of the water.

In collective works 37% of water is applied to the fields by surface methods (furrows, border, basins), 53% by sprinkling and 10% by dripping (Fig. 16.7) (Dercas et al. 2007). In general, during the last decades, we observe an increase in sprinkler irrigation and micro-irrigation and a tendency to reduce surface irrigation systems.

In private projects, 7% of water is applied to the field by surface irrigation methods, 49% by sprinkling, and 44% by drip irrigation (Dercas et al. 2007). It is obvious that in private projects farmers choose more efficient irrigation systems as they bear the entire financial cost thereof (operating, depreciation, maintenance).

It results from the above that besides the Greek State, which has spent large sums to build infrastructure, farmers have made considerable efforts and investments to

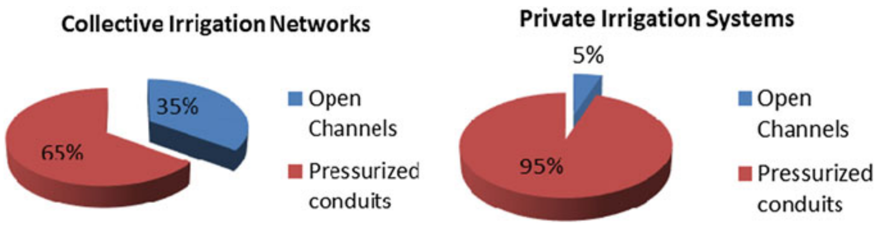

Fig. 16.6 Type of conduits (open channels and pipelines) used in collective irrigation networks and private irrigation systems (based on data from Karamanos et al. 2004)

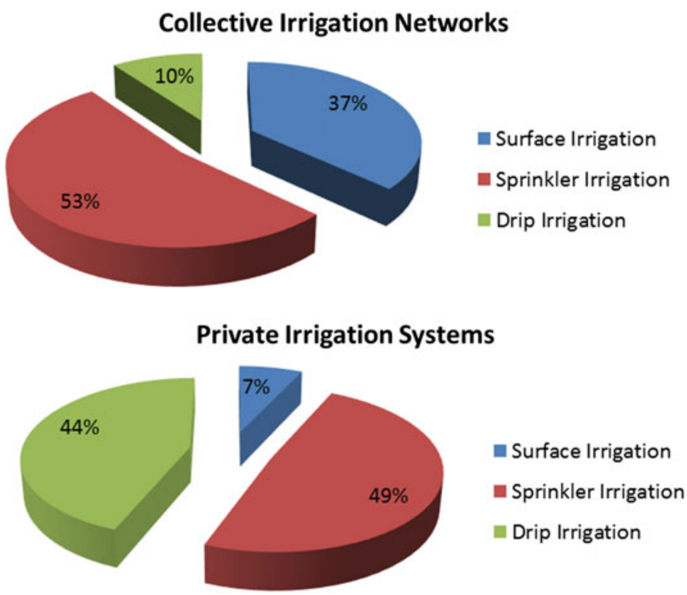

Fig. 16.7 Type of irrigation in collective irrigation networks and private irrigation systems (based on data from Karamanos et al. 2004)

develop irrigation. However, the works based on the underground aquifers have caused serious problems due to over-pumping and underground sea intrusion. It must be noted that Greek coastline is very long (16,500 km) and it increases the risk of seawater intrusion in case of poor management of the underground aquifers because it is very common that these aquifers are located near the coastline.

Sea intrusion in some cases is non-anthropogenic, but it is due to the geology of the area (Fig. 16.8). However, this problem is considered as the greatest environmental burden caused by agriculture in Greece (greater than that of agrochemicals). Degradation of groundwater then results in a reduction in yields, mainly in crops that are sensitive to salts (e.g. citrus) and degrades the soil. Several areas of the

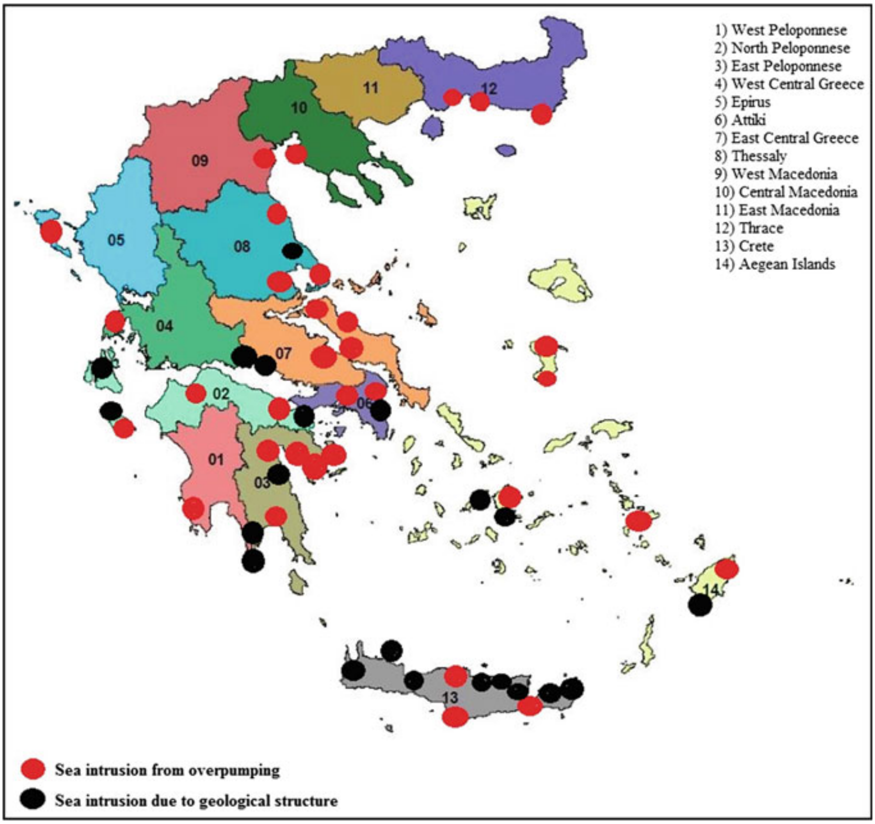

Fig. 16.8 Areas with sea intrusion problems in Greece (based on Ministry of Agriculture 2000, 1–14, *Water districts of Greece* (http://wfd.opengov.gr)

country, such as the Argolida plain, Marathon (Attica), the coast of Xanthi, regions of Thessaly, the Molai area in Peloponnese and many others face serious problems of sea intrusion.

16.3 Land Reclamation Works (for Irrigation and Drainage)

In modern Greece, the first land reclamation works were constructed after the foundation of the Greek State (19th century). These were mainly drainage projects aiming at the rehabilitation and creation of new agricultural land for cultivation by the landless.

The first land reclamation projects were the drainage of Lake Kopais, which began in 1856, and the flood protection works on the Acheloos River. Kopais was eventually dried out in the early 20th century.

Modern land reclamation projects are combined irrigation-drainage networks, with the emphasis most often on their irrigation role. This is due to the Greek climatic conditions, characterized by hot and dry summers, during which the needs of the crops in water are increased.

Major land reclamation projects, mainly drainage and flood protection works, were constructed from 1922 to 1940, in order to allow Greek refugees arriving from Asia Minor to settle and obtain land. These projects were constructed by foreign technical companies.

During the Second World War, which was followed by the Greek Civil War, no works were built. In the 1950s reconstruction started and new projects were planned and studied.

In the period 1960–1972, during the first two 5-year land reclamation programs, the following works were constructed:

(a) irrigation
Nestos, Axios, Aliakmon, Serres, Karditsa, Acheloos, Alfeios, Ioannina etc. with a total area of 270,000 ha.
(b) flood protection—drainage
Evros, Strymonas, Komotini plain etc.

16.4 The Evolution of the Institutional Framework on Irrigation

16.4.1 Initial Period, Decree 3881/1958[1]

The initial act regulating the operation of Land Reclamation Works (projects where most water is consumed) is the Decree 3881 of 1958 (Gov. Gazette Vol A, 181/30.10.1958).

Under Decree 3881/1958, the Ministry of Agriculture was responsible for the drafting of preliminary reports, the planning and agricultural exploitation, the operation, maintenance and management of all land reclamation projects aiming at the development and utilization of agricultural land of Greece, except flood control works which fell within the competence of the Ministry of Transport and Public Works.

The responsibility for the preparation of preliminary and final studies for all the aforementioned projects was granted to the Ministry of Transport and Public Works, except for the irrigation and drainage works that did not require large technical projects for areas of < 2000 ha, which were given to the Ministry of Agriculture. Also, the said Ministry was granted competence over tertiary irrigation

[1]The Present Tense is mostly used for the description of the initial period. Changes that have occurred at later stages will be pointed out in the next sections.

and drainage networks. The construction and maintenance of dams on big rivers and torrents as well as of serious water abstraction projects and concessions was delegated to the Ministry of Transport and Public Works.

Also, the Ministry of Agriculture set up a Supreme Council for Land Reclamation, which advised on planning and all general technical, economic and administrative issues for each class of land reclamation projects falling under the responsibility of the Ministries of Agriculture, Transport and Public Works. For the exercise of the responsibilities of the Ministry of Agriculture in the field of Land Reclamation Works, a Service of Land Reclamation (YEB, acronym in Greek) was established at this Ministry, which consisted of a Central and a Regional Service. A Central Advisory Council for Land Reclamation was established at the Central Service of the YEB, which provided advice on specific technical financial and organizational issues concerning training, implementation of the general and individual programs of land reclamation works under the responsibility of the Ministry of Agriculture and all matters raised by the Minister.

