The Handbook of Environmental Chemistry 70
Series Editors: Damià Barceló · Andrey G. Kostianoy

Abdelazim M. Negm
Martina Zeleňáková *Editors*

Water Resources in Slovakia: Part II

Climate Change, Drought and Floods

Springer

The Handbook of Environmental Chemistry

Founding Editor: Otto Hutzinger

Editors-in-Chief: Damià Barceló • Andrey G. Kostianoy

Volume 70

More information about this series at http://www.springer.com/series/698

Water Resources in Slovakia: Part II

Climate Change, Drought and Floods

Volume Editors: Abdelazim M. Negm · Martina Zeleňáková

With contributions by

D. Baroková · M. Červeňanská · L. Čubanová · I. Damborská · M. Fendeková · M. Gera · M. Jakubis · M. Jakubisová · Ľ. Jurík · T. Kaletová · D. Káposztásová · E. Krídlová Burdová · L. Labudová · M. Lapin · M. Melo · A. M. Negm · P. Purcz · I. Selecká · D. Simonová · M. Sládeková Madajová · T. Soľáková · Ľ. Solín · A. Šoltész · M. Turňa · S. Vilčeková · Z. Vranayová · M. Zeleňáková

Springer

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

Martina Zeleňáková
Faculty of Civil Engineering, Department of Environmental Engineering
Technical University of Košice
Kosice, Slovakia

ISSN 1867-979X ISSN 1616-864X (electronic)
The Handbook of Environmental Chemistry
ISBN 978-3-319-92864-7 ISBN 978-3-319-92865-4 (eBook)
https://doi.org/10.1007/978-3-319-92865-4

Library of Congress Control Number: 2018964914

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

The Handbook of Environmental Chemistry Also Available Electronically

The Handbook of Environmental Chemistry is included in Springer's eBook package *Earth and Environmental Science*. If a library does not opt for the whole package, the book series may be bought on a subscription basis.

For all customers who have a standing order to the print version of *The Handbook of Environmental Chemistry*, we offer free access to the electronic volumes of the Series published in the current year via SpringerLink. If you do not have access, you can still view the table of contents of each volume and the abstract of each article on SpringerLink (www.springerlink.com/content/110354/).

You will find information about the

– Editorial Board
– Aims and Scope
– Instructions for Authors
– Sample Contribution

at springer.com (www.springer.com/series/698).

All figures submitted in color are published in full color in the electronic version on SpringerLink.

Aims and Scope

Since 1980, *The Handbook of Environmental Chemistry* has provided sound and solid knowledge about environmental topics from a chemical perspective. Presenting a wide spectrum of viewpoints and approaches, the series now covers topics such as local and global changes of natural environment and climate; anthropogenic impact on the environment; water, air and soil pollution; remediation and waste characterization; environmental contaminants; biogeochemistry; geo-ecology; chemical reactions and processes; chemical and biological transformations as well as physical transport of chemicals in the environment; or environmental modeling. A particular focus of the series lies on methodological advances in environmental analytical chemistry.

Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last three decades, as reflected in the more than 70 volumes of *The Handbook of Environmental Chemistry*, there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry*, the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Editors-in-Chief

Preface

This volume was prepared by a collective of distinguished researchers and scientists from universities and research centers in Slovakia. The volume aims to provide useful tools to the scientists, practitioners, researchers, designers, and experts, although we hope that the students in the field of water management, water quality, water structures, and civil engineering will also find it of interest. We did our best to cover most of the essential topics concerning water resources in Slovakia with the needed depth to serve as a reference for graduates, scientists, practitioners, and experts of different organizations with responsibilities for water and landscape management.

Sustainable development of water management is based on the principle that water as a natural resource may be utilized only to that extent which ensures future generations sufficient usable supplies of water in the seas, rivers, lakes, and reservoirs, and that reserves contained in porous environments below the surface of the land remain preserved in the same quantity and quality. It is evident that surface waters are more vulnerable than groundwater in terms of their hygienic quality and safety, but also of their protection as a natural ecosystem and maintenance of their amounts. For this reason, it is necessary to devote all the more attention to the protection of water sources. The first step toward adequate protection of water resources is to know their size and distribution and manage the extreme events in the period of climate variability.

The volume is divided into 6 parts, and 16 chapters written by 27 experts from Slovakia are presented here. Part I presents water resources in Slovakia in the period of climate change. It is prepared by Martina Zeleňáková from the Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice; Mirka Fendekova from the Department of Hydrogeology, Faculty of Natural Sciences, Comenius University Bratislava; and Martin Gera from the Department of Astronomy, Physics of the Earth and Meteorology, Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava. The chapter "Climate Change Impacts on Water Resources" provides the assessment of the impact of climate variability on water resources in Slovakia. It is devoted to the evaluation of water consumption and the evaluation of climatic and hydrological variables in Hornad river basin. The chapter "Climate Changes in Slovakia: Analysis of Past and Present Observations and Scenarios of Future Developments" presents the scenarios of climate change calculated up to the year 2100 for Slovakia. These scenarios can be successfully used to prepare studies on the impacts of and the vulnerability to climate change in different economic sectors.

Part II is devoted to drought occurrence and assessment in Slovakia. It is prepared by Livia Labudová from Slovak Hydrometeorological Institute; Martina Zeleňáková from the Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice; Mirka Fendekova from the Department of Hydrogeology, Faculty of Natural Sciences, Comenius University Bratislava; Lubos Jurik from the Department of Water Resources and Environmental Engineering, Horticulture and Landscape Engineering Faculty, Slovak University of Agriculture in Nitra; and their coauthors. The first chapter of this part "Meteorological Drought Occurrence in Slovakia" is oriented to operational monitoring of meteorological drought in Slovakia. It presents two case studies, which could be the example of the linkage between climatological and hydrological approach in drought assessment on an operational level. The second chapter "Hydrological Drought Occurrence in Slovakia" identifies and analyzes statistically significant trends in stream flow characteristics of low water content in eastern Slovakia, which are used in the evaluation of hydrological drought. The third chapter "Groundwater Drought Occurrence in Slovakia" studies the occurrence of drought based on the height of groundwater levels in monitoring sites. The next chapter "Drought as Stress for Plants, Irrigation and Climatic Changes" proposes a new conceptual framework for drought identification in landscape with agricultural use. It focuses on agricultural drought – monitoring and evaluation of drought with impacts on food security. The last chapter of this part "Major Droughts in Slovakia in the Twenty-First Century" investigates the occurrence, duration, and severity of hydrological droughts in Slovakia during 3 years of the twenty-first century – 2003, 2012, and 2015. The evaluation was done by the statistical methods.

Part III is devoted to flood risk assessment, management, and flood protection measures. It was prepared by Lubomir Solin from the Slovak Academy of Science, Matus Jakubis from the Department of Forest Harvesting, Logistics and Ameliorations, Faculty of Forestry, Technical University in Zvolen, and Andrej Soltesz from the Department of Hydraulic Engineering, Faculty of Civil Engineering, Slovak University of Technology in Bratislava and their coauthors. The first chapter of this part "Flood Hazard in a Mountainous Region of Slovakia" concerns the identification of regional types of flood hazards in a mountainous region resulting from the physical geographic characteristics of the upper basins. A brief overview of flood events in Slovakia is also provided. The second chapter "Flood Risk of Municipalities in Upper Basins of Slovakia" presents a comprehensive, integrated flood risk assessment for municipalities located in the upper basins. An integrated approach perceives flood risk as the combination of flood hazard and vulnerability. The third chapter "Mountain Watersheds, Torrents, and Torrent Control in Slovakia" provides basic information about Slovakia's mountain watersheds and torrents and about the methods of determining watercourse type (river, brook, and torrent) through technical standards or calculation. It also presents the calculation procedure for the determination of T-yearly discharges in forestry practice in Slovakia.

Part IV deals with the topic of water management in buildings. It is written by Zuzana Vranayová, Silvia Vilčeková, and Daniela Káposztásová from the Faculty of Civil Engineering, Technical University of Kosice. The first chapter “Water Demand Management and Its Impact on Water Resources at the Building Level” presents the background for water use, regulations, and legislative framework in the context of a water conservation strategy and discusses water types in building water cycle connected to water–energy nexus in the wider environment. The second chapter titled “Water Distribution System in Building and Its Microbiological Contamination Minimization” deals with the most important factors causing contamination in water distribution system in Slovakia, temperature and water stagnation. The authors introduced a mathematical model based on actual measurements to predict contamination risk and hence one could reduce this risk. The third chapter in this part is titled “Decision Analysis Tool for Appropriate Water Source in Buildings” and presents decision analysis tool on alternative water use at the building level. This tool could fill the information gap on sustainable water strategies in Slovakia by a better understanding of the building water cycle and help to change the thinking of society to be in balance with nature.

Part V presents two chapters of the way of wetlands and management for sustainability at the building level. The chapter written by Andrej Šoltész, Lea Čubanová, Dana Baroková, and Michaela Červeňanská from the Department of Hydraulic Engineering, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Bratislava, Slovakia, entitled “Hydrological and Hydraulic Aspects of the Revitalization of Wetlands: A Case Study in Slovakia” focuses on the creation of a possibility for the design of technical measures for the revitalization of the rivers in the area of interest – the Medzibodrožie region, located in the southeastern part of the Slovak Republic. In this chapter, two technical alternatives of revitalization are proposed. The second chapter is written by Vilčeková, Eva Krídlová Burdová, and Iveta Selecká from the Faculty of Civil Engineering Technical University of Kosice, Kosice, Slovakia. The second chapter “Sustainable Water Management in Buildings” aims at introducing the building environmental assessment system (BEAS) which has been developed at the Technical University of Kosice. The Slovak system was developed on the basis of existing systems and methods used in many countries worldwide. The last part of the volume presents the main conclusions and recommendations of the volume which is titled “Update, Conclusions and Recommendations for Water Resources in Slovakia: Climate Change, Drought and Floods” and is written by the editors.

Special thanks to all those who contributed in one way or another to make this high-quality volume a real source of knowledge and latest findings in the field of water resources of Slovakia.

We would like to thank all the authors for their contributions. Without their great efforts and contributions, this volume could not be produced. Acknowledgments must be extended to include all members of the Springer team who had worked long

and hard to produce this volume and make it a reality for the researchers, graduate students, and scientists around the world. The editors cannot forget the significant efforts of Springer team which were very essential to ensure the highest possible quality. Much appreciation and great thanks are also owed to the editors of the HEC volume series at Springer for their advice and constructive comments.

The volume editor would be happy to receive any comments to improve future editions. Comments, feedback, suggestions for improvement, or new chapters for next editions are welcome and should be sent directly to the volume editors.

We would prefer to close this volume by the statement of Heraclitus: "No man ever steps in the same river twice, for it is not the same river and he is not the same man."

Zagazig, Egypt — Abdelazim M. Negm
Kosice, Slovakia — Martina Zeleňáková
April 2018

Contents

Climate Change Impacts on Water Resources

M. Zeleňáková and M. Fendeková

Contents

Abstract Water plays a vital role in both the environment and human life. Assessment of the impact of climate variability on water resources is an essential activity because we consider water as a strategic raw material. The quantitative characteristics of renewable water resources of a region or river basin can be determined by two approaches: by using meteorological data or by using river run-off observations. We have evaluated climatic and hydrological variables in selected river basins in Eastern Slovakia. We have compared the time series of observed variables over a period of about 60 years. The results of the work are the plots of observed variables,

M. Zeleňáková (✉)
Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia
e-mail: martina.zelenakova@tuke.sk

M. Fendeková
Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Bratislava, Slovakia

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 3–20,
DOI 10.1007/698_2018_268,
Published online: 11 May 2018

which we have evaluated. We have also been working on the using of water in selected Slovak river basins, namely by water abstraction and water discharge. The impact of climate variability on water resources in eastern Slovakia is minimal.

Keywords Climatic variables, Hydrological variables, Water using

1 Introduction

Research in hydrometeorology, water resources management, water use and water availability, and their temporal and spatial distribution, have all been based on the concept of climate stationarity. The implication has always been that climatic conditions and concomitant variations in water resources in the future would be analogous to those which have taken place during the past observational periods. In hydrology, this concept has also been used all over the world not only to assess water resources and water use but also to calculate extreme river run-off characteristics necessary for construction design. Long-term experience in design and exploitation of different water management structures in the world has shown the correctness and reliability – in any case, up to the present time – of using the premise of climate stationarity. However, the situation has changed dramatically in recent years with the question now raised of anthropogenic climate change due to atmospheric CO_2 increase arising from carbon fuel burning, industrial development and deforestation [1].

2 Assessment of Water Resources and the Impact of Climate Changes on Water Resources

The work focuses on the assessment of the use of water resources and climatological variables, especially in eastern Slovakia. The data were provided by the Slovak Hydrological Institute, regional centre in Košice.

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 the 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.

Among the most critical impacts of climate changes are their effects on the system of hydrology and water management and thus also on socio-economic systems. Therefore, it is necessary to obtain an adequate understanding of the potential impact of anticipated climate changes: (1) on the availability and reliability of freshwater resources, (2) on the demand for water, on the occurrence of floods and drought and (3) on the consequences for efficient managing and security of existing animal and plant species and projects and structures associated with water. This enables the planning and implementation of effective countermeasures in the case of harmful consequences and revised policies in the case of favourable outcomes. Efforts should be focused on national and international programs which would include complex monitoring of research and control. Data relating to water are therefore essential for studies relating to climate changes and variability [1].

3 The Use of Water

Relying only on volume data and natural changes in run-off from catchment areas is not sufficient to reliably assess the future usefulness of water resources and the current availability of water. In addition to this, it is necessary to take changes caused by human activities into consideration. In recent decades, natural changes in the run-off of water and quantitative and qualitative characteristics of renewable water resources have been significantly influenced by the overall complexity of anthropogenic influences. These include those associated directly with the taking of water from river systems for irrigation, industry and household use. They also include control over the catchment, the change of use of basin lands as well as reforestation and deforestation, terrain management, urbanization and drainage. All these factors affect the total volume of water sources, the run-off regimen of a river and water quality differently.

Estimating the real role of all anthropogenic factors is not easy. We should not examine those factors which reshape the morphology of a basin. Such factors can have a large impact on small and moderate flows, as well as on water quality. Under certain physiographic conditions, these types of human activities may even support the increase of renewable resources of water simply by lowering the overall loss of evaporation from reservoirs. The estimate of global impacts of anthropogenic influences on water resources is based mainly on consideration of the role of factors associated with the direct taking of water from watercourses and the control of run-off from reservoirs. Those factors which cause unilateral reduction of run-off of surface water and groundwater are widely scattered, most intensively evolved and capable of producing a major impact on water resources in large regions.

The activities of man, his impact on water resources, are unambiguous: the problem of global warming in consequence of increased concentrations of carbon dioxide in the atmosphere and the strengthening of “greenhouse” effects. The unexpected increase of the air temperature and change of run-off influences renewable water resources and the character of their economic use. The not insignificant anthropogenic worldwide climate change recorded over the past decades, however, is reflected more in an estimate based on the observation of water resources and water consumption.

In terms of calculations for the future, we must note that the prognosis of global warming for the majority of thus far accessible regions is very inconsistent, especially in the expected changes of run-off. Therefore, these are not useful for assessing the estimates of water resources and water consumption. Furthermore, according to recent assessments for the future, the most important anthropogenic changes in the global climate are expected only after the years 2030–2040.

A quantitative estimate of global water resources for the past years and for the future decades was based on the use of water for public and household needs, industrial production and agriculture (irrigation). In association with the construction of reservoirs, water surfaces were also included. All prospects into the future point to potential anthropogenic global climate change, i.e. to a fixed climatic situation.

3.1 The Consumption of Water in Towns

The consumption of water in towns is directly connected with the amount of water used by the population, towns, housing estates and public services. Public supply also includes water for industry, which directly provides the needs of the urban populace, and this demand also consumes high-quality water from town water mains. In recent years, a significant amount of water has been used for gardening and for irrigating vegetable gardens and household yards.

The volume of public water resources used depends on the size of the urban population and the provided services, such as, for example, the range of the pipeline networks for supplying water and sewerage or the centralized supply of hot water where it is available. This likewise depends on climatic conditions. The majority of large towns at present draw water in the amount of 300–600 L daily per person. By the end of this century, it is anticipated that specific drawing of urban water per resident will increase to 500–1,000 L daily in the industrially developed countries of Europe and North America. On the other hand, developing agricultural countries located in Asia, Africa and Latin America use only 50–100 L/person/day. In some regions with insufficient water supplies, consumption is not more than 40 L/day/person.

The larger part of the water which was taken from water mains is returned to the hydrological system after use (purified or not) as wastewater if the sewerage canals are functioning. The primary sources of real consumption are waters which are lost to evaporation, from sewerage pipes, drainage of recreational areas, washing of streets and irrigating of gardens. Therefore, to a large measure, the range of water loss also depends on climate conditions. In hot, dry regions, forests are more important than in cool and damp conditions. The consumption of water for personal needs is not significant in comparison with the losses of water as a consequence of evaporation.

The relative values for consumption are usually expressed as a percent of received water and to a significant measure depend on the volume of the water drawn from public resources. Therefore, in modern towns equipped with centralized supply and efficient sewerage systems, the specific amount of water may be 400–600 L/person/day and consumption is usually not higher than 5–10% of the total intake of water. Small towns with a larger number of individual buildings which are not fully equipped with a centralized system may have a specific need for water of 150 L/person/day. Consumption in this context significantly oscillates and may reach 40–60%, with lower values in more northern areas and higher values in dry, southern regions.

A modern trend in the development of public water supplies around the world is the construction of large and small towns with an efficient centralized system for storing water and taking off wastewater, which links a larger number of buildings and residential areas. In the future, however, an increase is expected in the specific needs for water per person, while water consumption itself, expressed as a percentage of drawn-off water, is significantly reduced.

3.2 Water in Industry

Water is used for cooling, shipping and washing as a solvent and also sometimes is found in the ingredients of finished products. Thermal production of electric energy heads the list of uses. A large amount of water is needed for refrigeration equipment. Volumes of industrial water are completely different in individual industrial sectors and also in different types of production, depending on the technology of the production process. This depends on the climatic conditions, because the use of industrial water usually seems to be significantly smaller in northern areas than in southern regions, where the air temperature is higher.

In addition to thermal energy, other primary uses of industrial water are chemical and crude oil equipment, iron and non-iron metallurgy, wood-processing and the paper industry and machine manufacturing. The most important characteristics of water use – the volume of use of freshwater, the consumption of water and the offtaking of water – depend to a great measure on the water supply system.

The range of industrial consumption of water is usually a less important share of actual consumption. In the process of producing thermal energy, this may be some 0.5 up to 3%, but up to 30–40% for specific industrial processes. Development of the use of industrial water is one of the main reasons for water pollution in the world. This is explained by the fact that in various countries industrial growth has increased and is worsened by the fact that a large proportion of waste is released as wastewater into watercourses, predominately untreated or only partially purified. In the battle with such pollution problems, many countries have approved energy measures for reducing the use and release of industrial waters. Since the 1970s and 1980s, a tendency towards stabilization and even a drop in the demand for industrial waters can be seen. It is expected that in the future in many countries the trend will be a downward one regarding the larger use of systems for supplying circulating water and many industrial branches will aim at dry technologies without water usage.

3.3 *Water for Agriculture*

The irrigation of land has been practiced over millennia through the need to maximize the supply of water, but dramatic expansion of land irrigation took place primarily in the twentieth century, and irrigation was the main use of water in many countries. Agriculture at present is considered to be the largest consumer of water, representing approximately 80% of the total water consumption. Before crops began being cultivated, intensive development of irrigation occurred on all continents, which led to the growth of irrigated areas and ensure the growth of crops. In 1981, however, the measure of the global growth of irrigated areas fell significantly even in developing countries. The reason is mainly the very high costs for irrigation networks, which then leads to contamination of soil as a consequence of a lack of a proper drainage system, the exhaustion of irrigation sources and problems of environmental protection. In many developed countries, the range of irrigated land has now stabilized or even gone down and done so as a consequence of a reduction in crop production.

At present, approximately 15% of all ploughed land is irrigated. Food production from crops is, however, nearly half of all crop production. In the modern world, population growth has reached a great magnitude, and at the same time, an acute food deficit is recorded by nearly two-thirds of the world's population. Therefore, irrigation represents a greater share in the increased production of arable land and the efficiency of livestock breeding, and it is anticipated that irrigation in agriculture will continue to develop intensively in the future, especially in these countries, and will do so with very rapid population growth and insufficient land and water resources.

Values for specific water needs usually differ. In the future, they will change significantly depending on advanced irrigation systems, improved requirements for irrigation, regimes and techniques, and all factors should be taken into account with projects. Information on water consumption and irrigated areas in individual countries allows the calculation of the specific use of water for irrigation under various physiographical conditions. Apparently, in the north, the smallest values for the specific drawing of water are observed. In northern Europe, the values are in the range of 300–5,000 m^3/ha, while in the southern and eastern countries of Europe values reach 7,000–11,000 m^3/ha. Returned water equals approximately 20–30% of water intake. In the future, demand for irrigation water management could be significantly affected by the use of the best and newest engineering methods and irrigation techniques, such as, e.g. sprinklers, drip irrigation, etc., which help increase crop yields and reduce the volume of irrigation water required.

In addition to irrigation, there may also be the problem of supplying high-quality freshwater to the rural population in many developed countries located in dry areas. However, costs for potable water are insignificant in comparison with costs for irrigation.

4 Use of Water Worldwide and in Slovakia

From the practice of everyday life and our own experience, we are able to say when water is sufficient, when there is too much of it, and when we suffer a lack of it. It is possible to objectify this experience with numbers, which we arrive at from more than a half-century of nationwide continual monitoring of our surface and groundwater resources [1].

Before we get to specific date, we familiarize ourselves with perhaps the most cited estimates of I. A. Shiklomanov resources [1], one of the most essential hydrologists of recent years, who dealt with the assessment of long hydrological orders on a common measure. He came into the awareness of the hydrological community with these estimates, which he presented in 1992 at the International Conference on Water and the Environment in Dublin. He processed data on water used per resident for every continent (Table 1), and he used the year 2000 as a prediction [2].

A similar calculation is also made for Slovakia and is in good agreement with his data for Central Europe. I introduce them, especially so that we can compare them with the world and so that we are aware that only the regions of southern Europe and northern Africa are comparable or worse in this regard. We introduce (Table 2)

Table 1 The use of water per person (adopted from [2])

	The use of water (m^3 10^3/year/person)				
Region	1950	1960	1970	1980	2000
Europe	5.90	5.40	4.90	4.60	4.10
North Europe	39.2	36.5	33.9	32.7	30.9
Middle Europe	3.00	2.80	2.60	2.40	2.30
South Europe	3.80	3.50	3.10	2.80	2.50
North America	37.2	30.2	25.2	21.3	17.5
Canada + Alaska	384	294	246	219	189
USA	10.6	8.80	7.60	6.80	5.60
Caribbean	22.7	17.2	12.5	9.40	7.10
Africa	20.6	16.5	12.7	9.40	5.10
North Africa	2.30	1.60	1.10	0.69	0.21
Asia	9.60	7.90	6.10	5.10	3.30
South America	105	80.2	61.7	48.8	28.3
Australia	112	91.3	74.6	64.0	50.0

Table 2 The use of water per person in the Slovak Republic (adopted from [3])

	1931–1980	1990	1993	1996	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Usable water (m^3 10^3/year/person)	2.84	2.40	1.37	2.84	2.36	2.37	1.96	1.30	1.88	2.30	2.76	1.72	1.88	2.00	4.22	1.73	1.41	2.62
Abstracted water (m^3/year/person)		397.7	297.6	256.1	220.8	214.9	203.5	193.3	190.9	168.3	141.5	127.7	122.8	115.8	111.0	109.7	123.1	118.0
% of abstracted water from usable		16.6	21.7	9.0	9.40	9.1	10.2	14.8	10.2	7.3	5.1	7.5	6.6	5.8	2.6	6.3	8.8	4.5

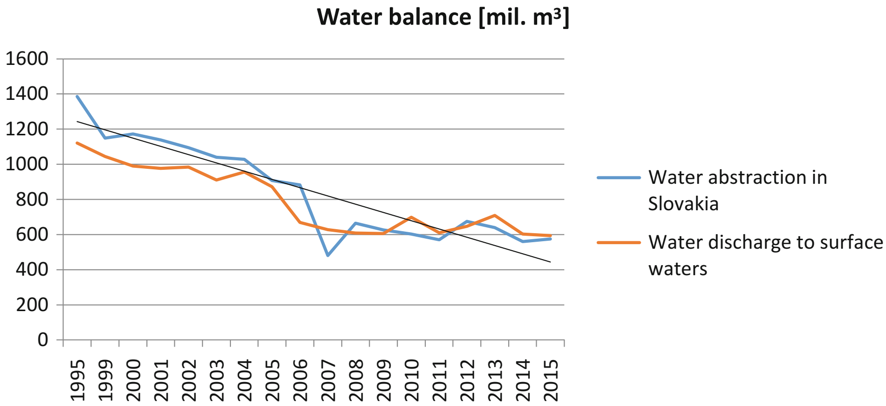


Fig. 1 Water balance in Slovakia (based on [4])

the state of use of water in Slovakia, namely on average up to 1980, then for selected years up to 2000 and for each year from 2000 to 2013 prediction [3]. The data are summarized for all basins in Slovakia.

The use of water in Slovakia from the point of view of water abstraction and water discharge during the period 1995 and 1999–2015 is depicted in Fig. 1.

5 Short Overview of Climate Change Studies in Slovakia with Respect to Water Resources

Possible changes in water resources due to the climate change impacts were studied since the beginning of the 1990s of the last century when the Czecho-Slovak National Climate Program (NCP) was established at the Ministry of Environment on 1 January 1991 [5]. The former Czecho-Slovak NCP was split into two separate state programs – the Czech and the Slovak ones after 1 January 1993. More than 23 subjects have participated directly in the Slovak NCP activities after 1993, coordinated by the Slovak Hydrometeorological Institute. The results were published in 12 monographs issued by the NCP in the 1994–2008 period and in four Slovak National Communications on Climate Change issued by the Ministry of Environment of the Slovak Republic in 1995, 1997, 2001 and 2005.

The first scenarios of expected climate change in Slovakia have been issued as early as in 1991, based on the incremental method. Later on, totally ten General Circulation Models (GCMs) from four world climate centres have been utilized in Slovakia [6]. At present, the regional models KNMI (The Netherlands) and MPI (Germany) are used to model possible climate change on the territory of Slovakia.

The impacts of climate change on water resources were studied by many authors. The main issues studied were oriented on changes in climate parameters and (1) long-term variability of discharges in Slovakia with respect to teleconnections [7], (2) long-term development in the water balance elements [8], (3) long-term run-off changes modelled by hydrological scenarios [9], (4) long-term drought occurrence in elements of the hydrological balance modelled by hydrological models [10], (5) reservoir water supply reliability [11] or (6) changes in spring yields and groundwater levels [12].

The results of hydrological studies published in Slovakia at the end of 1990s brought the following results. A significant run-off decrease over the whole territory of Slovakia during the spring and summer period was predicted [13]. The decrease around 20–25% was expected in the northern part of Slovakia; however, in the southern regions the expected decrease should reach from 30 to 40%, exceptionally, even more, up to 60%. On the contrary, a statistically significant run-off increase was predicted for the winter period, amounting about 20% in the northern regions and about 40% in the southern regions. The predicted changes in the spring yields, based on trend analysis, should reach the decrease in 10–60% depending on geographical location.

The results published after 2010 have confirmed that the increase in the long-term mean monthly run-off can be assumed in the winter and early spring. On the other hand, a decrease in the long-term mean monthly run-off can occur in the summer period [9]. As already indicated, the southern part of Slovakia and the lowlands will be more sensitive to run-off decrease. The decrease could reach in Southern Slovakia up to 67% and the southern part of the Eastern Slovakia up to 55% in 2075 [9]. At the same time, estimation of changes in the capacity of selected water reservoirs indicates that the expected change in climate would influence certainty of the water supply from reservoirs [9]. Evaluation of changes in groundwater resources between the period before 1980 and the period 1981–2009 was done in [12]. The results showed that decrease in groundwater resources already influenced at least 70% of the territory of Slovakia in 2009. The most significant adverse impact is predicted for the southern and central part of Slovakia, reaching 25–35% decrease in comparison to the period before 1980. The documented change in specific groundwater storage for the territory of Slovakia made $-250{,}000\ m^3\ km^{-2}$ in the period 1981–2009.

6 Assessment of Water Using Hydroclimatic Variables

6.1 Hornád River Basin

The Hornád River Basin (Fig. 2) is demarcated on the west by the Váh River Basin, on the south-west by the Hron River Basin, on the north by the Poprad River Basin, on the east by the Bodrog River Basin and to the south by the Bodva River Basin. Part of the southern boundary of the basin is formed by the state border with Hungary.

The partial basin of the Hornád River is defined by the ridge groundwater divide coming from the Kráľová hoľa group, which continues in a south-easterly direction through the Slovenský raj National Park along the ridges of the Volovské Mountains and at the hilltop Kojšová hoľa 1,246 m a s l turns to the Košice Basin, from where

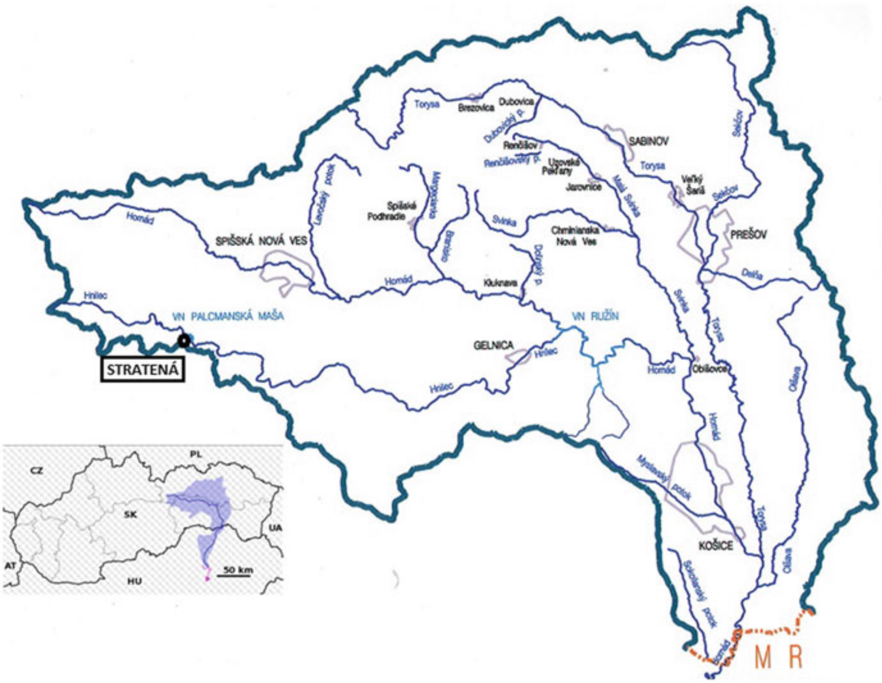


Fig. 2 Hornád River Basin

it leads as a valley groundwater divide along the highest places of the upland part of the basin at the state border with Hungary. Along the western side, the groundwater divide leads from the Kráľová hoľa group through Kozie chrbty. Then heads to the north-east and passes to the interface between the Poprad and the Hornád Basins, continuing by the ridges of the Levoča Hills in an easterly direction to the hill Minčol 1,157 m a s l in the Čergov Hills. From there, it drops further to the east to the hill Šipotská hora 557 m a s l in the Ondavská Uplands. Here, it takes a southerly direction and across the ridge of the Slanské Hills with the highest group Šimonka at 1,092 m a s l it again comes to the state border with Hungary [14].

The area of the partial basin of the Hornád is 4,414 km^2 [14]. Watercourses on the territory of the partial basin with an area greater than 1,000 km^2: Torysa. Watercourses on the territory of the partial basin with an area greater than 500 km^2: Hnilec. The long-term average discharge of the Hornád River at the closing-state border profile is 28.9 m^3/s.