There were also four Regional Land Reclamation Directions, which:

- Prepared and executed preliminary and final studies of projects under the responsibility of the Ministry of Agriculture,
- Handled the operation, maintenance and management of the networks,
- Managed the funds allocated to them and the mechanical equipment of YEB,
- Ensured the collection of contributions from the beneficiary users of the networks,
- Supervised and controlled Land Reclamation Agencies (LRAs) and
- Carried out any work falling under YEB's responsibility.

Also, a main Land Reclamation Experimental Station and three smaller Stations were set up to study irrigation, drainage and land use issues in general.

The budget of the YEB records annually funds for preliminary studies and related soil, topographical, hydrological, agro-economic and other relevant surveys and studies, for the performance of experimental work, recognition boreholes, tests and other similar works, as well as for the purchase of scientific instruments and books, magazines, participation in international conferences and organizations.

The Decree 3881/1958 introduced a classification of Land Reclamation Works, which is still in force today:

Class A: The main projects of general interest, which aim at the radical improvement of the agricultural exploitations of large areas. These are the major river and river basin management projects, the dams in the above-mentioned water courses, the main irrigation canals fed by them, the associated water abstractions and related works, the main ditches, canals and related tunnels for supply and drainage of water as well as the works to protect land affected by the sea.

Class B: These are works of local interest that are either complementary to Class A' projects or self-contained works within or outside the Class A' works. These are drainage trenches and irrigation canals, flood protection projects, saline soil or arid land use projects, enrichment of underground aquifers and other projects of major local importance.

Class C: These projects are the individual properties or small groups of properties such as cleansing, grubbing-up of agricultural land, deep-plowing, leveling of soil, boreholes and smaller local projects, either independent or complementary to the A' and B' class of works.

16.4.1.1 Competencies and Responsibility for the Execution, Maintenance and Operation of the Projects

Class A' projects are carried out by the State. Class B' projects are carried out either by the State or by the Land Reclamation Agencies (LRAs) or the Local Authorities (following approval by the Minister of Agriculture). Class C' projects are carried out by the interested parties (natural or legal persons) and on their behalf by the competent government services. Land reclamation works under the competence of the Ministry of Agriculture (today: Ministry of Rural Development and Food) are carried out either by supervision of YEB, or by the Land Reclamation Agencies concerned, or by contracts with the private sector upon the decision of the Minister of Agriculture, following a favorable opinion of the Central Advisory Council for Land Reclamation.

The necessary funds for State financing of Land Reclamation Works are ensured by the inclusion of the necessary credits in the Budget of Public Works.

After the end of the construction phase, the operation, maintenance and management costs of the works are entirely borne by the beneficiaries. In the case of insufficient resources, the maintenance and operation costs of Class A and B projects during the period of development of the area may be partly covered by the State (upon recommendation of the Central Advisory Council for Land Reclamation and approval by the Minister of Agriculture).

For the execution of Land Reclamation Works, land redistribution (land re-parcelling) became obligatory whenever necessary.

16.4.1.2 Land Reclamation Agencies (LRAs)

In the areas where A' and B' class projects were constructed, the Decree 3881/1958 provided for the creation of LRAs, which are the main managing bodies of land reclamation projects. These are either Local Land Reclamation Agencies (TOEB, acronym in Greek) or General Agencies (GOEB, acronym in Greek).

TOEBs are responsible for the management of B'class projects, while GOEBs for A' class projects. GOEBs assist the TOEBs on issues which the latter cannot handle on their own (e.g. big pumping stations management).

Policing on irrigation and land reclamation works belongs to the LRA and the Agricultural Guards. The aim is to ensure the rational use of irrigation water, to protect it from pollution and to preserve land reclamation works from deterioration and damage by imposing penalties on offenders. For this reason, the necessary number of watermen is appointed during the irrigation period (Decree 499/1975) (Gov. Gazette Vol A, 163/05.08.1975).

LRAs have the responsibility of administering the waters falling under their jurisdiction, as well as regulating and distributing them by imposing irrigation regulations and by taking the necessary measures.

Initially, LRAs were legal entities governed by public law under the supervision of the Ministry of Agriculture, which exercised administrative, technical and managerial control over them. Subsequently, by virtue of Legislative Decree 1218/1972 (Gov. Gazette Vol A, 133/29.07.1972), LRAs became private-law legal entities with the aim to facilitate recruitment and procurement by circumventing the rules of public accounting. The aim was to make LRAs more flexible and efficient.

LRAs bear their own operating costs, which always remain within the limits of their approved budgets.

The resources of TOEBs are the financial contribution according to the surface of the farm for the maintenance of the network (paid by all farmers in the perimeter) and the irrigation/drainage charges (paid only by the users of irrigation water). TOEBs pay GOEBs for the support services they provide. In case the B' class network is managed directly by the GOEB (when there is no TOEB), the irrigation charges are paid to the latter.

TOEBs are co-operative organizations whose members are farmers (users of irrigation water) who must represent 5/9 of the total benefiting area. Otherwise, it is not possible to establish a TOEB. They are managed by a Direction Board elected by the General Assembly of Delegates (farmers, water users). The members of the abovementioned Direction Board receive no salary compensation. TOEBs are mainly established for Class B' networks in their area, but they can also run Class C' networks (either at the request of the beneficiaries or on their own initiative if the networks are within their jurisdiction and have a substantial impact on class B' networks).

The General Land Reclamation Agencies (GOEBs) coordinate the objectives and actions of the TOEBs in their area of responsibility. They manage A' Class projects and they allocate the respective costs to the TOEBs (users of the infrastructure of these projects). They are obliged to take any appropriate measures to ensure that the users fulfill their financial obligations related to water consumption (either directly or through TOEBs).

GOEBs are governed by a seven-member council, of which five members are appointed by the Minister of Agriculture (upon the suggestion of YEB), and two are elected (representatives of the TOEBs). The Direction Board of LRAs may impose sanctions and mandatory measures on users who do not fulfill their obligations. Among the sanctions is the interruption of irrigation water.

Initially, GOEBs and TOEBs were under the supervision of the Ministry of Agriculture. The latter could modify the statutes of TOEBs in order to ensure their conformity with the law or to allow them to better fulfill their tasks. It is noted that, as mentioned above, the audit is carried out through the Direction Board of GOEB, the majority of which is appointed by the Minister of Agriculture.

At the time of the introduction of Decree 3881, irrigation networks in Greece were surface networks with canals and distribution with rotation system (scheduled distribution). In this framework, LRAs drew up obligatory irrigation programs and regulations in conjunction with annual crop programs for their jurisdiction area. The crop programs were prepared on the basis of instructions from the Ministry of Agriculture, while schedules and irrigation regulations were based on the YEB instructions. Members of the LRAs whose property suffered damages due to the non-compliance with the proposed crop programs were not exonerated from the irrigation fees. In addition, these farmers could not claim compensation for the damage suffered by their properties.

LRAs (i.e. GOEBs and TOEBs) carry out surveys and studies of all kinds concerning their projects, either through their own services or by delegating them to private specialist offices.

Both GOEBs and TOEBs paid their obligations to the State with respect to the repayment of the works that had been built in their area and which they managed.

The Land Reclamation Service (YEB) with its equipment assisted the LRAs for the maintenance of the networks and also for the operation of the organizations. Also, the YEB supervised the operation of LRAs.

According to the Decree 3881/58, class A' projects were subsidized up to 70% of their value. For projects of high importance to the national economy, the subsidy could reach 100%. For class B' irrigation, drainage and related road networks, the subsidy was up to 50% and for class C up to 40%. Following the amendments introduced in 1972 (Legislative Decree 1277/72) (Gov. Gazette Vol A, 213/01.12.1972), the construction costs of A', B' and C' class projects were no longer covered by the beneficiaries except for the costs of deep plowing, drilling of wells or drilling carried out on farms which were borne by them. In 1972, the debts of the benefiting farmers for the land reclamation projects that were already built or in construction were deleted. Legislative Decree 1277/72 also provided that the debts of water users to the LRAs would be paid via the Agricultural Bank and in case of non-transaction with this Bank, via the Public Treasury. In case the user did not pay, the payment of the debt would be ensured from various sources (agricultural loans, grants, etc.).

Also, under that law, the annual budget of LRAs was sent for approval to the Prefecture or the Regional Administration, which had the possibility to impose the costs deemed necessary. It must be noted that according to the Royal Decree 709/1970 (Gov. Gazette Vol A, 235/05.11.1970) on the decentralization of powers, several responsibilities had already been delegated to the Prefectures by the Central Administration.

In class A and B networks, in the event of flood damage or other causes of force majeure, the State would seek to address the problem to the extent that the users were unable to do so.

Restrictions were also imposed on the drilling of wells and on the amount of water they could draw beyond the actual needs of the drilling owner.

16.4.2 The Decentralization of Responsibilities

A fundamental change occurred in 1983 when several competencies in Land Reclamation Works were transferred from the Minister of Agriculture (i.e. the Central Administration Services) to the Prefectures. According to the Presidential Decree 332/1983 (Gov. Gazette Vol A, 119/08.09.1983), the Minister of Agriculture remained responsible only for projects belonging to more than one prefecture, as well as for projects with technical specificities and high cost.