The partial basin of the Hornád thanks to its complex orographic relations comprises of three climatic regions [14]:

- Warm: the south and south-eastern parts of the area fall into the climate zone of warm, moderately dry to damp with a cold winter. It is characterized by average annual precipitation of 600–700 mm. In the east, it extends up to the Sabinov area. Average annual air temperatures in the warmest areas are 9–10°C gradually falling in a northerly direction to 8°C.

Table 3 Hydrological balance in a partial basin of the Hornád River Basin (period: 1961–2000) (adopted from [14])

Partial basin	Area (km^2)	Precipitation (P) (mm)	Run-off (O) (mm)	P-O (mm)
Hornád	4,414	701	210	491
Slovakia	49,014	743	236	506

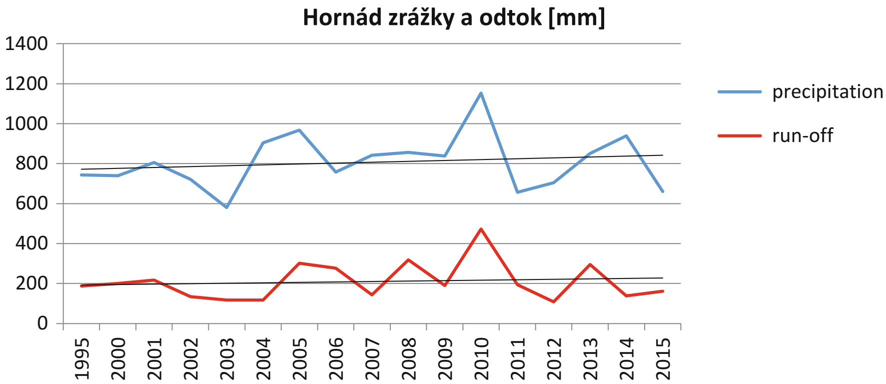


Fig. 3 Hornád River Basin precipitation and run-off (based on [14])

- Moderately warm: in the central part, is an area of moderately warm, moderately damp to damp, valley, foothill to uplands with average annual precipitation of 700–900 mm. This occurs on the territory of the Slanské Hills. Average annual temperatures reach 6–8°C.
- Cool: the northern and western part of the territory is a moderately cool area, which extends into the central part of the territory in the area of the Volovské Mountains with average annual precipitation of 700–900 mm. Average annual temperatures reach 4–5°C.

The Hornád River is the largest tributary of the Slaná River. The Hornád and Slaná rivers create, after the Bodrog River, the second largest river system in Eastern Slovakia. This river system forms a huge fan with its centre on Hungarian territory. The 81% (4,414 km^2) of the Hornád River Basin at the inflow into the Slaná River, out of the total area (5,436 km^2), is located on Slovak territory. This part is formed by the upper part of the Hornád River and its tributaries. Table 3 documents the basic elements of the hydrological balance in the Hornád River Basin.

Precipitation and run-off in the Hornád River Basin during the observed period 1995–2015 slightly increased, as it is depicted in Fig. 3.

6.2 *The Use of Water in Hornád River Basin*

The use of water in the Hornád River Basin from the point of view of water abstraction and water discharging during the period 1999–2015 is depicted in Fig. 4.

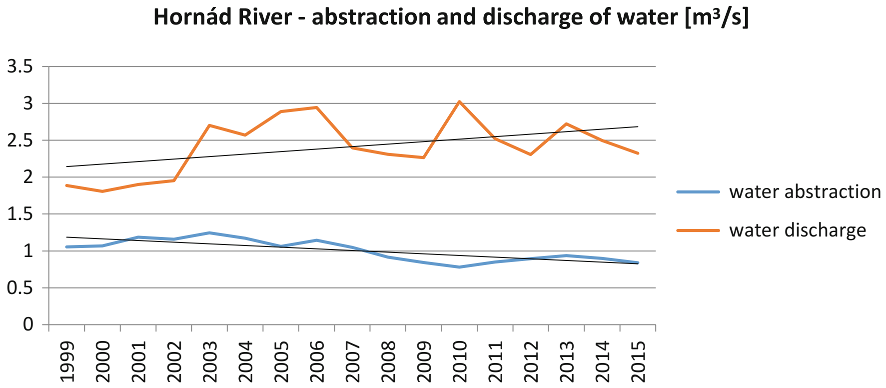


Fig. 4 Hornád River Basin: water abstraction and water discharging (based on data from [15])

Water abstraction has a decreasing tendency during the evaluated period 1999–2015, but at the same time, the water discharge is slightly increasing.

In the next section, the course of climatic and hydrologic variables in the river basin is analysed.

6.3 Course of Hydroclimatic Variables in the Hornád River Basin

Climatic and hydrologic variables are evaluated at the Stratená gauging station, ID 8530 (the Hnilec tributary). The following data were analysed:

- Stream flow [m^3/s]
- Surface water temperature [°C]
- Water stage [cm]
- Precipitation [mm]

The gauging station Stratená (see Fig. 2) is situated above the water structure (dam) Palcmanská Maša, in the territory of the Stratená village. It is located at the Hnilec River – the right-side tributary of the Hornád River.

The data between the years 1990–2000 are missing, so they are not included into the evaluation. Discharge values during the observed period 1954–1989 and 2001–2010 are slightly decreasing (Fig. 5). The water stage is also slightly decreasing as we can see from Fig. 6.

The station was moved approximately 1.5 km upstream in 1978. This is the reason of the abrupt change of water stage.

The surface water temperature was also observed at the monitored gauging station Stratená. The course of surface water temperature in Hnilec River is documented in Fig. 7.

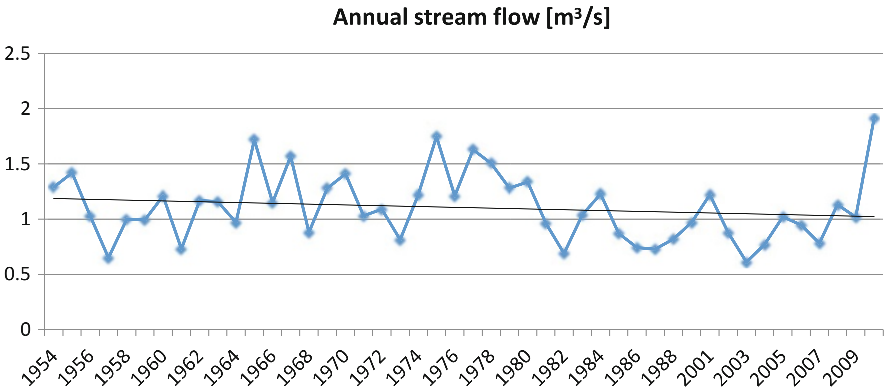


Fig. 5 Annual stream flow at Stratená gauging station in 1954–1989 and 2001–2010

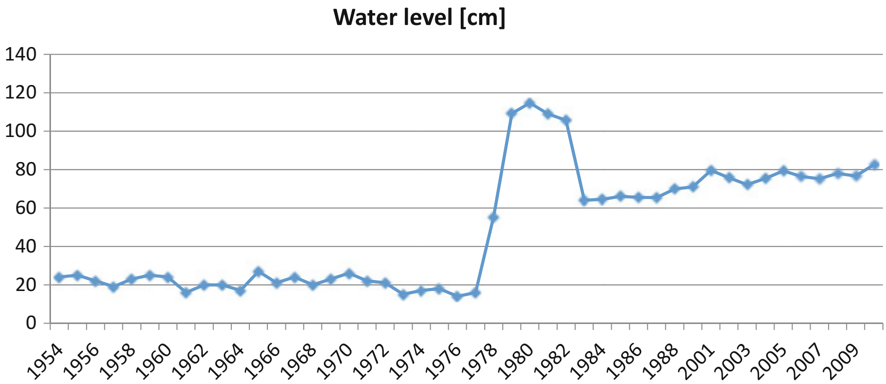


Fig. 6 The water stage at the Stratená gauging station in 1954–1989 and 2001–2010

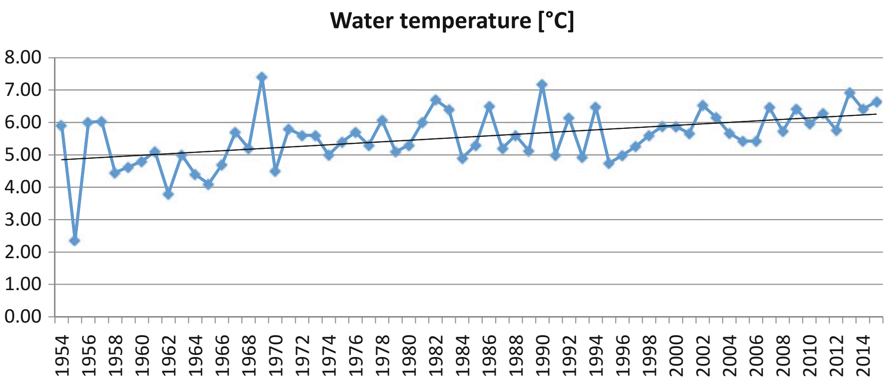


Fig. 7 Surface water temperature in Hnilec River at Stratená gauging station in 1954–2015

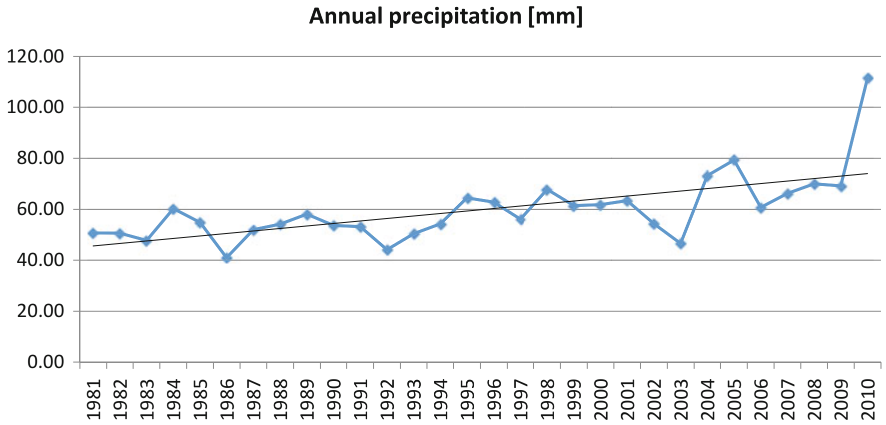


Fig. 8 Precipitation at Stratená station in 1981–2010

The annual surface water temperature in Hnilec River during the observed period increased in more than 1°C as it is depicted in Fig. 7. It is connected also with the increasing air temperature in the area during the last 50 years.

The course of precipitation was evaluated during the period 1981–2010. Precipitation increased in approximately 20 mm, as it is depicted in Fig. 8.

Water use – abstraction and discharging – was analysed in Sect. 6.2 together with other climatic and hydrological parameters for the Stratená gauging profile (Hnilec sub-basin) of the Hornád River Basin. The analysis proved that climate variability in Slovakia influences water resources only in slightly way, what is obvious from graphical evaluation.

7 Conclusion and Recommendations

Water management, like the power industry, is not a sector per se, but it does secure access to water for all other sectors and for society as a whole according to need. However, unlike energy, there are no alternative sources of water. And that is why for several years now we have considered water to be a strategic raw material. In addition to water provision, water management has another no less important task – protection from the undesired effects of hydrological extremes, such as drought and floods. Meteorology, climatology and hydrology, in particular, provide not only the marginal conditions but also direct input values into water management. For a long time, here in Slovakia and abroad, water management was determined based on the sources of water, the renewability of which was considered as a stationary process, whose central values and variance did not change over time. In considering of climate change, a phenomenon we are already confronting and which is primarily expressed in meteorological, climatologic and hydrological processes, it is shown that these processes are non-stationary. This means that we identify trends in time-related climatic as well as in hydrological orders. Water resources may decrease or increase depending on the development of climate elements. In the past, we were able to resolve annual or perennial fluctuations of available water sources either by using economic instruments or by creating water reserves in our conditions, with annual regulation.

Recommended activities include:

1. Increasing of cooperation between the climatological and hydrological communities with the elaboration of predictions on climate changes in individual annual periods and specific regions;
2. Strengthening the capabilities to collect, preserve and process data related to water, including data relating to climate changes;
3. The development of research programs on the national level and contributing to regional and international research projects related to the question of climate change, its early detection and its impact on the hydrological regimen. These should deal with the situation in developing and developed countries and could include cases focused on the elaborating and testing of speculative methods for impact assessment;
4. Assessment of the probable socio-economic and environmental impacts of such changes, the elaborating of strategies for reaction and financing and performing these strategies.

References

1. Shiklomanov IA. World water resources. http://www.ce.utexas.edu/prof/mckinney/ce385d/papers/shiklomanov.pdf
2. International conference on water and the environment development issues for the 21st. century, Dublin, 26–31 Jan. https://www.ircwash.org/sites/default/files/71-ICWE92-9739.pdf
3. Majerčáková O. Water resources in Slovakia. http://www.fyzickageografia.sk/geovedy/texty/majercakova.pdf
4. Slovak Hydrometeorological Institute (SHMI) Water balances of the Slovak Republic. http://www.shmu.sk/sk/?%20page=1834
5. Lapin M (2008) History of climate change study in Slovakia. In: Lapin M (ed) Proceedings of the discuss forum: climate changes – challenge for Europe. Head of the EC Representation in the Slovak Republic, The Embassy of the France in Slovakia and the Slovak Technical University in Bratislava, Bratislava, p 50
6. Škvarenina J, Szolgay J, Šiška B, Lapin M (eds) (2010) Climate change and landscape. Study of the Slovak Bioclimatic Society at SAS, vol 25(22), p 114
7. Miklánek P, Pekárová P, Pekár J, Škoda P (2007) Regionalisation of Slovak rivers with respect to climate change in 1930–2005 and their sensitivity to QBO and NAO phenomena. In: Heinonen M (ed) Proceedings of the third international conference on climate and water. Finish Environment Institute SYKE, Helsinki, pp 326–331
8. Majerčáková O, Škoda P, Faško P, Šťastný P (2004) Development of hydrological balance elements in 1931–1980 and 1961–2000. J Hydrol Hydromech 52(4):355–364

9. Szolgay J, Hlavčová K (2010) Impact of climate change and evaluation of vulnerability of the Slovak territory in the water management sector. In: Škvarenina J, Szolgay J, Šiška B, Lapin M (eds) 2010: Climate change and landscape. Study of the Slovak Bioclimatic Society at SAS, vol 25(22), pp 21–43
10. Fendeková M, Poórová J, Slivová V (eds) (2017) Drought and prognosis of its development in Slovakia. Comenius University, Bratislava, p 300
11. Halmová D, Melo M (2006) Climate change impact on reservoir water supply reliability, vol 308. IAHS-AISH Publication, Wallingford, 407–412.
12. Kullman E (2011) Evaluation of spring yield and groundwater level changes in the state hydrological network monitoring objects. In: Bottlik F, Malík P (eds) Proceedings of the conference: research of the climate change impacts on available groundwater amounts in Slovak Republic and compilation of the expert GIS. State Geological Institute of D. Štúr, Stará Lesná, 14–16 Nov 2011, pp 61–121
13. Majerčáková O, Fendeková M, Lešková D (1997) The variability of hydrological series due to extreme climate conditions and possible change of the hydrological characteristics with respect to potential climate change, vol 246, IAHS-AISH Publication, Wallingford, pp 59–66
14. Plan of the management of Hornád River Basin. Implementation of Directive 2000/60/EC from 23rd October 2000. http://www.vuvh.sk/download/RSV/PMCP2/Hornad/HornadVP.pdf
15. Ministry of Environment of the SR, Bratislava, Slovak Environmental Agency, Banska Bystrica (1995–2015) Reports from environment of the Slovak Republic. http://enviroportal.sk/spravy/kat21

Climate Changes in Slovakia: Analysis of Past and Present Observations and Scenarios of Future Developments

M. Gera, I. Damborská, M. Lapin, and M. Melo

Contents

Abstract Based on the modified model outputs and the measured data from meteorological stations for the period 1951–2016, the scenarios of climate change were calculated up to the time horizon of the year 2100. The alternative IPCC emission

M. Gera (✉), I. Damborská, M. Lapin, and M. Melo
Department of Astronomy, Physics of the Earth, and Meteorology, Faculty of Mathematics, Physic and Informatics, Comenius University, Bratislava, Slovakia
e-mail: martin.gera@fmph.uniba.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 21–48,
DOI 10.1007/698_2017_157, © Springer International Publishing AG 2017,
Published online: 9 December 2017

scenarios, the SRES A2, A1B, and B1, were applied. Scenarios for the variables: the maxima and minima of the air temperature, the daily means of the relative air humidity, the daily precipitation totals, the daily means of wind speed, daily totals of the global radiation, and also the water balance elements and the snow cover characteristics have been prepared. On the basis of the statistics obtained from the measured and modeled data, we adjusted the modeled data in the future in such a way as to best capture the predicted climatic characteristics of the region. The results show the case of air temperature that means an increase in the 30-year averages by about 2–4°C up to the end of the twenty-first century. Precipitation totals will also change in a relatively wide range, but generally, an increase of about 10% in annual totals is expected, more in the north and less in the south part of Slovakia. These scenarios can be successfully used to prepare studies on the impacts of and the vulnerability to climate change in different economic sectors.

Keywords Climate change, Impacts, Statistical downscaling, Trend analysis, Vulnerability, Water balance

1 Introduction

Significant increases in global, hemispheric, and regional temperatures have been registered in the last 30–60 years (only small changes in annual precipitation totals, a decrease in relative humidity, and an increase in potential evapotranspiration have occurred in Slovakia). These changes have negatively impacted most socioeconomic sectors and natural ecosystems. The climate change scenarios designed around 1995 seem to fit well with the temperature trends observed not only in Slovakia but also in the Northern Hemisphere in general. In Slovakia, the increase in temperature (based on several stations) has been about 2 °C since 1981 and also since 1881 as a linear trend. Four general circulation models (GCMs) have been used to design climate change scenarios in the Slovak region since 2011. Two of them are global (Canadian CGCM3.1 and German ECHAM5), and two are regional (Dutch KNMI and German MPI); the last two have the ECHAM5 GCM boundary conditions. All the GCMs offer outputs of several variables with daily data in the period from 1951 to 2100. Based on these outputs and the measured meteorological data, daily scenarios for a number of climatic and precipitation stations all over Slovakia have been designed. Scenarios based on GCMs have been prepared for the following variables: the maxima and minima of air temperatures, the daily means of relative air humidity, wind speeds, and daily totals of global radiation and precipitation [1, 2]. These scenarios can easily be used to prepare studies on impacts of and vulnerability to climate change. Based on these modified model outputs and measured data at about 30 meteorological stations from 1951 to 2016, scenarios of water balance elements and snow cover have been calculated up to the time horizon of the year 2100 [3–5].

2 History and Analysis of Climatologic Measurements in Slovakia

Meteorological measurements began in Slovakia in the middle of the nineteenth century; there were about 10 meteorological stations that performed complete measurements by the year 1881 (including air temperature and humidity) and about 100 precipitation stations with measurements of daily totals. The number of meteorological and precipitation stations increased continuously up to the year 1950 and then stabilized at about 100 complete meteorological stations and 700 precipitation gauges (including snow cover measurements). When analyzing all the data measured, we noted that more than 30 meteorological stations have complete monthly and daily data of all the important elements for the period 1951–2016. About 550 of the precipitation stations from 1951 to 2016 can be considered as complete. The monthly precipitation data from 203 stations from 1901 to 2016 are complete.

In 1968 the creation of a computer database began at the Slovak Hydrometeorological Institute (SHMI). Daily data from all the meteorological stations (about 100 each year) since 1961 are in the database as well as daily precipitation data since 1981 (from about 700 stations). Historical daily data have also been recently edited and prepared as a computer database from the most important and the most nearly complete stations.

Based on the monthly meteorological data from the higher-quality stations, the calculated elements have also been prepared using simple meteorological models. The first model involved was the calculation of water balance elements (soil moisture, potential, and actual evapotranspiration) by the Budyko complex method [6], which was modified by Tomlain [7] for Slovakia. Complete monthly data since 1951 is available from 32 stations in Slovakia. The second model involved was the calculation of radiation balance elements (global solar radiation, the radiation balance on the Earth's surface) since 1951 from about 50 stations [8]. Using the monthly data from 203 precipitation stations, the monthly areal precipitation totals in Slovakia were calculated using the double weighted average method [9].

2.1 Air Temperature

In Slovakia, the air temperature (T) has been measured by a classic mercury thermometer in a meteorological shelter 2 m above the ground at 7, 14, and 21 h MLT (mean local time) by the same method since 1851. To calculate the areal deviations of the monthly and seasonal means from the long-term averages of 1901–2000, three stations were selected. They are Hurbanovo (115 m amsl, SW Slovakia), the Košice airport (230 m amsl, SE Slovakia), and Liptovský Hrádok (640 m amsl, N Slovakia). These stations have been measuring the air temperature since 1881. Comparisons with the mean deviations calculated from more stations from

1981 to 2010 showed only insignificant changes from those calculated by the three stations mentioned.

Figure 1 shows the deviations of the mean temperatures and trends in Slovakia for a cold half year (CHY, Oct–Mar) and a warm half year (WHY, Apr–Sept). It is clear that the mean temperature in Slovakia has increased by about 2°C since 1881 as a linear trend, and nearly the same increase has also occurred since 1981 both in the CHY and WHY. A higher increase in the mean temperature occurred in the months from January to August (Fig. 2 for Hurbanovo only).

2.2 Air Humidity

In Slovakia, the air humidity is also measured under the same conditions as the air temperature by dry and wet mercury thermometers (the psychrometric method). Since 1951, daily data from all the meteorological stations have been available. A longer data series of good quality are available from Hurbanovo (since 1901, Fig. 3). The trends in relative humidity (RH) are also comparable to other lowland stations (a decrease in WHY means by about 5% since 1901). The trend is somewhat lower in the mountains and in the northern half of Slovakia. Figure 4 shows that the most significant decrease in mean relative humidity has been registered in the months from March to August. Water vapor pressure is increasing in accordance

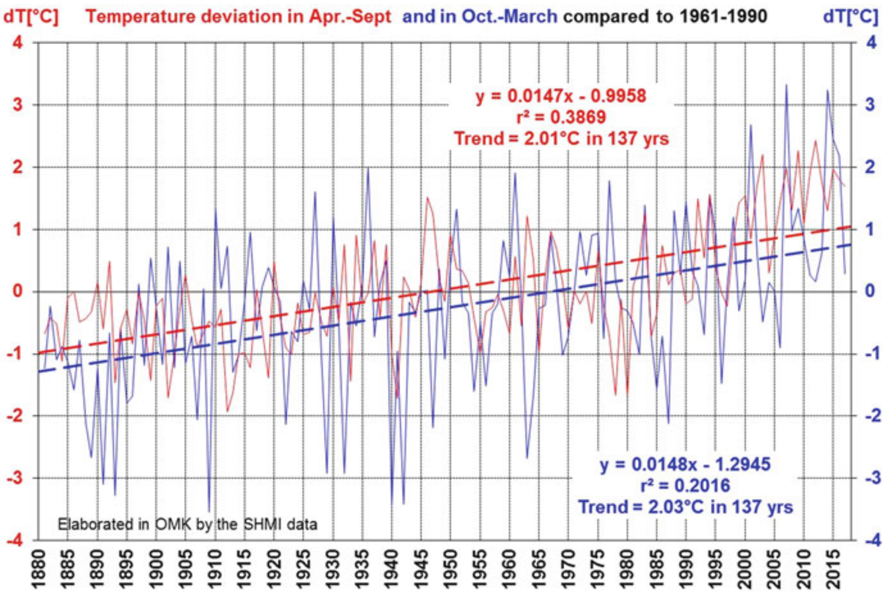


Fig. 1 Deviations of mean temperatures (*dT*) and trends in Slovakia for a cold half year (CHY, Oct–Mar) and a warm half year (WHY, Apr–Sept) in 1881–2017

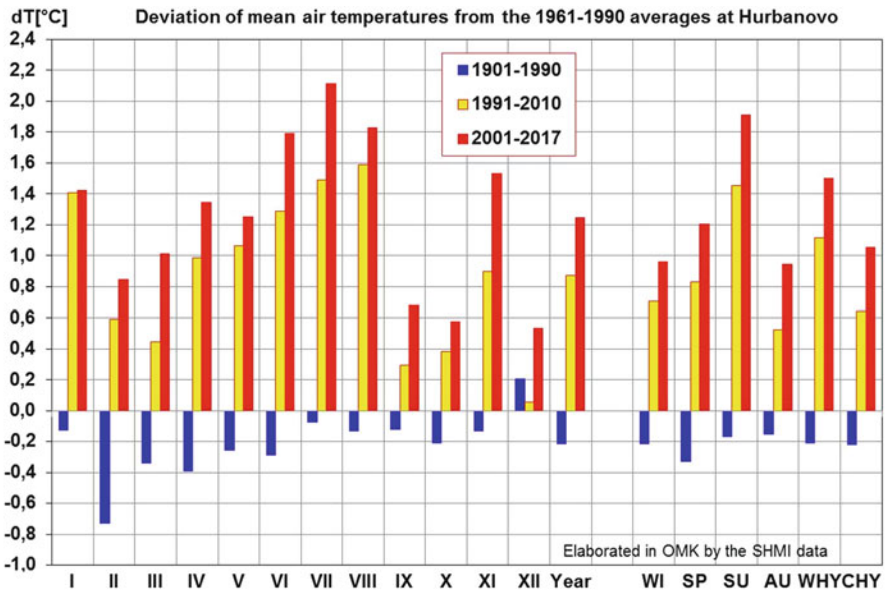


Fig. 2 Deviation of mean monthly and seasonal temperatures (*dT*) at Hurbanovo from the 1961–1990 averages in 1901–2016 (preliminary 2017)

with the increase in air temperature. What is more important is an increase in the saturation deficit Δ (an example from Hurbanovo is in Fig. 5). The increase in Δ is highest in the SW Slovak lowlands and the least in the N Slovak mountains.

2.3 *Precipitation*

Daily precipitation totals are measured in Slovakia with the Metra 886 national gauge (1 m above ground and with a 500 cm^2 orifice) by the same method since 1921 (some different methods were used before 1921). Annual and seasonal totals have not exhibited any significant trends since 1881 (Fig. 6). In the CHY a decreasing trend was found in southern Slovakia and an increasing trend in northern Slovakia (Fig. 7). A greater variability in the annual and seasonal totals and an increasing share of the convective precipitation have been registered since 1995.

2.4 *Evapotranspiration*

Evapotranspiration totals have been calculated in Slovakia as monthly values for 32 stations since 1951 by the Budyko complex method [6], which was modified for

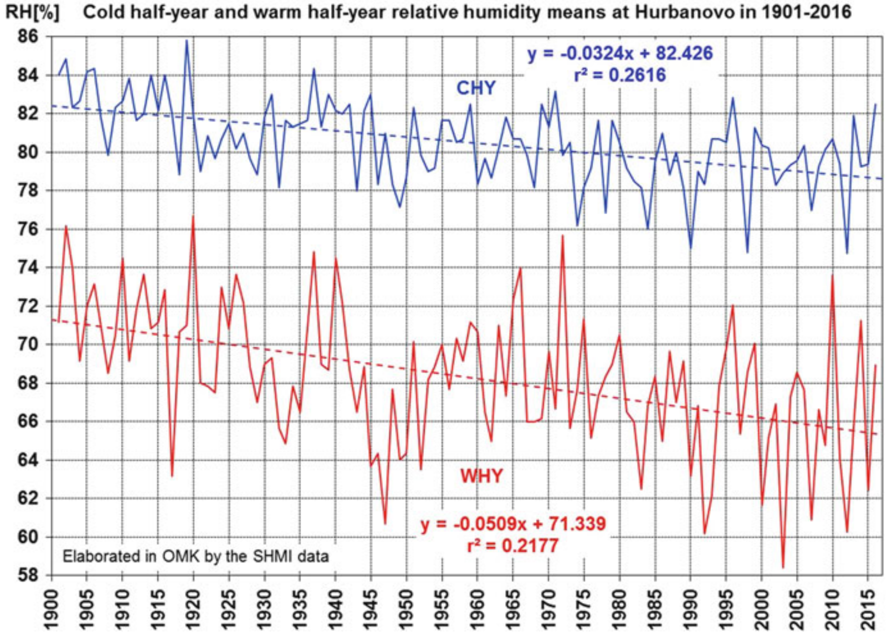


Fig. 3 Mean relative air humidity (RH) and trends at Hurbanovo for a cold half year (CHY, Oct–Mar) and a warm half year (WHY, Apr–Sept) in 1901–2016

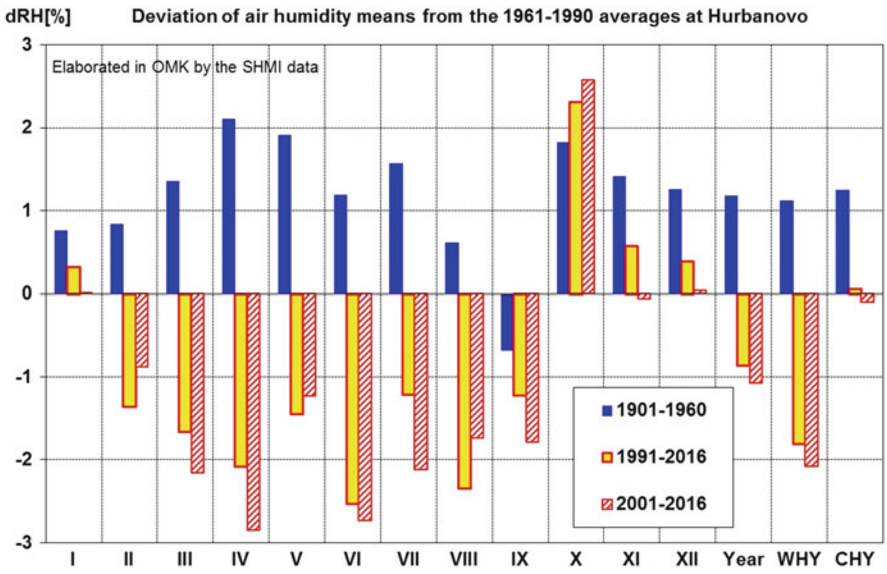


Fig. 4 Deviation of monthly and seasonal relative air humidity means (dRH) at Hurbanovo from the 1961–1990 averages in 1901–2016

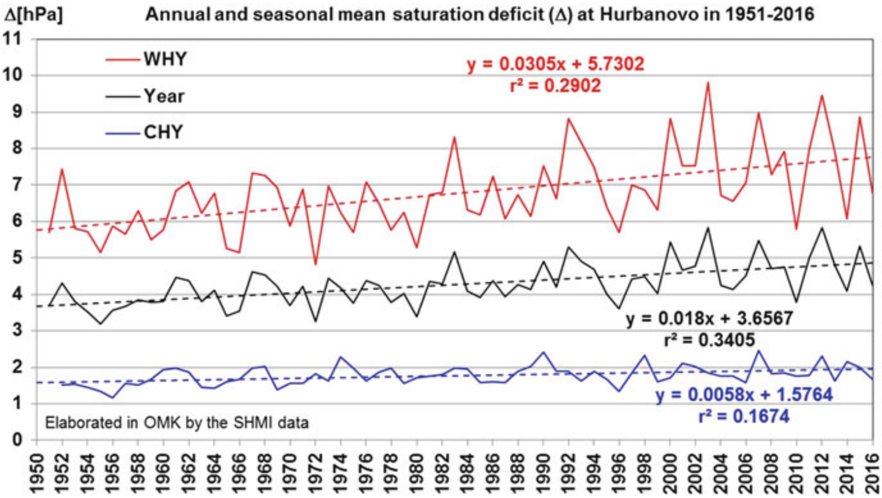


Fig. 5 Mean saturation deficit (Δ) at Hurbanovo for the year, cold half year (CHY, Oct–Mar) and warm half year (WHY, Apr–Sept) in 1951–2016