Also, Pr. Decree 332/1983 abolished the mandatory opinions and recommendations of the Central Boards of Reclamation works. More generally, the transfer of powers to the Prefectures operated in 1983 was wider and more substantial than the one operated in 1970 with R. Decree 709/1970.

By virtue of Law 1739/1987 (Gov. Gazette Vol A, 201/20.11.1987), the Ministry of Energy and Technology was competent for coordinating and monitoring the activities of research, exploitation, use and protection of water resources. It also controlled the exercise of rights and the fulfillment of water-related obligations. An Inter-ministerial Water Committee (IMWC) was created in the Ministry of Energy and Technology, which was an advisory body for the planning of the national water resources management policy. The committee was composed of one representative from the Ministries of Interior, National Economy, Agriculture, Environment, Spatial Planning and Public Works and the Industry, Energy and Technology.

Law 2026/1992 (Gov. Gazette Vol A, 43/23.03.1992) transferred the machinery of Land Reclamation Service (YEB) to the Prefectural Funds. Hence, the YEB was deprived of significant equipment that allowed it to intervene in the works and assist the LRAs in maintaining and repairing the networks.

Another important amendment to the Decree 3881/1958 was made by Law 2332/1995 (Gov. Gazette Vol A, 181/31.08.1995), which provided that the responsibilities for the administration, operation and maintenance of the A and B Class Land Reclamation Works constructed by the Ministry of Agriculture can be transferred to local authorities (municipalities, councils, local councils) by decision of the Ministers of the Presidency, Interior and Agriculture, following opinion of the Central Advisory Council on Land Reclamation works.

Also, under the new organization of Prefectures, the Regional Land Reclamation Directorates were downgraded to Departments within the Public Works Directorate.

16.4.3 The Harmonization with Directive 2000/60/EC

In 2003, Law 3199/2003 (Gov. Gazette Vol A, 280/09.12.2003) on the protection and management of waters was adopted, which incorporated into the Greek legal order Directive 2000/60/EC of the European Parliament and the Council of

23 October 2000. This law has set up the National Water Committee, the National Water Council and the Central Water Authority.

The National Water Committee draws the water protection and management policy; also, it monitors and controls its implementation and approves, upon advice from the Minister of Environment and Energy and the opinion of the National Water Council, national programs for the protection and management of the country's water resources. The National Water Committee consists of the Ministers of (a) Environment and Energy, (b) Interior, (c) Economy and Development, (d) Finance, (e) Health, (f) Administrative Reconstruction, (g) Infrastructure and Transport, (h) Rural Development and Food (ex-Minister of Agriculture) and (i) Labor, Social Security and Social Solidarity.

The National Water Council is a public consultation body presided by the Minister of Environment and Energy. It is composed of one representative per:

- Each party of the Parliament,
- The Association of Greek Regions,
- The Central Union of Municipalities and Communities of Greece,
- The Union of Municipal Water Supply and Sewerage Companies,
- The Water Supply and Sewerage Companies of Athens and Thessaloniki,
- The Public Power Corporation,
- The Technical Chamber of Greece,
- The Geotechnical Chamber of Greece,
- The Hellenic Agricultural Organization "Dimitra", etc.

The National Water Committee submits to the Parliament and the National Water Council an annual report concerning the state of the country's water environment, the implementation of legislation on water protection and management and its compatibility with the "acquis communautaire".

Also, a Central Water Authority has been set up at the Ministry of Environment and Energy, which has several responsibilities, mainly the following:

(a) It sets up national programs for the protection and management of the country's water resources, monitors and coordinates their implementation. National programs can be long-term with a duration of more than six years, or medium-term with a duration of two to six years. Prior to their adoption, programs are introduced for consultation at the National Water Council.
(b) It coordinates the competent public services and bodies, and it participates in the relevant EU agencies on any issue concerning the protection and management of water.
(c) It proposes the general rules for water cost evaluation and pricing and monitors compliance with them in practice.
(d) It proposes legislative and administrative measures for the protection and management of water.

(e) It monitors at the national level the quality and quantity of waters in cooperation with the Water Directorates of the Regions, and it ensures the development and operation of the national quality and quantity monitoring network.
(f) It manages hydrological and meteorological data at the national level.
(g) It monitors the operation of the Water Directorate of the Regions, and it provides guidance on the exercise of their tasks.
(h) It monitors the operation of the Water Directorates in the Decentralized Administrations (formerly: Prefectures) and it provides directions and instructions through circulars. It also provides them with technical and functional support.
(i) It sets the National Water Uptake Registry.

Also in the Ministry of Environment, Energy and Climate Change (as renamed), a Special Secretariat for Water was created, where a Water Advisory Committee was established.

A National Network for monitoring the quality and quantity of waters has been set up, by a joint ministerial decision (Ministers of Environment, Spatial Planning and Public Works, Agriculture (now: Rural Development and Food), Development, Economy and Finance, Health and Welfare) This network specifies the measurement stations and the operators responsible for their functioning. The protection and management of river basins belong to the Decentralized Administration (DA) of their location. If the catchment area extends to the administrative boundaries of two or more Decentralized Administrations, the above responsibilities are exercised jointly.

A Water Directorate has been established in each Decentralized Administration, which carries out water protection and water management tasks. Its responsibilities include the following:

(a) the prevention of surface and groundwater degradation;
(b) the progressive reduction of pollution;
(c) the promotion of sustainable use of water;
(d) ensuring a balance between water abstraction and recharging of aquifers;
(e) dealing with impacts from floods and droughts;
(f) the specification and implementation of long and medium-term programs for the protection and management of river basins;
(g) the drawing up and implementation of management plans and programs of measures;
(h) the drawing up of the annual report of implementation of measures and its submission to the Central Water Service;
(i) the establishment of a registry of protected areas;
(j) the collection and processing of water quantity and quality data and the uploading thereof on the basis of hydrological and meteorological data;
(k) the coordination of all actors on issues related to the use and protection of water;
(l) the economic analysis of water-related issues.

In every Decentralized Administration (DA) a Regional Water Council has been set up, which is a body of social dialogue and consultation for water protection and management. This council is composed of:

- the coordinator and the Head of the Water Department of the DA,
- a representative of the Region or Regions that run the catchment area,
- a representative from each Regional Union of Municipalities, from the Municipal Water Supply and Sewerage Enterprises, from each Chamber (Technical, Geotechnical, Commercial, etc.),
- a representative from each Land Reclamation Works Agency (LRA) in the catchment area and
- one representative from each management body of the protected areas.

The Regional Water Council gives its opinion prior to the adoption of the management plan and expresses its position to the Secretary General of the Region on matters of water protection. Its opinion on the management plan is subjected to public consultation.

Urban (drinking water) use has priority over the other uses of water in terms of quality and quantity. Each water use must aim at a sustainable and balanced fulfillment of development needs and ensure the long-term protection of water, the sufficiency of its reserves and the preservation of its quality, especially the reduction and prevention of pollution. Water use needs are satisfied as far as possible at the river basin level.

The procedures, methods and levels of cost recovery of water services in different uses are defined by a decision of the National Water Committee, which is published in the Government Gazette and takes into account:

(a) the analysis of the characteristics of the catchment areas,
(b) the impact assessment of human activities on the quality and quantity of surface water and groundwater;
(c) the economic analysis;
(d) the 'polluter pays' principle;
(e) the social, environmental and economic effects of recovery cost as well as the geographic and climatic conditions of the region.

According to the Law 3852/2010 (Gov. Gazette Vol A 87/07.06.2010) the GOEBs were transferred to the Regions (elected administrations). By Law 4456/2017 (Gov. Gazette Vol A 24/01.03.2017) the TOEBs were also transferred to the Regions because the Municipalities as local authorities had no staff or know-how to carry out the tasks assigned to them. The Land Reclamation Directorate of the Ministry of Rural Development and Food has suggested the creation of appropriate structures in the regions (e.g. Land Reclamation Department or Office with trained staff to improve networks management).

16.4.4 Comments Concerning the Evolution of the Legislative Framework

Analyzing the evolution of the institutional framework concerning irrigation, land reclamation and water resources, one comes to the following conclusions:

The design, construction and management of infrastructure related to irrigation (Land Reclamations) were initially regulated by a strong and efficient central administration. The decision to decentralize led to the transfer of responsibilities to the Prefectures (today: Decentralized Administration) and to the Regions and the Local Authorities. However, such transfer was made without the necessary study and organization of the supporting structures. Also, a well-structured and staffed Service such as the Service of Land Reclamation (YEB) with specialized personnel and significant know-how and equipment was practically downgraded and lost all its regional services without, on the other hand, creating other services that would be located next to the LRAs in order to successfully assist them in their tasks.

16.5 Operation and Management Problems of Irrigation Networks in Greece

Land Reclamation works raise significant issues, as a deviation is usually observed between their design and their development; this is mainly due to the fact that it is not easy to assess the development of crop pattern and irrigations for the entire lifetime of the project (30 to 40 years). It is necessary to apply a “follow up” strategy in order to progressively adjust the works in accordance with their developing conditions and needs.

Collective irrigation networks in Greece were built following obligatory land redistribution (re-parceling), as agricultural properties are very small (averaging 4.3 ha) and dispersed (on average $\sim$6 plots per agricultural property) (National Statistical Service of Greece 1996). Re-parceling determines the size and dimensions of the irrigation unit. The term “irrigation unit” means the area where one or more farmers have parcels that are irrigated by the same outlet. In the case of surface networks, a module is allocated to the irrigation unit (usually through a rotation mode between the sectors of the network based on a program defined by the administrator) and it is used by the farmers of the irrigation unit (using an internal rotation if there are more than one farmer, which is usually the case).

In the case of pressure irrigation networks, the collective network operates mainly according to “on-demand” system [according to Clément models (Clément 1966; Clément and Galand 1979)] or on the basis of a program defined by the network administrator. Usually the farmer does not have his own water outlet (he shares it with his neighbors), with the result that the “on-demand” principle is altered, and there is, in fact, a “restricted” demand (the farmer can irrigate whenever he/she wishes, provided that the user/s of the same outlet does/do not irrigate).

Fig. 16.9 Hydrant with 12 outlets in Crete. (Stefopoulou 2013)

Therefore, in order for the system to work, there must be an understanding among farmers who use the same outlet. Due to the rotation of the outlet use in on-demand networks, it is impossible to charge in accordance to the volume of water consumed; this results eventually in water costing based on the irrigated area rather than on the volume of water consumed. This situation leads to overconsumption of water. Only in special cases, such as in areas where micro-irrigation is used (low pressure and discharge), an outlet serves many farmers (with own structures and individual hydrometers). This is the case in Crete, where the extended use of drip irrigation allows for the use of an outlet by many producers (e.g. 4–5 or more) (Fig. 16.9).

16.5.1 Operational State of the Networks

Most networks are not in a sound operational state but rather in a state of survival, which is unstable and will be maintained only with the help of new investments whose importance will increase continuously. This situation will deteriorate if no immediate measures are taken to repair and maintain the networks.

16.5.1.1 Head Supply Works and Pumping Stations

Main canals and tanks are often in poor condition due to cracks in concrete and vegetation (Fig. 16.10). Regulators (AMIL, AVIO, AVIS) are rarely in good condition due to poor maintenance.

Remote monitoring and control of the pumping stations (where available) is insufficient due to inappropriate installation (e.g. flow meter devices near valves), or inadequate maintenance. Thus, the measurements of various parameters are not always accurate.

A typical malfunction example is the Alphios-Pinios projects in West Peloponnese, where water consumption is estimated on the basis of the electricity charged at the pumping stations and not on instrument data, even though such data are registered and send information to the remote control and data transfer center.

Furthermore, the buildings of pumping stations and control centers are not properly maintained. Although this is not a substantial operational problem in itself, it creates a bad working environment for the staff responsible for regulation, maintenance etc.

16.5.1.2 Distribution Networks

In surface networks, many control structures are out of order. In pressure networks, several components are often in a bad state (oxidized air exhausters, flooded

Fig. 16.10 Channel in the network of Kopais (photo: N. Dercas)

instrument chambers, etc.). Water outlets have many deficiencies due to the lack or removal of components (pressure regulators, flow limiters, hydrometers, etc.). Farmers remove pressure regulators and flow limiters, either because privately owned irrigation systems (e.g. big travelers and guns) in their farms require high discharge and pressure (in this case these irrigation systems are not suitable for these collective networks) or because they want to accelerate irrigation as many users wait to be served from the same outlet.

In many networks under pressure, especially at the early stages of implementation of such projects that were launched during the 70's, mobile material was allocated free of charge to the farmers of each irrigation unit. As this material was shared by the farmers of the same irrigation unit, it was not well maintained. This situation caused water losses (e.g. leakage from connections), which induced farmers to increase the discharge from the outlet (Karantounias and Dercas 1999).

16.5.2 Exploitation and Maintenance of Networks

The exploitation and maintenance of the networks has raised several issues which mainly concern:

- The supply and distribution of water as well as its use for irrigation.
- The financial situation of the competent agencies (GOEB/TOEB).

These issues are considered to be the main causes that have led to the degradation of the exploitation conditions of the projects. This situation will deteriorate if appropriate measures are not taken as soon as possible.

16.5.2.1 Headworks and Pumping Stations

The general conception of the projects, the regulation applied, and the status of the regulation apparatus (AMIL, AVIO, etc.), have an impact on their operation and the efficiency of water utilization.

In works that have been built in Western Greece (Acheloos area), pumping stations pumped directly from the channels. As a result, the manager was forced to divert high volumes of water from the river in order to avoid a shortage of water in the pumping stations. In the event of a breakdown of irrigations downstream (e.g., electricity cut or unexpected rain that led farmers to cancel irrigation events) significant amounts of water were led to the drainage networks. A study carried out in 1985 showed very low water efficiency ($\sim 10\%$) due to this inappropriate construction option (pumping directly from the channels).

Other projects such as in the Alphios—Pinios area (West Peloponnese) have not been studied with the view to operate at low-capacity situations. Thus, in spring and autumn, when water demand is small, the control structures exceed the limits of their nominal operation, and the flow cannot be properly regulated. The difficulties in regulating the water supply works result in a high water abstraction at the head and a low final efficiency of the water use. In the case of Pinios, this performance was calculated at the beginning of the '80s at only 32%. The flow rate at the head was 18.5 m^3/s, and the really necessary flow rate (for crop needs) did not exceed 5.9 m^3/s. It is obvious that only a third of the diverted water was necessary. This efficiency was very low compared to the international literature, which refers to water use efficiency of 50% or more (Matarese 1971; De Leon-Mojarro 1986). According to the General Agency of Land Reclamation (GOEB of Alfios-Pinios), the situation is now better due to improved network management and maintenance.

The main characteristic of pumping stations exploitation in Greece is the high energy consumption, which is mainly due to the high water consumption, but also to other factors such as:

- Automation failures. Pump automation often does not work, so it is necessary to control the pumps manually. It is a frequent phenomenon that staff does not intervene in time and pumps run out of optimum performance limits or continue to feed reservoirs that have already overflowed.
- Frequent failures of pressure and flow rate measurement instruments in pumping stations. The lack of such data has an adverse effect on network management.
- Clogged suction filters. The suction filters are often clogged or damaged, resulting in loss of energy and reduced pump performance.
- Pump damage. When a group of a station's pumps is switched off, the other pumps are forced to operate at a higher flow rate than their nominal one and thus have a poor performance.

16.5.2.2 Distribution Networks

Maintenance of networks is occasional and not properly scheduled. Generally, interventions take place only when a problem occurs. Their operation cannot be controlled due to the lack of updated plans, pressure and discharge measurements and precise dynamic piezometric line calculation.

Insufficient cathodic protection also raises important issues and leads to the rapid aging of steel tubes. Even in cases where cathodic protection exists, due to the poor financial status of the management organizations (farmers have difficulties in meeting their financial obligations), it is often stopped because the power supply is interrupted in winter.

The poor state of the networks is often due to insufficient maintenance as well as to the behavior of farmers who intervene in the controlling instruments to increase the flow rate in certain areas of the network. Such interventions, especially in pressure networks, dramatically deteriorate the quality of services provided to users and the reliability of the networks' operation.

16.5.2.3 Farmer Estate Size

Despite the re-parceling that took place before the construction of the networks, the lack of a legislative framework prohibiting the redistribution of the properties resulting from land re-parceling often leads to a new division and scattering of the properties.

Agricultural properties consist of small plots (average surface less than 1.0 ha), which are often scattered over a range of several kilometers. Due to this fact, farmers lose a lot of time to move among their parcels. They thus strive to minimize both the time spent on each parcel and their movements between parcels. To achieve this, they reduce the number of irrigation sub-units and the irrigation duration at each location by interfering with the supply controlling instruments.

16.5.2.4 The Drainage Networks

The state of drainage networks is as poor as that of irrigation networks, given that earthen channels are not properly maintained, and vegetation often disrupts their operation.

16.5.2.5 Water Pricing

In most mainland irrigation networks, the fee for the supply of irrigation water is determined on the basis of the irrigated area and not on the basis of the volume of water consumed. This pricing policy leads to overexploitation of water since farmers have no incentives to save (there are recordings of 10,000 m^3/ha/year in the case of irrigation with sprinkler and 15,000 m^3/ha/year in the case of surface irrigation). In addition, management of irrigated land is carried out mostly by temporary staff, which has less incentives to offer services of equivalent quality to the ones provided by permanent staff. In some networks in mainland Greece and Crete, water is charged based on m^3 consumption.

The cost of agricultural water represents 5–20% of the gross income of farmers/consumers. The cost is higher when farmers apply the method of traditional surface irrigation using water taken from a pipeline outlet. In order to minimize this type of practices, which are due to the lack of familiarization with modern irrigation methods, network operators (local land reclamation agencies “TOEB”) “punish” these farmers by imposing higher prices on irrigation water.