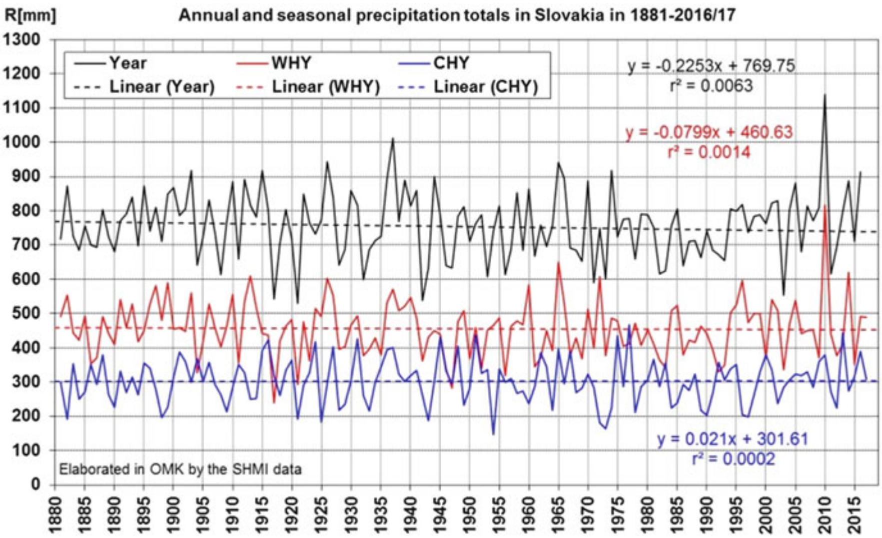


Fig. 6 Annual and seasonal [CHY (Oct–Mar) and WHY (Apr–Sept)] precipitation totals (*R*) in Slovakia in 1881–2016/2017 (based on 203 stations)

Slovakia by Tomlain [7]. The monthly sums of potential (E_o) and actual (E) evapotranspiration are considered to be evaporation and transpiration from a standard natural grass plot at the meteorological stations. The complex method also enables the calculation of the monthly means of soil moisture (W) in the upper 1 m soil layer. These data

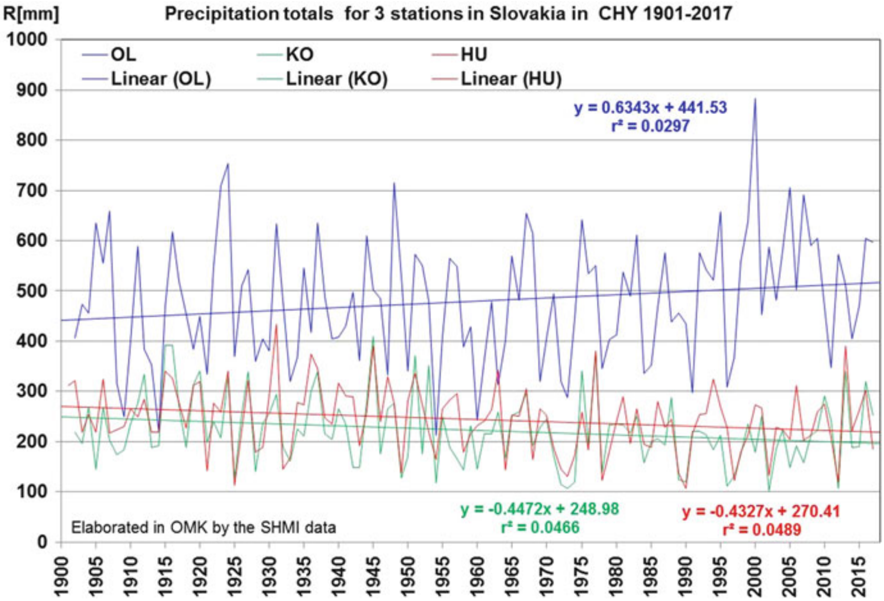


Fig. 7 Cold half year (CHY, Oct–Mar) precipitation totals (*R*) for 3 stations in Slovakia in 1881/1882–2016/2017 (Hurbanovo, 115 m amsl, SW Slovakia; Košice, 230 m amsl, SE Slovakia; Oravská Lesná, 780 m amsl, NW Slovakia)

can also be applied for the calculation of evapotranspiration from different surfaces by the recommended methods. Figure 8 shows the mean E_o and Fig. 9 the mean E for selected stations in Slovakia during the periods 1951–1990 and 1991–2016. It is obvious that E_o is increasing in accordance with the rising air temperature and saturation deficit. Changes in E are dependent not only on the development of E_o but also on precipitation (R) and the availability of W. This is why the deviations of E from 1991–2016 as compared to 1951–1990 are more variable than at E_o (Fig. 10). The method developed by Zubenok [10] in Russia (based only on saturation deficits and geobotanic regions) is also used in Slovakia for simple estimations of E_o. The Zubenok method provides higher monthly sums of E_o compared to the Budyko method in the CHY (Fig. 11) because ground condensation and deposited precipitation are not considered there.

3 Previous Climate Change Scenarios in Slovakia

Climate change scenarios represent the expected development of a climate due to the enhancement of the greenhouse effect by human activities [emission of greenhouse gases (GHGs) and aerosols and land use changes (forests, urbanization, irrigation, melioration, etc.)]. The final effect of such enhancement is a radiative forcing in the global climate system (more than 2 W m^{-2} at present). If there is a supposed stationarity in natural

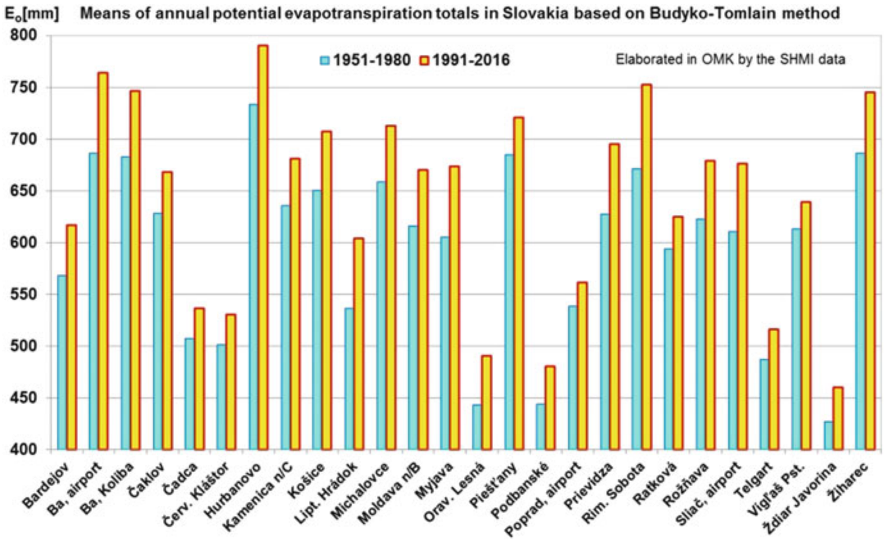


Fig. 8 Mean potential evapotranspiration totals (E_o) at 26 stations in Slovakia for the periods 1951–1990 and 1991–2016 by the Budyko-Tomlain method (Michalovce, 112 m amsl, Ždiar Javorina, 1,020 m amsl)

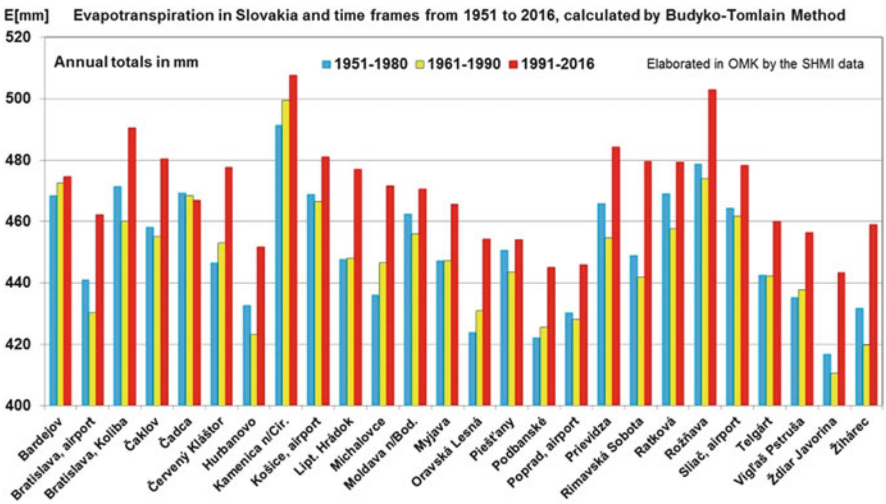


Fig. 9 Mean actual evapotranspiration totals (E) at 26 stations in Slovakia for the periods 1951–1990 and 1991–2016 by the Budyko-Tomlain method

climate-forcing factors, the increase in the greenhouse effect will only be one of the causes of climate change during the next century [11–13]. Most climate change scenarios are based on the supposition that natural climate-forming factors (solar radiation, volcanic activity, etc.) will be stable (with no long-term trends). The anthropogenic enhancement of

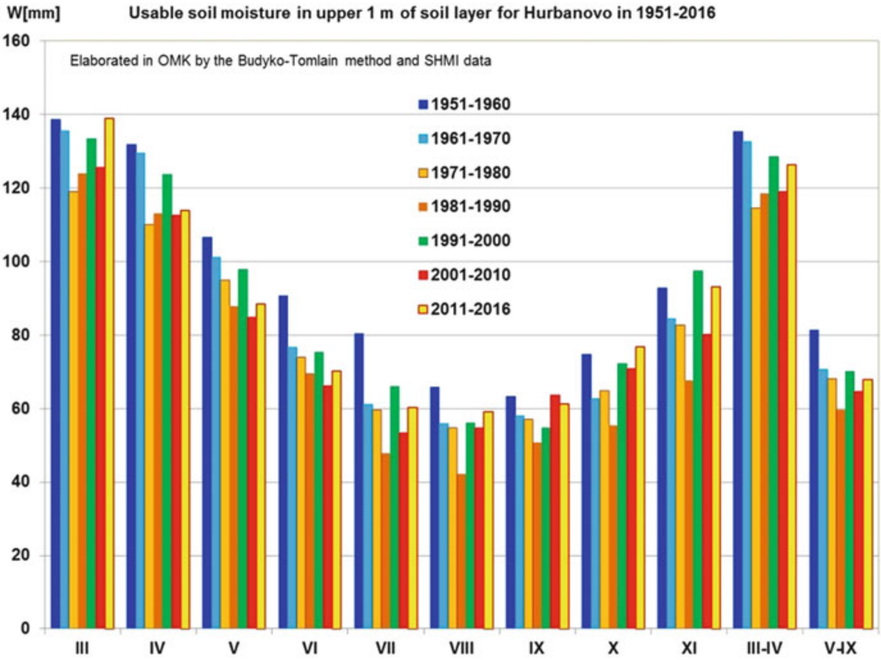


Fig. 10 Mean monthly and seasonal soil moisture (W) at Hurbanovo for the period 1951–2016 by the Budyko-Tomlain method

radiative forcing will reach the interval (based on several possible scenarios) from about 2.6 to 8.5 W m^{-2} by the year 2100 [12].

3.1 Methods

There are several possible methods as to how to prepare reliable climate change scenarios for future years and decades. It is possible to use the scenarios based on the atmospheric general circulation models (GCMs) – global GCMs and regional RCMs. Next are the scenarios based on historical analogues (mainly warmer periods). Other variant are incremental scenarios that are acceptable for testing impact models at present. Furthermore, the stochastic weather generator-based time series of daily data as scenarios could be used. Finally, there are combined scenarios where the selection of reliable T (temperature), R (precipitation), and s (specific humidity) GCM (RCM) as based scenarios is done in the first step. And the calculation of analogues for other climatic/hydrological elements using correlation/regression and simple modeling methods follows in the second step. Such scenarios are designed for a whole distribution range. We count these as priorities in Slovakia for elements with low reliability in the GCM/RCM outputs.

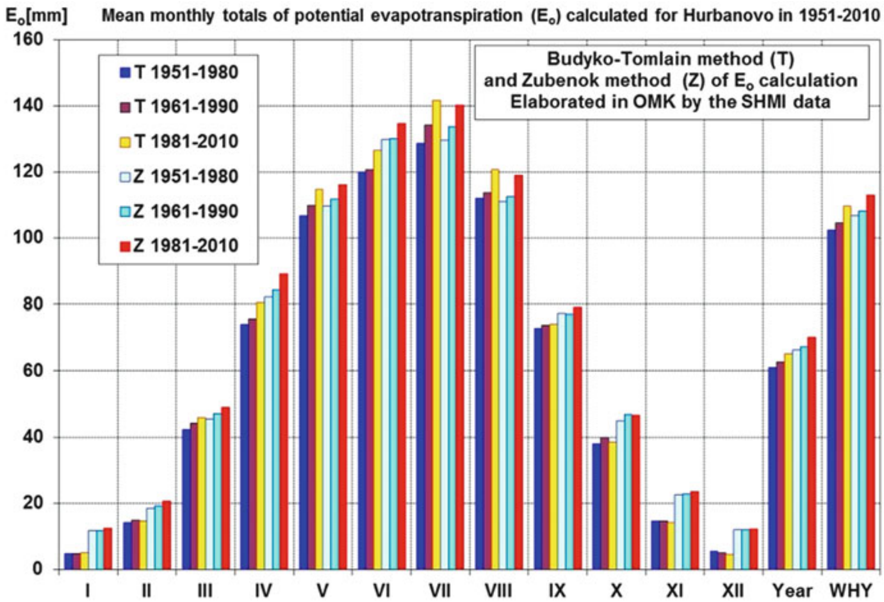


Fig. 11 Comparison of mean monthly potential evapotranspiration sums (E_o) at Hurbanovo calculated by the Budyko-Tomlain method and the Zubenok method for the period 1951–2010

All the scenarios can be prepared for 30-year (25 or 50 years) time frames, long-term series (daily, monthly), selected events, extremes, etc. The first series of scenarios was designed for Slovakia prior to 1995 [3], the second one in 1996–1997 [14], the third one in 2000–2010 [1], and the last one in 2013–2017 [4, 5, 15].

3.2 Data and Models

In 1990, the Second World Climate Conference was held in Geneva, Switzerland, and the first usable series of climate change scenarios was presented [16]. Based on these simple scenarios and the data measured in Slovakia, some alternative scenarios for mean air temperature and precipitation totals have been prepared for users in Slovakia [3]. In 1994, Slovakia began participating in the US Country Studies Project [14], where Slovak researchers obtained new outputs from GCMs [CCCM (Canada), GISS, and GFD3 (USA)]. The Country Study Project resulted in new climate change scenarios with adaptation and mitigation options for Slovakia (Country Study Slovakia, 1997). This research continued as a part of several projects from 1998 to 2001 [3]. An evaluation of the reliability of the selected scenarios from 1993 to 2000 is presented in Figs. 12 and 13.

3.3 Evaluation of Reliability

The climate change scenarios designed in 1995–2000 contained estimates of the mean air temperature and precipitation in the time frame 2010 (period of years: 1995–2024, 1990–2029, or shorter 2000–2019). Now it is possible for the first time to evaluate the reliability of the predicted scenarios using the data measured from the period 2000–2016. As can be seen from Fig. 12, the air temperature scenarios meet the measured values very well. Some of them are even lower than the measured averages (the climate change seems to be greater than expected). On the other hand, the measured values for the precipitation are far from the mean totals predicted by the scenarios (Fig. 13). There are several reasons for this discrepancy. The control period 2000–2016 is too short a time for an analysis of precipitation totals; the development of precipitation changes is not as simple as that of the air temperature; the GCMs from 1990 to 2000 may not have involved a correct physical assumption of the evolution of the precipitation regime during the period of climate change. Despite these discrepancies, we consider our climate change scenarios to be successful for utilizing in the impact studies featured in several socioeconomic analyses [15].