The following Tables (16.2 and 16.3) refer to some indicative values that show the significant gaps existing among networks and also among regions:

In a PhD thesis at the National Kapodistrian University of Athens (NKUA) Department of Economics, “Agricultural Policy and Resource Management in the

Table 16.2 Pricing of irrigation water by volume (Dercas, contact with corresponding Agencies)

Region	Agency	Price
Crete	OAK	0.25 €/m^3
Crete	TOEB Varipetrou	0.07 €/m^3
Argolida (Peloponnese)	TOEB of Iria	0.15 €/m^3

Table 16.3 Price of water according to the irrigated area (Dercas et al. 2007)

Area	Agency	Price of water Euros/ha/year	Comments
Tyrnavos/ Larissa	TOEB in Mati Tyrnavos	250	For all cultivations
		310–440	Using the surface network, and depending on the cultivation
Kopais plain	Agency of Kopais, network administrator	88	For fields inside the area administrated by the Agency of Kopais
		147	For fields outside the area administrated by the Agency of Kopais
PiniosIlias	TOEB Savalion	120	Drip irrigation
		150	Other irrigation methods
	TOEB Lehainon	80–255	According to the irrigation method and the cultivated crop

Sustainable Economic Development" (Mantzou 2008) the minimum management cost for the irrigation water in Thessaly is considered to be 0.08 €/m^3 (without taking into account new investment cost, resource cost, environmental cost, etc.). According to the above thesis, a full estimate of the financial cost would require an irrigation water price up to six times higher than the current one (0.05–0.06 €/m^3).

However, in the case of privately owned boreholes in Thessaly, the pumping cost per m^3 is multiplied due to very low aquifers. Furthermore, it must be noted that the cost of water is also determined by the size of the irrigation system (economics of scale that reduce the specific operating costs, €/m^3) as well as the sufficiency of surface water (no need for drilling). Also, in case of boreholes, the final cost of water is determined by electricity cost and local conditions (water table depth).

Given the above, it is obvious that there is a need for charting the existing situation in all the networks in Greece. This will assess the needs, record the consumption, the losses and the maintenance costs in order to have an initial cost estimate of irrigation water.

Of course, the costs of new investments in project modernization, environmental costs and natural resource costs should also be taken into account.

The latter two cannot be fully covered everywhere immediately. However, all European states are obliged to include in the cost of water the environmental and resource costs.

16.5.2.6 The Personnel

The most important problem in the management of land reclamation works is the limited number of scientific staff in the General Land Reclamation Agencies (GOEB). Also, Regional Land Reclamation Agencies (TOEB) have neither organizedservices nor scientific staff. As a result, the GOEB and TOEB are unable to provide high-quality services and to address all the issues that arise. Therefore, no one is scientifically engaged in irrigation and farmers' consultancy at the regional level. The only advice farmers receive comes from representatives of irrigation equipment companies.

The majority of technical staff, are craftsmen without formal specialization.

In order to provide information from international sources, Table 16.4 presents data concerning the staff employed in the networks of South France by category of employees (GERSAR—TETRACTYS 1983). An example of the staff needed for a 20,000 ha network is also provided.

Given the situation in Land Reclamation Agencies, it is clear that the operation and maintenance staff of both General (GOEB) and Regional (TOEB) Agencies are insufficient in number and specialization. There is a lack of agronomists, engineers and skilled technicians, which is due to the staff recruitment restrictions imposed on the Public Administration, also applying to legal persons governed by private law. Today this problem has been lifted, and it is possible for Agencies to recruit staff.

Table 16.4 Staff employed at South France's irrigation networks (Karantounias and Dercas 1999)

Employment	Staff/1,0 ha	Staff needed for 20000 ha (pipelines network)
Exploitation of collective networks		
Pipeline networks	1/500	40
Open channel networks	1/125	–
Maintenance	1/750	27
Planning of complementary works	1/5000	4
Commercial management	1/2000	10
Administration/Financial management	–	10
Technical support of irrigation	1/4000	5
Executives and foremen	1/5 of the above staff	20
Board of directors		8
Total for 20.000 ha		124

16.5.3 Financial Management of Networks

During the first period of a network's lifetime (5 years), the costs of maintenance and exploitation of projects (excluding energy costs) are partly covered by the State. The rest is covered by farmers/consumers contributions. State participation amounts to 3% of the initial investment (0.6% per year). After the first 5 years, costs are only covered by farmers/consumers' contributions. In the event of damage caused by a storm or another natural disaster, any time during the life of the network, the State (through the Ministry of Rural Development and Food, ex Ministry of Agriculture) intervenes to cover repair costs.

Energy costs should also be covered by farmers/consumers' contributions, but (until recently) the latter did not regularly fulfill their financial obligations, thus putting the relevant bodies, GOEBs and TOEBs in debt.

At this point, it should be noted that due to over-consumption of water, energy costs are higher than those related to staff and maintenance, while the opposite should apply in order to ensure the rational use of water. In addition, proper exploitation and maintenance require that the corresponding budgets reach the level considered in international practice as adequate to ensure the proper functioning of the networks. The French experience has shown that this level for the network (pipelines system) is set at 1% of the investments, duly adjusted (excluding energy costs).

16.6 Conclusions

The situation concerning irrigation water management is degraded in many ways. In public works, although several infrastructures have been constructed, most of them are outdated and their management is not appropriate. A major issue concerns the maintenance of the works as well as the lack of qualified staff in the LRAs. This is partly due to the economic crisis, because recruitment in the public sector was not allowed for several years.

In private irrigation systems (use of private boreholes) there is no control concerning the quantity of water pumped. Moreover, many illegal boreholes have been spotted. This situation leads to non-rational management of aquifers (problem of over pumping); also, in several regions of the country a considerable lowering of underground water (increase of pumping cost), along with sea intrusion, is observed.

Farmers do not receive technical support and thus irrigation is performed only on the basis of their own experience. In many collective networks, water is charged according to the irrigated surface, thus leading to a considerable waste of water and energy (in case pumping stations are used).

The institutional framework is extremely ineffective, because the responsibility to manage the works has been entrusted to agencies, which have neither the financial and technical means nor the necessary staff in order to carry out their tasks.

It is clear that the current situation is deteriorated as compared to past years. In the past the central administration of the Ministry of Agriculture (now: Ministry of Rural Development and Food) was structured as a pyramid and it was thus able to support and control the LRAs through the Land Reclamation Service (YEB). Today these competences have been transferred to the Regions, which do not have such a support and control Service. The old YEB, which had considerable know-how, high quality equipment and qualified staff, has been degraded and even abolished in the periphery. No other services have been created, which could support the LRAs and satisfy their administrative and technical needs. Therefore, LRAs are not able to provide high quality service and to reduce the cost of irrigation water; this task is imperative within a competitive international environment, which affects the price of agricultural products. Furthermore, farmers are not willing to participate in the administration of LRAs and to pay their financial obligations (contribution, fees etc.), and thus the LRAs face economic problems with an impact on the quality of management.

As already mentioned, agriculture is a big consumer of water and at the same time a big polluter and therefore there is an urgent need for a radical improvement of irrigation water management.

16.7 Recommendations and Suggestions for Improvement

An effort to improve the situation should start with a detailed inventory of the current state of the networks with regard to the following parameters:

- Operation, exploitation and maintenance of collective networks.
- Technical support for irrigation to the farmers.
- Studies and scheduling of complementary projects where necessary.
- Commercial, administrative and financial management.

Based on this analysis, specific measures need to be taken to reverse the current situation. These measures are:

16.7.1 Involvement of Agencies Able to Carry Out Water Management Successfully

The task of management should be entrusted to an organization that has the capacity to carry it out efficiently. Management should be based on optimization and it should aim at reconciling the needs of the farmers, the State and the water distribution agency.

Farmers should not be alienated from management; they should be able to assess it through a marginal cost pricing. Pricing in an irrigation network leads to a price comprised of two factors (CNARBRL 1984): (a) the cost of water consumption; and (b) the cost corresponding to the agreed discharge that the organization is obliged to make available to the consumer. Under this approach, the consumer is well aware of the costs endured by the management agency according to the discharge chosen (and consequently the cost that he generates in the system) and, on the other hand, of the benefit provided by the contract he has signed. He will realize that excessive discharge is not the best solution and he will progressively understand that irrigation material of good quality that works with less discharge must be preferred over cheap irrigation material which leads to excessive discharge. Additional costs should also be introduced in the price of water, namely environmental cost and resource cost.

Managing organizations will be able to fulfill their mission, only if they have sufficient and qualified staff (agricultural engineers, but also civil, mechanical electrical and electronics engineers, senior administrative staff, etc.) as well as a sufficient number of technicians. Organizations must, therefore, recruit qualified staff. Moreover, the level of the existing staff needs to be improved by means of seminars, workshops etc., in order to analyze network problems, propose different solutions, and complement the theoretical knowledge of staff. The lack of specialization is particularly noticeable in the field of electronic equipment of pumping stations. Remuneration of the staff should also be increased to give incentives for more efforts.

Staff, in order to be effective, should not face a bureaucratic administration. Administrative procedures need to be simplified, the exchange of information between the Ministry of Agriculture and the Region must be unhindered, and the services must be equipped with a sufficient number of vehicles enabling staff to supervise the operation of the projects.

Technical support for the farmers by agronomists will allow network users to better manage new irrigation techniques.

16.7.2 Rehabilitation of the Existing Networks and Planning for New Projects

The first step towards high-level management and exploitation is the rehabilitation/reorganization of networks. In rehabilitated/reorganized networks, each field whose surface exceeds a defined limit should have its hydrant/outlet. As a result, conflicts between farmers who want to irrigate at the same time are avoided. Also, all water outlets must be equipped with flow limiters and pressure regulators. Of course, such a project requires a hydraulic analysis of the network, which will reveal its weaknesses and will indicate the necessary reinforcement interventions. If problems occur at the edges of the network, they can be addressed by installing a program on the respective hydrants (scheduled irrigation). All these modifications will completely change the network's operating and management conditions, as they will allow pricing according to the volume of water consumed.

In the context of rehabilitation/reorganization, networks must also be adapted to modern irrigation needs and techniques. Modern systems used by farmers (cannons, gun travelers) reduce the required human resources, but they imply high pressures and benefits, which do not exist in most Greek networks. This must be taken into account when studying and building new irrigation networks or when extending existing networks. Increased discharge and pressure will prevent farmers-water users from intervening and removing flow rate limiters and pressure regulators and thus from disrupting the operation of networks. Of course, this should be the subject of an optimization that will concern the whole "collective-private networks" (Fund et al. 1971; Oron and Walker 1981; SCP 1985; Khadra et al. 2013), since their operation is interdependent. Technical support to farmers and pricing of water based on the volume consumed will ensure more rational use of water and a reduction in energy consumed for pumping.

Planning of land reclamation works and management should be ensured. In general, most projects are decided under the pressure of problems urgently seeking solutions and are not considered in the framework of an overall strategy. It is, therefore, necessary to record and plan the works to be carried out.

We also need to face the shortcomings observed in the design and implementation of the complementary and repair works. In order to achieve this, detailed analyzes should be carried out during the phase of the study of complementary projects—as in the design phase of new projects—so that the designers are well aware of the existing situation and predict as accurately as possible the future development of the networks. Such studies (Benmouffok 1984; Dercas 1989), which could be carried out on the basis of the experience gained in similar networks, are indispensable for the success of a project of this magnitude, since the impact of the sub-dimensioning or over-dimensioning, on the operation and the economy of the projects is devastating.

16.7.3 Effective Technical Support

Since the main problem in the management of irrigation water in Greece is the inappropriate institutional framework, and the lack of technical support to project management agencies, an Organization/Company should be created in every large area; that Organization will have the necessary size, appropriate staff and know-how to support the agencies which currently manage the agricultural water technically. The role of these Organizations can be extended to urban, industrial and waste water (sewage) in order to ensure an integrated approach of water resources and increased size and economic potential. For the big urban centers of Athens, Thessaloniki, Patras etc. there is no such need because there are already appropriate Companies carrying out this work. Also, in Crete, this role is played by the

Organization for the Development of Crete (OAK, acronym in Greek). In the rest of the territory, urban water and sewerage management agencies, as well as LRAs, should continue to play their role but the new organization will be able to support and advise them on water management issues in their area, and they will have appropriate staff to deal with complex technical problems.

This Organization/Company must be a Private Law Legal Entity of Public Interest (e.g. Public Company governed by private law). We are referring to a non-profit undertaking with a social scope which will operate under private economic criteria and serve the public interest. In this organization, the State, Regions, Local Authorities, Agricultural Cooperatives, Agencies of Irrigation Water Management, Urban Water and Sewerage Organizations will participate as shareholders, and they will be represented in the Direction Board.

The Company will fill the gap created by the abolition of the YEB, and its structure will be tailored to the new organizational and operational requirements; its competence shall extend to all water management agencies that need technical support due to their reduced size and structure. It will analyze existing networks (Labye et al. 1975; Bethery et al. 1981; CEMAGREF 1983; Lamaddalena and Sagardoy 2000; Lamaddalena and Pereira 2007; Calejo et al. 2008; Daccache et al. 2010; Stefopoulou and Dercas 2012, 2017; Kanakis et al. 2014; Stamouli et al. 2017) and it will recommend the necessary studies, it will plan new projects as well as the extension and rehabilitation (Burt and Styles 2004; FAO 2007) of existing projects. Also, it will set up the standards of the new projects, and it will control their design and their execution by private companies.

We believe that this approach will allow the irrigation water and more generally the water resources management in Greece to be upgraded; also, it will allow the country’s hydraulic infrastructure to be modernized and to continue to play their important role in development and production.

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Part IX
Conclusion

Chapter 17
Update, Conclusions, and Recommendations for "Water Resources Management in Balkan Countries"

Ionut Minea, Martina Zelenakova and Abdelazim M. Negm

Abstract This chapter presents the update of the topic of water management in Balkan countries, main conclusions, and recommendations of the chapters presented in the book. Reliable information about the state and trends of a country's water resources—surface water, waters in an unsaturated zone and ground water—about amounts and quality, are assessed for several purposes, such as, for example: evaluating the potential sources and potential for storage of present and foreseeable demand. The protection of people and property against dangerous associations with water. Planning, designing and operating water projects and monitoring the off-take of water units for anthropogenic impacts, variability and climate change and for other environmental factors. Recommendations for future research is pointed out to direct the future research towards sustainability of water resources management in Balkan countries.

17.1 Introduction

The management and assessment of water resources, including studies on floods, droughts and desertification and hydrological predictions, should be based on the preservation of the relevant scientific principles depending on the technology of

I. Minea
Faculty of Geography and Geology, Department of Geography, Alexandru Ioan Cuza, University of Iasi, Iasi, Romania
e-mail: ionutminea1979@yahoo.com

M. Zelenakova
Faculty of Civil Engineering, Department of Environmental Engineering, Technical University in Košice, Košice, Slovakia
e-mail: martina.zelenakova@tuke.sk

A. M. Negm (✉)
Faculty of Engineering, Water and Water Structures Engineering Department, Zagazig University, Zagazig, Egypt44519
e-mail: amnegm@zu.edu.eg; amnegm85@yahoo.com

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their implementation. Research and development activities should, therefore, be based on strategic analysis of the needs of the country. They should take into consideration and strengthen national expertise. This book presents topical issues in water resources management in Balkan countries.

The assessment of water resources is determining the amount, quality and availability of water resources, on which an evaluation of the possibilities of sustaining their development, management and control is established. The assessment of water resources offers the basis for a broad scale of activities related to water. Without such an assessment it is impossible to plan, design, administer, operate and sustain projects for irrigation and drainage, ameliorating floods, industrial and household supplying of water, urban drainage, the production of energy (including hydropower), health, agriculture, fishing, moderating drought and preserving water-based ecosystems and littoral waters.

The nature of decisions based on information on the assessment of water resources may include large capital investments with a potentially massive impact on the environment. This demonstrates the value of the assessment of water resources and its tangible and intangible benefits. For ensuring sustainable development in the future, appropriate government policies and programs are needed. Therefore, greater knowledge regarding the amount and quality of surface and groundwater is needed, and extensive monitoring, which would direct the management of these resources, is required.

This conclusion chapter presents a summary of the water management in Balkan countries, essential findings and conclusions of the studies on water quality and the quantity related to climate change. A set of recommendations extracted from all contributions are presented to help academicians, practitioners, scientists, and decision-makers to go forward towards sustainable management of water resources in Balkan.

17.2 Update

Integrated monitoring and information systems should be established, and data should be collected and preserved on all aspects of water resources management which are necessary for complete understanding of the nature of these sources and their sustainable development. Information includes not only hydrological data but also associated geological, climatological, hydrobiological and topographical data and data on types of soil, the use of soil, desertification and deforestation as well as information about subjects such as the using and reusing of water, wastewater treatment, point and exceptional sources of pollution and runoff into the seas and oceans. This includes the installation of observation networks and other mechanisms for gathering data determined for the monitoring of various climatic and topographical regimes and for the development of tools for storing data. In places where on the national, regional and international levels information related to water with the number of information systems is managed, it is important that these systems be coordinated.

Those who plan, design and operate water projects and those who deal with the protection of life, property and the environment, especially from natural catastrophes, should have access to the information related to water necessary for their work. They should be informed about the availability of such information and should be capable of obtaining it in a form which is suitable for their use, including the free mutual exchange of data necessary for ameliorating natural catastrophes. Commercialization of information associated with water should not prevent its complete use, and distribution of information associated with water should be based on a non-profit basis.

The Balkans region has always constituted an area with multiple geographic and historical valences. The social issues that have characterized this area over the history, whose reminiscences are still felt today, have had a significant impact on the management of natural resources. As a result, water resources have suffered, in the sense that the anthropic impact has been markedly at the level of the natural environment through landscape changes due to armed conflicts. At the same time, the natural conditions (climatic, geological and geomorphological) that characterize this area must be taken into account. The influences of the Mediterranean climate, with rainfall in the cold season and with severe manifestations of hydrologic droughts during the hot season require a translation of water volumes from one season to another. To this is added the geological and geomorphological characteristics of the area where the limestone rock dominates and the mountain relief restricts the accumulation of water on the surface and favors its accumulation in the underground. In the absence of an efficient water storage mechanism at the surface, human communities have focused on capitalizing on underground water resources. This has had significant consequences on the quality and quantity of groundwater (see the situation in Slovenia, Croatia and Greece) where uncontrolled exploitation has led to critical situations. Apparently, in the last decades, the demand for the exploitation of good quality water has become more and more increasingly. Water supply systems developed to satisfy the growing demand for tourism and agriculture have put pressure on water resources. In this sense, new solutions are sought to reduce the anthropogenic impact or recycle the most efficient water used in various fields (agriculture, industry, tourism).