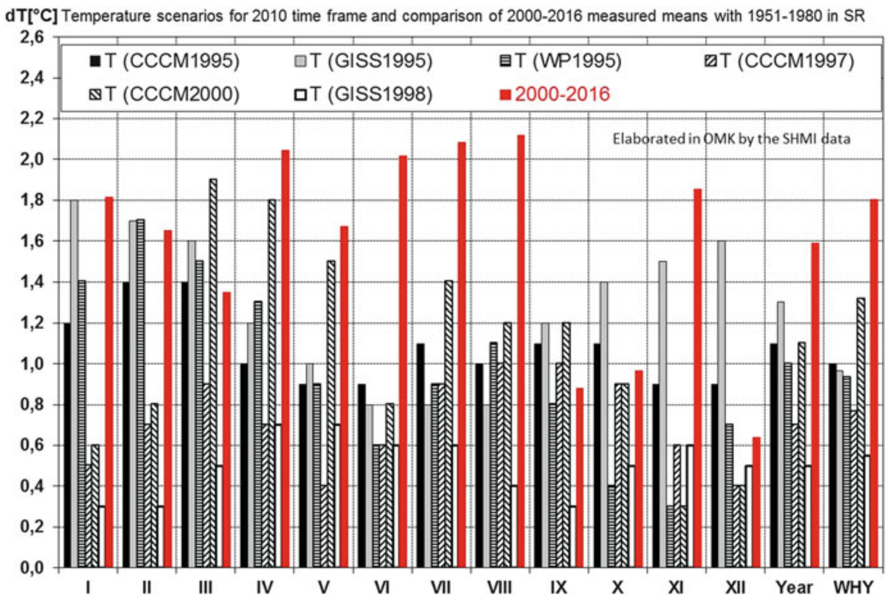


Fig. 12 Evaluation of climate change scenarios reliability for Slovakia and the 2010 time frame by measured air temperature averages in Slovakia in 2000–2016 (*red*)

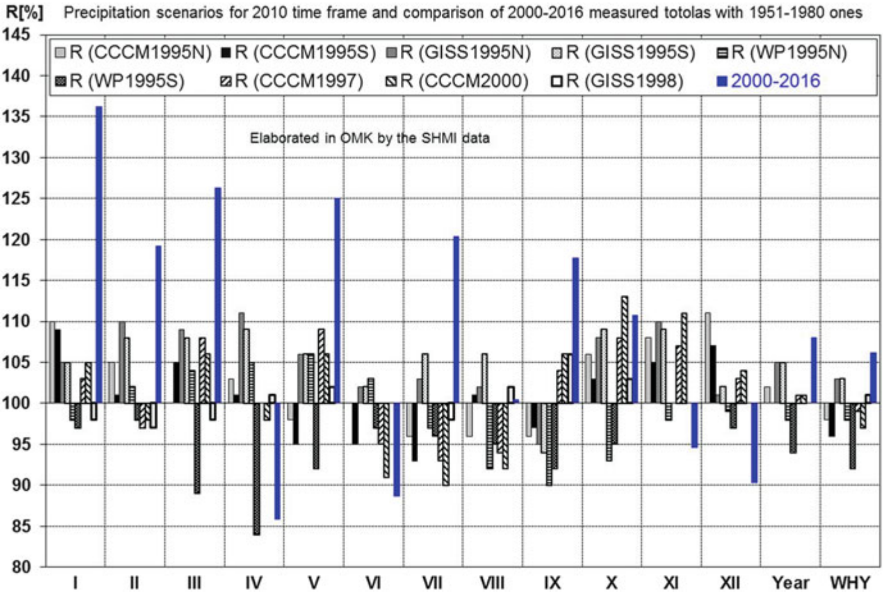


Fig. 13 Evaluation of climate change scenarios reliability for Slovakia and the 2010 time frame by measured precipitation totals (average in Slovakia) in 2000–2016 (*blue*)

4 Evapotranspiration

Evapotranspiration is a very important element of any water balance, agrometeorological and biometeorological analysis, or research. It consists of evaporation and transpiration. While total evaporation from a free water surface or bare soil can be measured and calculated quite successfully, plant transpiration is a serious problem, especially concerning assessments of the daily transpiration totals. There are several examples as to how to overcome this problem [17].

4.1 Measurements

Evaporation has been regularly measured in Slovakia as free water evaporation from the Russian GGI3000 cm^2 evaporimeters at about 30 stations since 1968. The development of the GGI3000 data measured can be found in Lapin and Koštálová [18]. These data are used every year for water balance assessments at the SHMI. A limited number of stations (2–6) have also measured evapotranspiration in Slovakia by simple lysimeters from the soil with short grass in the past.

4.2 Calculations

Monthly potential evapotranspiration totals (E_o) are denoted by the equation for water vapor diffusion in the atmosphere using the Budyko complex method [6], which was adopted for Slovakia by Tomlain [7, 8]. Here, we present only a brief description of this method:

$$E_o = \rho D(q_s - q_2),$$

where ρ is the air density, D the integral diffusion coefficient, q_s the saturated specific humidity at the temperature of an evaporating surface, and q_2 the specific humidity in a meteorological shelter. The actual evapotranspiration (E) is supposed to be proportional to the E_o as follows:

$$E = E_o \frac{\bar{W}}{W_o}$$

The water storage $\bar{W}$ is specified as the moisture stored in the upper soil layer of a 1 m depth. W_o is the critical value above which E equals E_o. W_o usually represents a layer of 100 to 200 mm of water with seasonal and regional variations (only a simplified version of the Budyko [6] complex method of calculation is presented here). W_o depends on the root system development, the mean monthly air temperature and the ratio of the annual potential evapotranspiration and precipitation totals (R). The average soil moisture $\bar{W} = (W_1 + W_2)/2$ is determined from the water balance equation by a step-by-step approximation method. W_1 is the moisture stored in the soil at the beginning of the month and W_2 at the end. The applied model works with the upper soil horizon 1 m thick.

The Zubenok [10] method is even simpler than the one mentioned above. It is based on the use of a saturation deficit (Δ) in different geobotanic regions (the steppe-forest region was taken into account in southern Slovakia). The E_o monthly and seasonal totals can be calculated by the formula $E_o = k{\cdot}\Delta$, where k is the coefficient dependent on the mean radiation balance and turbulence (wind), which is assessed empirically. The coefficient k is therefore different for each month and each geobotanic region. This method can also be easily applied to climate change scenarios of E_o and E using just Δ and R data from the modified GCM and RCM outputs. Because of limited space, we are only presenting trends of scenarios for potential evapotranspiration totals (E_o) in Sect. 6.2.

4.3 Trends Since 1951

The potential (E_o) and actual (E) evapotranspiration as well as the calculated soil moisture (W) seasonal value trends since 1951 are presented in Figs. 14, 15, and 16 for the Hurbanovo station only. Due to the significant dependence E on precipitation

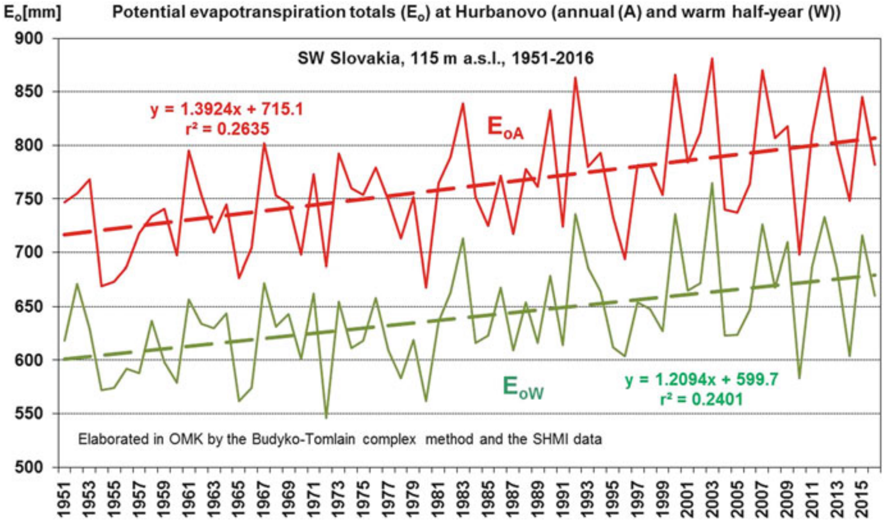


Fig. 14 Trends of annual (*A*) and of warm half year (*W*) potential evapotranspiration totals (E_o) at Hurbanovo in 1951–2016

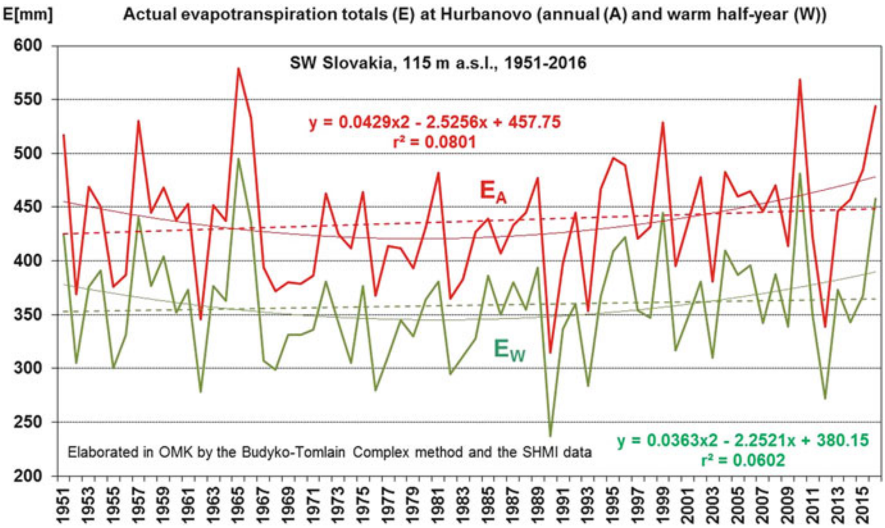


Fig. 15 Trends of annual (*A*) and of warm half year (*W*) actual evapotranspiration sums (*E*) at Hurbanovo in 1951–2016

totals (*R*) and soil moisture (*W*), the development and trend of *E* values is different from the E_o. It can be seen in Fig. 15. The *W* values decreased at most of the stations (mainly in the lowlands), which resulted in a decrease of *E* until the year 1993. Then,

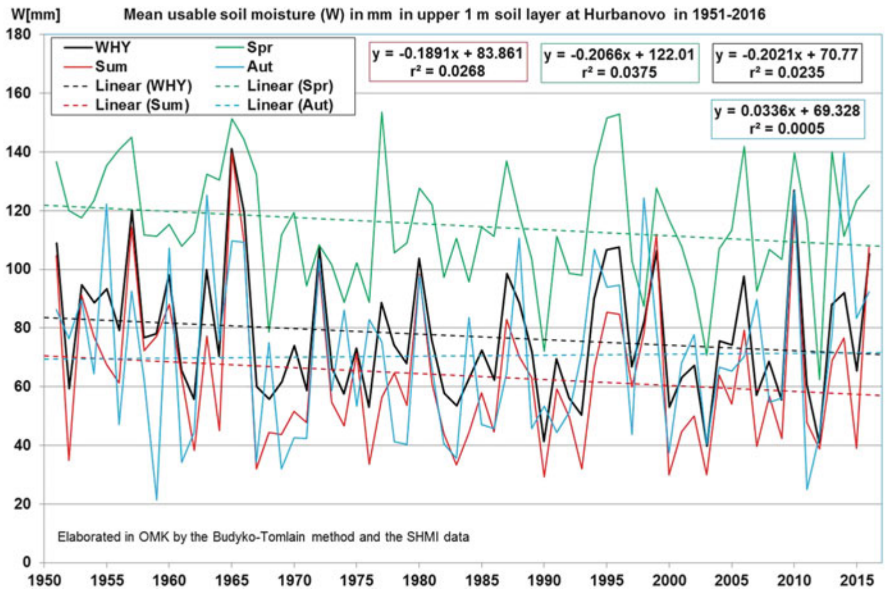


Fig. 16 Trends of mean seasonal usable soil moisture (W) at Hurbanovo in 1951–2016 (WHY, Apr–Sep; Sum, June–Aug; Spr, Mar–May; Aut, Sep–Nov)

an increase in R was observed in the vegetation period, which also influenced an increase of E, while a continuation of a decrease in W was observed. As can be seen from Fig. 14, the potential evapotranspiration (E_o) is mainly increasing in the vegetation period (Apr.–Sep.). Comparable increases were also obtained for other lowland stations in Slovakia and some lesser increases for sites in northern Slovakia.

5 New Climate Change Scenarios

5.1 Basic Information About the Climatic Models Used

Four new general circulation models (GCMs) have been used to design climate change scenarios for Slovakia since 2010 (selected from 10 global GCMs and 15 regional RCMs). Two of them are global (Canadian CGCM3.1 and German ECHAM5) and two regional (Dutch KNMI and German MPI, both of which have ECHAM5 boundary conditions). All the GCMs and RCMs offer outputs of several variables with daily data for the period from 1951 to 2100. Based on these outputs and the meteorological data measured, the daily scenarios for climatic and precipitation stations for all of Slovakia have been designed using a statistical downscaling method. The period 1961–1990 (or 1981–2010) was considered as the reference period, and the period 1951–2016 was used to control the reliability of the scenarios.

Scenarios for the following variables have been prepared: the daily means; the maximum and minimum of the air temperature; the daily means of the relative air humidity, all of which were measured at a 2 m elevation above the ground; the daily precipitation totals, which were measured at a 1 m elevation above the ground; the daily means of "wind speed measured at a 10 m elevation above the ground; and daily totals of the global radiation" [1]. These scenarios can be easily used to prepare studies on the impacts of and vulnerability to climate change.

Based on these modified model outputs and the data measured at about 30 meteorological stations from 1951 to 2016, scenarios of the water balance elements, snow cover characteristics, and some other climatic/hydrologic elements can be calculated up to the time horizon of the year 2100 [3–5].

5.2 *Downscaling Methods*

The model simulations provide physically consistent outputs of meteorological variables in space and over time. Currently, the biggest problem that contributes most to output errors is the inaccuracy of the inputs. In the case of general air circulation climatological models (GCMs and RCMs) for long-term simulations, e.g., several decades, the quality of the input data and the scenarios used are important, especially if we know that great uncertainty can enter these input files. Another source of inaccuracies is the spatial resolution of the model. Even in RCMs, this resolution is in tens of square kilometers because the calculations are so time-consuming.

The great spatial resolution of the grid points means the shape of the modeled orography differs from the actual one. The shape of the relief and its properties are important in the physical interactions between the atmosphere and the surface. These inaccuracies cause variations in the model outputs relative to the actual measured data. For future long-term simulations, we have not had the opportunity to immediately check the quality of the model outputs if the data has not yet been measured. Therefore, we chose a reference period to verify the outputs of least 30 years, since we have measured and modeled data available.

We can then evaluate the suitability and quality of the selected climatological models by statistical comparisons. In our case, we chose RCMs of KNMI and MPI, the spatial resolution of which is approximately 25 $\times$ 25 km. Since the measurement points are mostly located outside the model's grid, we need a relevant method, for example, interpolation, to obtain a model value at the point of measurement for further statistical processing. The method used depends on the spatial variability of the quantity analyzed. For air temperature, it is reasonable to use weight interpolation from the four surrounding grid points of the model.

For precipitation totals, the situation is different; a more appropriate alternative seems to be to take the model point closest to the point of measurement or the best representative grid point of the geographic condition for the station where the measurement was done, due to the roughness of the surrounding terrain, the prevalent flow, etc.

In the following, we are only describing the methodology presented in Lapin et al. [1], which has applied for the years 2015–2017. The data modeled and the data measured are represented by a time series of selected meteorological variables. The time series can be divided into three components: trend, seasonal (cyclical), and random.

To properly process the data, we must take into account the periodic components contained in the time series. The most important seasonal cycle in our length of the time series is the annual cycle. When processing variable X, therefore, we apply two indices, i.e., the trend (index i, year of processing) and the cyclic (index j, day of the year) indices to the time series. On the basis of the statistics obtained from the measured and modeled data from the reference period, we are ready to adjust the modeled data in the future in such a way as to best capture the predicted climatic characteristics of the region. In this way deviations due to inaccuracies from the inputs or the model structure of the simplified equations are minimalized. The statistical parameters in the reference period are determined depending on the type of variable for which they are calculated. In the calculations we try to:

- Not disturb the physical consistency between the elements
- Minimize the difference between the average of the model outputs and the average of the measured data in the longest reference period
- Minimize any variability in the modeled and the measured variability over the longest period

For variables with a Gaussian probability distribution (e.g., mean air temperature, maximum and minimum air temperature, relative air humidity, shortwave radiation), we chose to modify the statistical average of the model data using a correction using the mean deviation from the measured data that was calculated for the reference period. Because of the error rate changes over the year, we calculated the average variations for each day of the year for the daily data. The deviation averages were calculated for the selected reference period, i.e., mostly for the 30-year period:

$$\overline{d_j} = \frac{1}{n_\mathrm{r}} \sum\nolimits_{i=1}^{n_\mathrm{r}} \left(x_{i,j}^\mathrm{s} - x_{i,j}^\mathrm{m} \right).$$

$\overline{d_j}$ represents the mean deviation for a given day of the year, with x^m being the daily data modeled and x^s the daily data measured, $j \in (1, \ldots, n_\mathrm{d})$, n_r are the number of days in the reference period for the chosen day of the year, and n_d is the number of days in 1 year).

Due to the existence of noise in the processed data, we chose to deploy a filter, i.e., an 11-day moving average with a periodic boundary condition on the average daily deviation $\left(\overline{d_j}\right)_{11}^\mathrm{c}$. The overall modification of the model data with respect to the average when using the correction for the mean deviation is given by the expression:

$$x_{i,j}^{\mathrm{mn}} = x_{i,j}^{\mathrm{m}} + \left(\overline{d_j}\right)_{11}^{\mathrm{c}},$$

where $i \in (1, \ldots, n_{\mathrm{f}}), j \in (1, \ldots, n_{\mathrm{d}})$, and n_{f} is the number of years for which the adjustment is being made.

The next step was the correction of the variability of the model data. It is necessary to adjust the data without affecting the average of the given quantity. Modifying the data can be done using a ratio of the standard deviations of the modeled and the measured data calculated for the reference period:

$$s_j = \sqrt{\frac{1}{n_{\mathrm{r}} - 1} \sum\nolimits_{i=1}^{n_{\mathrm{r}}} \left(x_{i,j} - \overline{x_j}\right)^2},$$

where $\overline{x_j} = \frac{1}{n_{\mathrm{r}}} \sum\nolimits_{i=1}^{n_{\mathrm{r}}} x_{i,j}, j \in (1, \ldots, n_{\mathrm{d}})$, n_{r} represents the day of the year, and n_{d} is the number of days in 1 year.

For the overall modification of the model data, we used the mentioned ratio of the sample standard deviations and the moving average (21 days) to eliminate the noise in the data:

$$x_{i,j}^{\mathrm{mnf}} = \left(x_{i,j}^{\mathrm{mn}}\right)_{21}^{\mathrm{c}} + \left[x_{i,j}^{\mathrm{mn}} - \left(x_{i,j}^{\mathrm{mn}}\right)_{21}^{\mathrm{c}}\right] \frac{s_j^{\mathrm{s}}}{s_j^{\mathrm{m}}},$$

where operator $(x)_{21}^{\mathrm{c}}$ represents the ratio of the measured standard deviation and the model data sample's standard deviation and the indices are $i \in (1, \ldots, n_{\mathrm{f}}), j \in (1, \ldots, n_{\mathrm{d}})$. Now the result $x_{i,j}^{\mathrm{mnf}}$ is the required result of the total adaptation of the model data.

For variables that do not have a Gaussian probability density distribution, we only use a modification with respect to the mean. Due to the large skewness of these data, we did not apply the modification to the variability because it could affect the mean correction applied.

Another problem that we need to deal with concerning data such as precipitation or wind is the difference in the number of zero precipitation or calm days. The aim is to minimize the difference in the number of these days between the model and the measured data. The task is realized by applying the mean deviation:

$$x_{i,j}^{\mathrm{m0}} = x_{i,j}^{\mathrm{m}} + d_j^0,$$

where $i \in (1, \ldots, n_{\mathrm{f}}), j \in (1, \ldots, n_{\mathrm{d}})$.

The negative values obtained for $x_{i,j}^{\mathrm{m0}}$ are reset to obtain a new frequency for the model data for non-precipitation days or for days with no wind. In this way, we did not interfere with the physical consistency of the data; we only reestablished the number of zero occurrences between the model output and the measurement.

The model outputs represent an area in the grid point scheme; in our case, this is up to the size of $25 \times 25\ \mathrm{km}^2$ in the KNMI and MPI RCMs. From this point of view, it is logical to perform an adaptation for the data's multiplicity because the model outputs have to be interpreted as an area representation of the value; it triggers overestimates of the data's frequency, especially for the occurrence of low rainfall totals.

Because of the nonnegative data values, we could implement a modification of the mean by using a quotient method. We eliminated the incidence of noise by using 21-day moving averages. For the quotient given as the ratio of the filtered means we have:

$$\overline{q_j} = \frac{\left(\frac{1}{n_\mathrm{r}}\sum_{i=1}^{n_\mathrm{r}} x_{i,j}^{\mathrm{s}}\right)_{21}^{\mathrm{c}}}{\left(\frac{1}{n_\mathrm{r}}\sum_{i=1}^{n_\mathrm{r}} x_{i,j}^{\mathrm{m0}}\right)_{21}^{\mathrm{c}}},$$

where $j \in (1, \ldots, n_\mathrm{d})$.

The overall correction of the entire set of model data based on the calculated quotient for the reference period was now realized using the relationship:

$$x_{i,j}^{\mathrm{m0n}} = x_{i,j}^{\mathrm{m0}} \cdot \overline{q_j},$$

where $i \in (1, \ldots, n_\mathrm{f}), j \in (1, \ldots, n_\mathrm{d})$.

5.3 Example of Temperature, Precipitation, and Humidity Scenarios for Slovakia

Because of limited space, only examples of climate change scenarios as time series of seasonal values are presented here for the period 1951–2100. Mean air temperatures (T) have increased from 1951 up to the present by about 2°C, and another increase of 2–4°C is expected up to the year 2100 in most of Slovakia (Fig. 17). Total annual precipitation (R) will increase by about 10% (more in northern Slovakia, less in southern Slovakia) up to 2100. The scenarios for summer precipitation totals seem to be mostly decreasing, especially in southern Slovakia (Fig. 18). Mean annual and WHY relative air humidity (RH) are expected to have only an insignificant decreasing trend or no trend up to 2100. On the other hand, the saturation deficit (Δ) trend will probably be positive for the whole country. A greater increase in Δ is expected in the WHY for the southern lowlands of Slovakia (Fig. 19).

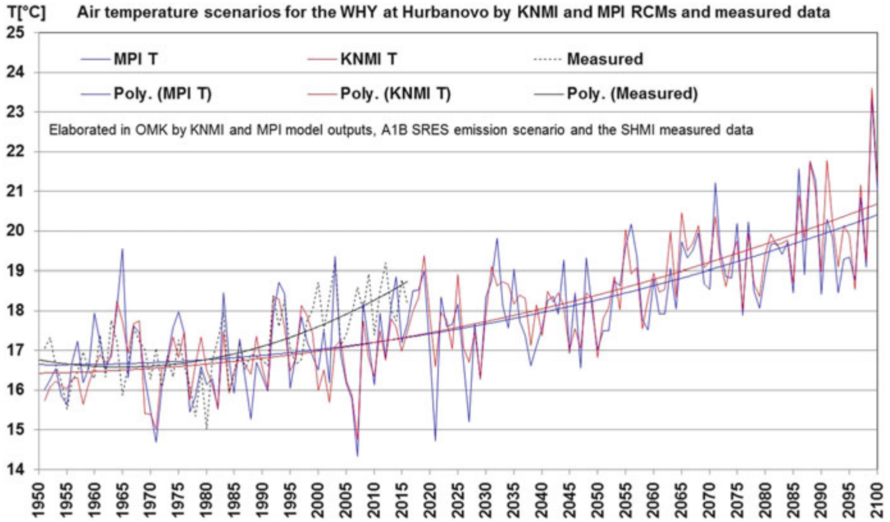


Fig. 17 Scenarios of mean warm half year air temperature (T) at Hurbanovo for 1951–2100 and measured values in 1951–2016

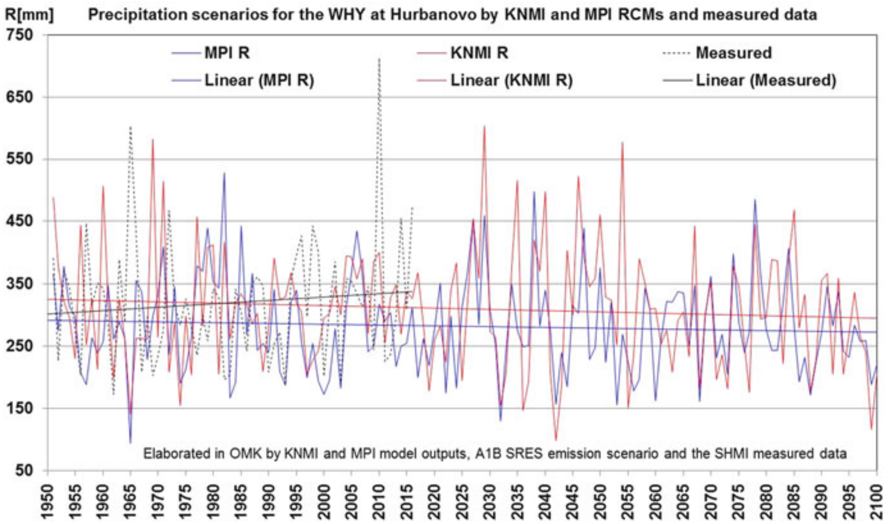


Fig. 18 Scenarios of warm half year precipitation totals (R) at Hurbanovo for 1951–2100 and measured values in 1951–2016

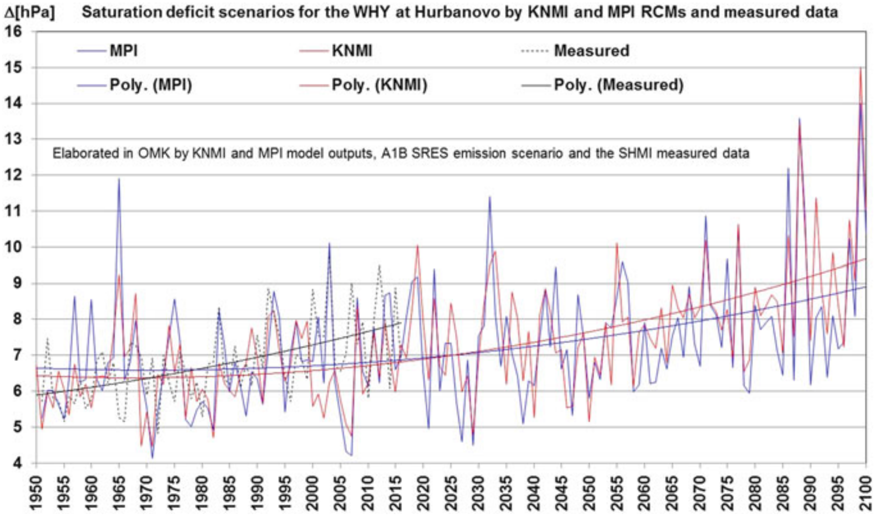


Fig. 19 Scenarios of mean warm half year saturation deficit (Δ) at Hurbanovo for 1951–2100 and measured values in 1951–2016

6 Potential and Actual Evapotranspiration Scenarios

As was previously mentioned, the potential (E_o) and actual (E) evapotranspiration are complex phenomena with quite debatable methods of assessment. Even more problematic is the process of scenario design. The GCM and RCM models offer some outputs for average evapotranspiration totals around the grid points. These values are often far from the reality in the reference or control period. Therefore, we decided to apply the simple Zubenok and complex Budyko methods to calculate the monthly and seasonal E_o and E totals.

6.1 Simple Zubenok Method and Complex Budyko-Tomlain Method

The Zubenok method [10] is based on saturation deficits (Δ) applied in defined regions such as a steppe-forest, deciduous forest, conifer forest, etc. The daily values of Δ can easily be calculated from the modified GCM/RCM outputs for the daily averages of air temperature (T) and relative humidity (RH). The calculated monthly averages of Δ from the daily Δ values are very reliable, so this method seems to be comfortable calculating for the E_o monthly totals up to the year 2100.

The Budyko method, as modified by Tomlain [7] for Slovakia, needs monthly data of T, RH, snow cover and cloudiness, or the duration of sunshine for E_o calculations. Snow cover and duration of sunshine monthly data are not directly available from GCM and RCM outputs and must be calculated indirectly by a regression method. That is why the calculation of E_o scenarios by this method is more difficult (see Sect. 4.2).

If the monthly E_o and R data are available, the calculation of monthly E totals is quite easy for any station. The trend of E will be very different for each station up to the year 2100 because of complicated relationships among the basic water balance phenomena (precipitation, soil moisture, runoff, potential evapotranspiration, and the temporal regimen of those values). This can also be seen from the E totals at the selected 26 stations in 1951–2016 (Fig. 9) or in the time series of the water balance data (Figs. 14, 15 and 16).

6.2 Example of Potential Evapotranspiration Scenarios for Slovakia

Figure 20 shows an example of possible changes in the WHY and CHY E_o totals at Hurbanovo from the period 1951 to 2100, including the values based on measurements (all from the results of the Zubenok method). A significant increase in E_o totals in the WHY (Apr.–Sep.) can be seen on the one hand and a rise of the interannual

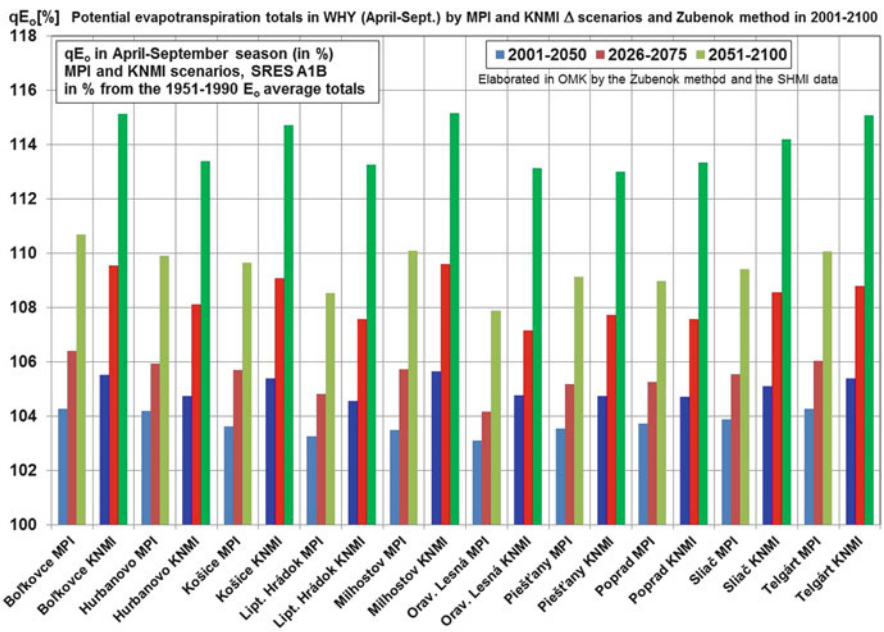


Fig. 20 Scenarios of potential evapotranspiration totals (E_o) at 10 stations in Slovakia by the KNMI and MPI RCMs saturation deficit D scenarios and the Zubenok method for the periods in 2001–2100 (Milhostov, 105 m amsl, Telgárt, 901 m amsl)

variability on the other. A similar development can also be expected for the other lowland sites and the lower localities in northern Slovakia.

7 Discussion on the Use of Climatic Scenarios in Hydrology

The hydrology, water resources, and water management sectors are very complex from a scientific point of view. All of them use different models and different input data. They are mainly precipitation, runoff, air, water and soil temperatures, air humidity, evapotranspiration, solar radiation, snow, wind, soil moisture, soil and land surface characteristics, etc. In the climatology sector, we have been able to prepare a very detailed climatic historical data series for Slovakia since 1951 and in some places since 1881. In the recent decades, serious changes in the mentioned elements have been observed. The rise in the air temperature and the changes in runoff regimes are so significant that possible developments in the future years and decades are frequently discussed among the experts and politicians with apprehension.