This volume includes a series of general and particular analyzes on the management of water resources in the Balkans region which can be extrapolated to socially, historically and geographically similar regions in Europe or elsewhere in the world. An approach to capitalizing on the Balkans' water resources could not refer to the largest aquatic ecosystem in this part of the world. Even if it is somewhere in a peripheral area of the Balkans, the Danube River is the main collector of the northern Balkans region. In this sense, a volume dedicated to the management of water resources in the Balkans could not be started without reference to the Danube Delta area and the water quality of this biosphere reserve. The ever-increasing anthropic impact of the last decades, imposed by a series of political mechanisms in the communist period (until 1989), has diminished the quality of life and water in this reserve. The socialist "five years' period" that concerned agricultural development and industrial valorization of natural resources have left their mark on water quality that has significantly decreased (Gâștescu and Știucă 2008; Gâștescu 2017). Improvement hopes stem from the decline in industrial activities and pollutants discharged into the delta area. However, the Danube as the main wastewater collector in Central and South-Eastern Europe brings water volumes with questionable chemical properties that pose problems in terms of quality water and the future of this reservation. (Brețcan et al. 2009; Romanescu et al. 2016a, b) in the conditions of anthropogenic impact and climate change increase (Bîrsan et al. 2014; Croitoru and Minea 2015; Sfică et al. 2017; Prăvălie et al. 2019).

Gradually the volume introduces us to the issue of water resource management at the level of each country. Slovenia, for example, although from a hydrological point of view it is a country with high hydrological potential, it is currently facing problems with the volumes of water exploited and their quality. The problems lie in the increasing frequency of hydrological droughts (Frantar 2008; Zorn and Komac 2011; Vertačnik et al. 2018) and the quantities of polluted wastewater entering the hydrographic and underground network (Steinman and Banovec 2000). However, it is trying to find solutions (Kopač et al. 2017) to reduce the anthropogenic impact on water resources, especially underground ones (as presented by Kopač and Vremec in the chapter *Induced riverbank filtration (IRBF) for managed artificial groundwater recharge (MAR) in Slovenia*).

Much more extensive is the issue of water management in Croatia. Despite its spatial dimensions and geographical heterogeneity, Croatia is ranked third on the European level as regards Total Renewable Water Resources per capita. Through the gradual implementation of the EU Water Framework Directive, Croatia is slowly changing management practice towards more environmentally friendly solutions. A particular emphasis was placed on the surface water quality analysis (in the chapter *Water quality status of Croatian surface water resources written by* Tadić et al.) and those from underground (in the chapter Groundwater resources in Croatia written by Orešić, and Čanjevac). Water quality analysis of different Croatian rivers and lakes (natural and artificial) shows an critical influence of the catchment area including geographical features, hydrological regime, land use, population, etc.

In some cases, it was challenging to define the dominant sources of pollution but the recorded data shows an improvement of the most analysed parameters (Tomas et al. 2011; Repac et al. 2015). In Croatian karst region, the main groundwater reserves are tied to prevailing highly permeable carbonate rocks. Concerning underground water resources, Croatia has an estimated reserve of 22,430 million m^3/year. The total water withdrawal in Croatia amounts to about 1 billion m^3 of water annually, some 40% of it being groundwater withdrawal, mostly for the public water supply. The groundwater reserves are in general not overused. However, most essential aquifers are vulnerable, and locally under environmental pressure (Bačani et al. 2010). Nevertheless, groundwater reserves are still mostly in good condition regarding their quantity and quality, dar în anumite areale apar semne care indică un declin al nivelului hidrogeologic (Vujević and Posavec 2018).

Much more synthetic is the analysis of Bosnia and Herzegovina's water resources because there is no clear organized structure for water management at the state level. This is undoubtedly a major challenge since the entities in this state have their separate constitutions and separate legislation, including water management legislation. But, in some areas, there are signs indicating a decline in the hydrogeological level. The relative annual availability of water resources per capita rank Bosnia and Hertegovina in the countries of "average water availability" is between 5.000–10.000 m^3/capita; the rivers from this state are characterized by high gradients and relatively high flow rate (22 l/s/ km^2). At the level of the water resource management, essential steps are taken regarding the unification of the analytical methodologies at the level of the various state entities and the implementation of the European legislation.

The management of water resources in Serbia faces specific problems as it is maintained in the chapter *Water resources of Serbia and its utilization* written by Blagojević et al. The transit waters account for 90% of the total water volume in the territory of Serbia. This has a major impact on both the way and volume of water consumption and utilization. The entire country is well into finding solutions in the regional water supply systems to enable a more reliable water supply for the population (Djordjević 2014). It is assessed a stable water supply in the future would require about 4 billions m^3 of water annually. This is several times more than the current drinking water delivery. At the same time, it is necessary to take into account the evolution of climatic parameters, especially since the area of Serbia is increasingly affected by the frequent flood and drought episodes (as specified in the chapter *Precipitation and drought analysis in Serbia for the period 1946–2017,* written by Gocic et al. 2014). The north part of Serbia is the area with the least amount of precipitation and the south, and the southeast part have the moderate precipitation regime, while the west part is the wettest part. According to the applied analysis, it is evident that the stations in the western part of Serbia have the significant increasing trend in annual precipitation with an impact in the volume of surface water transported by rivers (Gocic and Trajkovic 2013; Gocic and Trajkovic). It is also worth mentioning the issues related to surface water pollution in Serbia used in irrigations that have an impact on food safety (analyzed in chapter *Microbial Quality of Irrigation Water in Serbia: Risks to Food Safety* written by Rudić et al.). In Serbia, all surface water resources (canals and rivers) are polluted to some extent, which becomes obvious particularly during the growing season. The presence of *Escherichia coli*, *E. coli O157: H7*, *L. monocytogenes*, *Salmonella spp*. on different kind of fresh vegetables become a potential risk for food safety.

Bulgaria's water resources are limited and unevenly distributed within its territory. 15% of the population has problems with providing the necessary water resources (approximately 500 settlements with about 1.17 million inhabitants). The water consumption per person per day is 120 l with a tendency to decrease due to the increased water price and improved accuracy of the measurements (drinking water losses for the country are about 52%). 70% of the water supply in Bulgaria comes from surface water, and 30% comes from groundwater. These include the impact of climate change that is conducive to the occurrence of long-lasting hydrological droughts (Chilikova-Lubomirova 2016) (as specified in the chapter

River Systems under the Anthropogenic and Climate Change Impacts: Bulgarian Case written by Chilikova-Lubomirova).

North Macedonia has significant water resources but unequally distributed. All of the 10 largest water springs are located in the western part of the country, spring area of river Vardar and river Crni Drim basin. The eastern part is much dryer, poor in spring waters and predominantly depends on the accumulated water in the dams. The more organized managing of water resources started in the post-war period in the 20th century with establishing the Water Management Authority. With this public body largest irrigation systems were created and more than 300 dams were built to keep the water obtained in the wet period and use it in the dry period of the year. The water volume stored in these dams is mainly used for water supply of population, industry and agriculture.

Various sources of pollution seriously endanger the waters in the major rivers in the Republic of North Macedonia, but the primary point sources are household waste, industry and mining. The problematic sources of pollution such as agriculture and wastewater from the dispersed population are also a problem. The data that as many as 40% of the total number of dwellings are not equipped with installations for discharging wastewater from the households into public sewage system show that little care is taken in the Republic of North Macedonia for protection of the environment from household wastewater (Dimitrovska et al. 2012; Blöschl et al. 2017).

The dry-warm climate of Greece, with wet winters and dry summers, leads to the need for irrigation in many crops in order to achieve satisfactory production and income. Private systems are based on boreholes drilled by the farmers. Since there are several illegal boreholes in addition to legal ones, this led to situations of over-pumping and high pressure in aquifers. Given that Greece is a coastal country (more than 16.500 km of coastline), the phenomenon of sea intrusion is intense and it is the biggest problem caused by agriculture to the environment (even greater than that of agrochemicals). These problems were analysed by Nicholas Dercas in the chapter *Water management in the agricultural sector in Greece*.

Finally, we can draw some major conclusions and recommendations on the management of water resources in the Balkans.region. Firstly, surface water resources are insufficient (in the case of Bulgaria, Serbia and Greece) and unevenly distributed spatially (for Croatia, Serbia, Bulgaria and North Macedonia). This has led to a series of adaptations in the management of these resources through the construction of reservoirs (Northern Macedonia, Bulgaria, Serbia, Slovenia) and the increasingly intensive use of underground water (in Bulgaria, Greece, Croatia and Slovenia). As a result, groundwater pollution (in Slovenia and Croatia) or underground water intrusion occurred in coastal areas (in Greece). Against the backdrop of increasing and more pronounced climate changes in this area (with effects on increasing the frequency and duration of hydrological droughts) it is necessary to take managerial measures as efficiently as possible by increasing the sewage treatment capacity and its reuse in various economic fields (Slovenia, Croatia, Serbia and Bulgaria) and the identification of new sources of water supply to the population (Bulgaria).

17.3 Conclusions

In the next sections, the conclusions extracted from the chapters in this volume of the Environmental Earth Science are presented.

1. The Danube Delta in Romania is a complex, open and interactive system that revolves around two major components—water circulation and human intervention. The greatest significance in the pollution with nutrients compounds have agriculture sources, some of them entered into the delta as pollutants in the Danube River.
2. Slovenia has an above-average quantity of water. However, because of droughts, pollution, and problems with the drinking water supply, over the past decades' issues concerning the available quantity of water first attracted the attention of the professional community and soon after that also the attention of the Slovenian public.
3. Managed artificial groundwater recharge systems coupled with induced riverbank filtration have proven itself as an irreplaceable contributor in the protection of the pumping station Vrbanski Plato and pumping stations Podgrad and Segovci on Apače field in Slovenia.
4. Water resources management has a rather long history in Croatia and is still mainly led by the civil engineering sector. That is reflected in technically oriented (grey) solutions for flood protection and, even more in river regulations, which have been proved to be inadequate in many European countries.
5. The proposed analysis of Croatian surface water quality status made on the basis of the recorded data shows improvement of the most analysed parameters. They are the result of the implementation of the Water Framework Directive, the Nitrate Directive and improvement of the sewage water system by the construction of wastewater treatment plants. However, there are still some improvements which can be done, mainly during dry hydrological conditions.
6. Groundwater resources in Croatia are still mostly in good condition regarding their quantity and quality although it can be concluded that the most important inland aquifers are under environmental pressure.
7. In Bosnia and Herzegovina significant issue is the development of the institutional framework for water management sector. Due to the complexity of governance, the management capacities of the responsible authorities in the water resources management are limited, especially the capacities of public authorities at the state level.
8. Water resources in Serbia are diversified both in water quality and quantity and characterized by an uneven temporal and areal distribution. The most industrially developed and populated, northern part of the country is scarce in domicile waters, while all transit waters are concentrated in it.
9. In Serbia all surface water resources (canals and rivers) are polluted to some extent. Even the quality of shallow groundwater occasionally exhibits the levels of faecal indicator bacteria that exceed the limits proposed by international standards for irrigation water quality.

10. Spatial distribution of annual mean precipitation in Serbia showed that the north part of Serbia is the area with the least amount of precipitation, while the west part is the wettest part. Analysing of precipitation is very important for water resources planning and management of irrigation systems.
11. Bulgaria's water resources are limited and unevenly distributed within its territory. Water is a precious, vital resource for Bulgaria. It provides vital needs for the population. This natural renewal wealth should be reasonably used, stored and preserved. This is in the interest of the people of Bulgaria and not only.
12. Bulgaria is a country with a dense river systems network, resulting in the topological specifics of the territory. Rivers are characterized with periods of spring floods and summer and winter low flows, formed with regard to the precipitations and groundwater recharge. In Bulgaria both floods and drought events occur; they are irregularly distributed in space and time, showing various grades and emerging significant impacts.
13. There are significant water resources in North Macedonia but unequally distributed. The western part of the country is five times richer in precipitation than the central part of the country. The eastern part is much dryer, poor in spring waters and predominantly depends on the accumulated water in the dams.
14. Various sources of pollution seriously endanger the waters in the major rivers in the Republic of North Macedonia, but the primary point sources are household waste, industry and mining. The problematic sources of pollution such as agriculture and wastewater from the dispersed population are also a problem.
15. Agriculture is a big consumer of water and at the same time a big polluter, and therefore there is an urgent need for a radical improvement of irrigation water management.

17.4 Recommendations

The following recommendations are mainly extracted from the chapters presented in this volume:

1. Water level dynamics is an important factor in shaping numerous processes in river systems and wetlands. Therefore, more research effort should be concentrated on links between the main pressures like heavy metals pollution or eutrophication under different water levels.
2. Danube's transnational character makes the conservation and the protection of the Danube Delta Biosphere Reserve in Romania to be a major environmental concern for all of Central and Eastern Europe. Interdisciplinary researches are needed to bring together stakeholders, politics, ecology, hydrology, social sciences.

3. To date, the aspects have primarily been at the forefront of studying waters in Slovenia, such as their use for generating power, regulation, and flood protection, because it has been unimaginable that the problem of insufficient water supply, which is common in many places around the world, could also exist in Slovenia.
4. Today the fact that climate change is a reality suggests that one of the effects of this change is also a change in the quantity of water.
5. To get all the benefits of managed induced riverbank filtration and managed artificial groundwater recharge systems versus recent current practice this should now be upgraded to the appropriate Decision Support System based on remote data acquisition and transmission, including GIS physically based fully distributed numerical modeling to continuously monitor and manage well fields, reducing costs and human-operated activities.
6. The Decision Support System combining and integrating all needed measurements and the modelling environment can give operators of these systems an alert system about the scheme performance and reaching limits of infiltration rates against cost-effectiveness or water quality indices.
7. Accession to the EU encourages Croatia and the water resource management system to accept new paradigms and approaches, which will lead to integral and sustainable management of water resources.
8. Scientific cooperation, interdisciplinary and stakeholder participation is a challenge which Croatia's water management sector should accept in order to improve and manage fragile water resources in a more sustainable way.
9. Besides the action plans and measures defined by water management strategies, it is necessary to continue the development of established water quality monitoring programmes not only in Croatia.
10. Frequency of sampling and accuracy of observed data cannot assure reliable water quality categorization, especially on small and medium rivers in the karst region of the Adriatic Sea Basin. Although widening of existing water quality monitoring network will take time and other resources, it certainly will contribute to the final goal—having safe and clear surface water.
11. In order to manage groundwater reserves in a sustainable way it is highly important to protect and preserve them as karst waters can be easily polluted, and the natural auto purification is very poor in the absence of clastic rocks acting as filters.
12. Vulnerability of the aquifers and their water resources should take into the account that a considerable portion of the groundwater resources is shared with neighbouring countries.
13. In order to improve the state of governance in the water sector authorities in Bosnia and Herzegovina, it should be focused on strengthening the institutional framework, preparation of strategic, planning and legal documents at the state level; improving cross-sectoral cooperation and coordination at all levels of government; harmonization of water legislation and planning documents with EU policies and legislation; improving water management infrastructure and

develop adequate economic and financial instruments in the management of water resources.

14. Well water resource management should be a priority in the development plans of each country.
15. There are several significant opportunities for water resources utilization in Serbia, including the navigation in rivers and canal network, spa tourism, and hydropower production.
16. While the legal, regulatory and institutional framework for further development and progress in the water resources utilization sector is laid out within the integral water resources management approach, it is estimated that time, investments, and human resources are the key factors in achieving long term strategic goal of the Republic of Serbia.
17. Due to expected water scarcity, the availability of good-quality water for irrigation will be affected, and irrigated agriculture will be challenged. Therefore, a sufficient resource for quality water for irrigation is crucial for sustainable agricultural production.
18. Water is a very effective vector of the transmission of human pathogen to plants, so microbiologically safe water has a special role in safe food production.
19. Drought policy must be based on the proactive approach and associated with the preparedness plans. Furthermore, the productivity risk assessment of arable land should be the first step in defining the strategy for mitigating the impacts of climate change on the soil.
20. Drought management plan stands out of all plans both as an administrative tool and additional planning document for the enforcement of preventive measures and measures for mitigation drought consequence aiming to mitigate the impact of drought and to improve drought resilience.
21. A major problem is the deterioration of freshwater quality due to the disposal of industrial and domestic wastewater. A large part of Bulgaria's waters, especially the rivers, are heavily polluted by wastewater and sewage waters of the settlements. The construction of water treatment plants, the multiple uses of water, the reduction of leakage from watercourses, etc. are necessary.
22. As a result of the pollution of the running waters, there is already an acute shortage of drinking water in a number of areas of the country, and especially during the warm half-year the settlements pass into a water supply regime. This is particularly true for the regions of Northwestern Bulgaria. Stringent measures are needed for the rational and full use of water and its conservation.
23. To mitigate extreme events—floods and droughts—various legislative and practical measures are implemented in practice. One of them is providing specific water management measures, including ecosystems protection, briefly presented within the Bulgarian site.

24. Another extreme events mitigation is the initiation and performance of additional activities, based on the particular river basins studies and characterization. This course of interconnected implementation of legislative, theoretical and practical developments is the only way to guarantee the best results are obtaining.
25. The basic recommendations in the North Macedonia water management are complementary with the Organization for Economic Cooperation and Development, where main topics of managing of water quantity, improving water quality, success in managing of water risks and disasters, ensuring good water governance, sustainable financing and pricing of water services.
26. Improving the system of water resources management in North Macedonia includes gathering information about water resources in the country, higher water sector funding, employment of adequate professional human resources in water management sector, building new water structures.
27. The appropriate measures that would improve ecological status in the major watercourses in the Republic of North Macedonia are increasing percentage of the population connected to sewer systems and providing a high percentage of purification of the urban wastewaters.
28. The water quality in North Macedonia will also be improving by providing a strict level of control and prevention from polluting and contaminating the watercourses from the industry and by controlled use of the mineral fertilizers and pesticides.
29. An effort to improve irrigation water management should start with a detailed inventory of the current state of the networks with regard to the following parameters: operation, exploitation and maintenance of collective networks; technical support for irrigation to the farmers; studies and scheduling of complementary projects where necessary; commercial, administrative and financial management.
30. Concrete measures need to be taken to reverse the current situation in irrigation water management in Greece: Involvement of agencies able to carry out water management successfully; rehabilitation of the existing networks and planning for new projects; effective technical support.

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Correction to: Water Resources Management in Balkan Countries

Abdelazim M. Negm, Gheorghe Romanescu and Martina Zelenakova

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This book was inadvertently published with the incorrect country name as "Macedonia". The belated correction updated "Macedonia" to "North Macedonia". This has now been amended throughout the book.

The updated version of the book can be found at
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