Climatological science has prepared several series (generations) of possible climate change scenarios, which have a direct relationship with the hydrological cycle, water resources, and water management. Discussing these issues with the experts involved from the branches mentioned, we decided to only prepare 3–5 alternative climate change scenarios (the IPCC and some other foreign sources offer more than 25 scenarios as climatic model outputs). We have concentrated our efforts on the most probable scenarios of the development of the greenhouse gas emissions; they are between the SRES B1 (as an average minimum) and SRES A2 (as an average maximum) assessments. In the case of air temperature that means an increase in the 30-year averages by about 2–4°C up to the end of the twenty-first century. Precipitation totals will also change in a relatively wide range, but generally, an increase of about 10% in annual totals is expected (more in the north and less in the south of Slovakia).

The hydrological cycle and processes are also affected by the changes in regimes and the variability of climatic elements on a shorter scale (daily and hourly data). It seems that a significant increase in the variability of precipitation can be expected, including long periods with low precipitation totals and short periods with very high precipitation totals. Such developments may be accompanied by great changes in the soil moisture, the intensity of precipitation, and the runoff regime and will also surely result in new challenges for water management in Slovakia. New model assessments have confirmed the serious danger (or serious risk) of occurrence of unusual hydrologic situations in the near future (severe droughts in one hand and flash or regional floods on the other). Using the scenarios based on the higher (pessimistic) emission scenarios (SRES A2) also results in more dangerous (worse) hydrological scenarios.

8 Conclusion

The scenarios of climate change and changes in the water balance elements and in the snow cover characteristics were calculated up to the time horizon of the year 2100 [3–5]. The modified model outputs (GCMs, RCMs, and simple statistical/ physical models) and the measured data at about 30 meteorological stations for 1951–2016 were used for this purpose. Our assessments were based on alternative IPCC emission scenarios (the SRES A2, A1B, and B1) and resulted in significant changes in the climatic and hydrological conditions up to the year 2100. This will negatively affect changes in the soil water (dW), the totals of areal evapotranspiration (E), and the runoff (q) regime, since the equation of the hydrological water balance is $R = E + q + dW$.

These scenarios can be successfully used to prepare studies on the impacts of and the vulnerability to climate change in different sectors, including agriculture, hydrology, water resources, and water management. Some results of such research have already been published in several papers and monographs, e.g., [19–24], etc.

9 Recommendations

The research aimed to the climate change scenarios applied in water balance assessment resulted in several recommendations: (1) significant increase of air temperature, decrease of relative air humidity, and changes in precipitation regime will surely negatively impact hydrological balance in Slovakia; this issue needs to be solved more in details; (2) the scenarios of evapotranspiration based on GCM and RCM output are less reliable and need to be calculated by another methods; (3) potential evapotranspiration monthly totals calculated from scenarios of air temperature and air humidity are sufficiently reliable; improving is possible by application of modified Budyko method and more climatic variables as scenarios; (4) design of scenarios of actual evapotranspiration monthly totals is a serious problem, but it can be solved within a new research project in close future; (5) after calculation (design) of reliable scenarios of monthly potential and actual evapotranspiration totals, also daily totals and soil moisture values could be calculated by several methods.

Acknowledgment The chapter was created with the support of the projects APVV-0303-11 and APVV-0089-12. The authors also thank the Slovak Hydrometeorological Institute for data. This task was partly supported also by the Grant Agency of the Slovak Republic under the project VEGA No. 1/0940/17.

References

1. Lapin M, Bašták-Ďurán I, Gera M, Hrvoľ J, Kremler M, Melo M (2012) New climate change scenarios for Slovakia based on global and regional general circulation models. Acta Met Univ Comen 37:25–74
2. Štefunková Z, Hlavčová K, Lapin M (2013) Runoff change scenarios based on regional climate change projections in mountainous basins in Slovakia. Contrib Geophys Geod 43 (4):327–350. ISSN 1335-2806
3. Lapin M, Melo M (2004) Methods of climate change scenarios projection in Slovakia and selected results. J Hydrol Hydromech 52(4):224–238
4. Lapin M, Damborská I, Gera M, Hrvoľ J, Melo M (2015) Trends of evapotranspiration in Slovakia, including scenarios up to 2100. In: International bioclimatological conference: toward climatic services. Slovak Bioclimatological Society SAS, Nitra, 5 p
5. Lapin M, Damborská I, Gera M, Melo M, Hrvoľ J (2016) Potential and actual evapotranspiration in Slovakia in 1951–2015 and possible scenarios up to the year 2100. In: Proceedings of the international conference in Kutná Hora, 28.-29.4.2016. Půdní a zemědělské sucho, Praha, VÚMOP, 210-225 [USB], ISBN 978-80-87361-55-9 (in Slovak)
6. Budyko MI (1974) Climate and life. Gidrometeorizdat. Leningrad (in Russian)
7. Tomlain J (1980) Evaporation from soil and its distribution over the Czechoslovak territory. Vodohospodársky časopis, XXVIII(2). (in Slovak)
8. Hrvoľ J, Lapin M, Tomlain J (2001) Changes and variability in solar radiation and evapotranspiration in Slovakia in 1951-2000. In: Acta Meteorologica Universitatis Comenianae, vol 30. Comenius University, Bratislava, pp 31–58. ISBN 80-223-1692-X
9. Šamaj F, Valovič Š (1982) Areal precipitation totals in Slovakia in 1881-1980. Meteorologické zprávy 35:108–112 (in Slovak)
10. Zubenok LI (1976) Evaporation on continents, Gidrometeoizdat. Leningrad, 264 p. (in Russian)
11. IPCC (2007) IPCC fourth assessment report. Working Group I Report "The Physical Science Basis" Oct. 2007. 996 pp. http://www.ipcc.ch/ipccreports/ar4-wg1.htm
12. IPCC (2014) Climate change 2013. The physical science basis: Cambridge University Press, UK, 1552 p. ISBN: 9781107661820. https://www.ipcc.ch/report/ar5/wg1/
13. Peixoto JP, Oort AH (1992) Physics of climate. American Institute of Physics, Springer, New York, 520 p
14. Marečková K, Lapin M, Minárik B, Mojík I, Závadský I, Závodský D, Zuzula I (1997) Country Study Slovakia, Final Report, U.S. Country Studies Program, Slovak Ministry of the Environment, Slovak Hydrometeorological Institute, Bratislava, 108 p
15. National Communications on Climate Change, vol 1–6 (1995, 1997, 2001, 2006, 2009, 2014) Slovak Ministry of the Environment and Slovak Hydrometeorological Institute, Bratislava. http://unfccc.int/national_reports/annex_i_natcom/submitted_natcom/items/7742.php
16. IPCC (1995) Climate change 1995: the science of climate change. In: Houghton JT, Meira Filho LG, Callander BA, Harris N, Kattenberg A, Maskell K (eds) WMO, UNEP, Cambridge Univ. Press, 572 pp
17. Kabat P et al (eds) (2002) Vegetation, water, humans and the climate. The IGBP series, Springer, New York, 566 p
18. Lapin M, Košťálová J (1987) Evaluation of free water evaporation measured by GGI-3000 in Slovakia. In: Meteorologické zprávy, vol 40(4), pp 106–110
19. Fendeková M, Horvath O, Vrábliková D, Fendek M, Danáčová Z, Slivová V, Gera M (2016) Climate change impact on water resources in Kysuca river basin. Proceedings of the 7th international conference on water resources and environment research ICWRER2016, Kyoto, 2016, 2 p on USB
20. Gaál L, Beranová R, Hlavčová K, Kyselý J (2014) Climate change scenarios of precipitation extremes in the Carpathian region based on an ensemble of regional climate models. In: Advances in meteorology. 14 pp

21. Hlavčová K, Lapin M, Valent P, Szolgay J, Kohnová S, Rončák P (2015) Estimation of the impact of climate change-induced extreme precipitation events on floods. In: Contributions to geophysics and geodesy, vol 45(3), pp 173–192. ISSN 1335-2806
22. Lapin M, Gera M, Hrvoľ J, Melo M, Tomlain J (2009) Possible impacts of climate change on hydrological cycle in Slovakia and results of observations in 1951-2007. Biologia 64(3):454–459
23. Pekárová P, Szolgay J (eds) (2005) Scenarios of changes in the selected components of hydrosphere and biosphere of river Hron and Váh catchments due to climate change. Veda – Publication of the SAV, Bratislava, 494 p. (in Slovak)
24. Šiška B, Takáč J (2009) Drought analyses of agricultural regions as influenced by climatic conditions in the Slovak Republic. Időjárás 113(1–2):135–143

Meteorological Drought Occurrence in Slovakia

L. Labudová and M. Turňa

Contents

Abstract Slovakia is located in the Central Europe, and its complex surface consists of mountains, valleys, but also lowlands, which are crucial for agricultural production. In the neighbouring countries, especially in Hungary and the Czech Republic, there has been paid great attention to drought occurrence for a longer time. In Slovakia, hydrological drought assessment was more often under investigation than the meteorological aspect of the drought in the past. The regionally developed methods were primarily used for its estimation, while the internationally established indicators were rarely applied. In the last years, the drought became to be discussed more frequently in the Slovak climatology, which led to the start of operational drought monitoring in Slovakia in 2015. Drought periods, which occurred in the last years and caused also yield losses in agriculture, raised the interest of the public and experts from different economic sectors in this phenomenon. The intersectoral approach seems to be the crucial way of further drought research.

This chapter aims to present two case studies, which could be the example of the linkage between climatological and hydrological approach in drought assessment on an operational level. The first case study describes the operational meteorological

L. Labudová (✉) and M. Turňa
Slovak Hydrometeorological Institute, Bratislava, Slovakia
e-mail: livia.labudova@shmu.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 51–68,
DOI 10.1007/698_2017_155, © Springer International Publishing AG 2017,
Published online: 14 December 2017

drought monitoring, which has run since 2015. The slightly modified methodology of widely known indices (SPI and SPEI) shows promising results, which can be obtained on a daily basis. It enables them to be used in intersectoral drought analysis. The example of such analysis is presented in the second case study, in which the linkage between meteorological and hydrological drought was examined. The knowledge about the causalities between these two drought types brings higher assumption for the successful design of effective integrated drought monitoring.

Keywords Hydrological drought, The Kysuca river basin, Meteorological drought, Operational monitoring, SPI

1 Introduction

Several studies focused on meteorological drought have been published in Slovakia. In the past, Šamaj and Valovič published their own newly developed methodology for the identification of drought periods in the 1970s [1]. The methodology was based on cumulative daily precipitation totals. It consisted of three criteria for drought occurrence: (a) at least 15 consecutive days with cumulative precipitation total below 1 mm, (b) at least 20 consecutive days with cumulative precipitation total below 2.5 mm or (c) at least 30 consecutive days with cumulative precipitation total below 5 mm. These criteria are stricter than well-known consecutive dry days (CDD) index, which counts the days with daily precipitation below 1 mm without considering their accumulation. According to the methodology, the regions with the highest number of drought periods were the region of Záhorie, the Danubian Lowland, the East Slovakian Lowland, the Southern Slovak Basin, the Levoča Mountains and the Podtatranská Basin (due to the precipitation shadow of surrounding mountains).

Later, more attention was paid to the research of floods and water management mitigating flood impacts in Slovakia. It was the result of great damages caused by floods, which are easier to calculate and to prove them than the damages by drought. It is the "disadvantage" of drought that its progress is very slow and not as visible as it is in the case of a flood. Additionally, it is very hard to quantify its damages in agriculture, because there can occur more negative meteorological factors influencing yields (late frosts, heat waves, hails, etc.). Especially heat waves causing the heat stress for plants can quite often accompany the drought periods.

New studies about meteorological drought have been published since the 2000s. They were the part of hydrological studies very often. Separate climatological studies on drought occurred only rarely. One of them was published by Patassiová et al. [2], who used the Palmer Drought Severity Index (PDSI). The same index was used by Litschmann and Klementová [3]. Later, the Standardized Precipitation Index (SPI) was used by Fendeková and Ženišová [4] in the hydrogeological study.

The drought is a complex problem, and it can spread through different sectors. The meteorological drought is the starting point, and its longer duration can result in the soil drought and hydrological and hydrogeological drought. Therefore, the drought research was the part of the soil, or agricultural research. For example, Skalský et al. [5] simulated the relations within the system soil-plant-atmosphere. The model WOFOST was used to assess drought impact on spring barley in the period 1997–2007. Takáč [6] used the SPI as one of the drought indicators in his study about agricultural drought in Slovakia. The newest study oriented on drought impact on yields was focused on the agriculturally most productive regions in Slovakia – the Danubian Lowland and the East Slovakian Lowland [7]. The authors used the SPI and the SPEI (Standardized Precipitation and Evapotranspiration Index) to find the relationship between drought occurrence and the yields of different crops. There was found a high significant correlation between both variables, but only in the Danubian Lowland due to complicated soil conditions in the southeast of Slovakia.

In the last years, not only the studies were the main outputs of the drought research in Slovakia. The Slovak Hydrometeorological Institute (SHMI) established its own meteorological drought monitoring in March 2015. The monitoring is based on the modified SPI and SPEI as well as on the Crop Moisture Index (CMI), and it is weekly updated. Besides the actual situation, it offers 7-day forecast of all indices based on the ECMWF data [8]. To bring more complex information for the farmers and foresters, the SHMI joined to the integrated soil drought monitoring called Intersucho in autumn 2015. This monitoring was developed by the CzechGlobe (Global Change Research Institute of the Czech Academy of Sciences), the Masaryk University and the Mendel University in Brno, Czech Republic [9]. It is based on the integrated soil model, which considers the soil parameters and simulates the soil water content in near real time.

In this chapter, two case studies are presented on operational meteorological drought monitoring and assessment, including connection to hydrological drought.

2 Case Study 1: Operational Meteorological Drought Monitoring

As it has already been mentioned in the Introduction, the Slovak Hydrometeorological Institute (SHMI) established its own operational meteorological drought monitoring in March 2015. In this case study, the results of the first monitoring season 2015 are presented. During this period, extremely dry conditions occurred in Slovakia, which was very well monitored by SHMI's drought monitoring. In the second part of the case study, the relationship between meteorological drought monitoring and relative soil humidity is demonstrated on the example from the monitoring season 2016.

2.1 Methods

The drought monitoring in Slovakia is primarily focused on meteorological drought. Therefore, it requires only climatologic data from the station network of the Slovak Hydrometeorological Institute (SHMI) except the Crop Moisture Index (CMI), which also requires the information about available water content (AWC) in the soil. The AWC data were provided by National Agricultural and Food Centre – Soil Science and Conservation Research Institute (NAFC – SSCRI). The climatologic data consisted of precipitation totals; maximum, minimum and average air temperature; relative air humidity; average wind speed; and sunshine duration on a daily basis. The monitoring is currently based on three indices – Standardized Precipitation Index (SPI), Standardized Precipitation and Evapotranspiration Index (SPEI) and Crop Moisture Index (CMI). During the first testing season, we also used Palmer Z-index, but it was excluded due to dissatisfying results.

The Standardized Precipitation Index was defined by McKee et al. [10] to establish the tool, which would enable the comparison of drought conditions in different climatic conditions. The precipitation totals are fitted with the gamma distribution and standardized to reach non-dimensional value. It is the worldwide used index because it requires only precipitation data in its calculation. However, its data simplicity means some disadvantage in the areas, where evaporation has an important impact on the water balance. The increasing air temperature [11] enhances the evaporation, but the SPI is not able to reflect the temperature changes in the drought assessment. Therefore, the Standardized Precipitation and Evapotranspiration Index was established by Vicente-Serrano et al. [12]. It is based on the similar principal as the SPI, but it considers simple water balance, precipitation (P) minus potential evapotranspiration (PET), instead of single precipitation. The index uses the log-logistic distribution for the data approximation. The original methodology uses the Thornthwaite's PET estimation method [13]. However, the World Meteorological Organisation and the Food and Agriculture Organisation recommend the Penman-Monteith's method [14]. Both indices can be calculated for different time steps originally defined on a monthly scale. Therefore, we had to slightly modify their methodology to get the daily operational data. In principal, all steps were preceded as they were defined by their authors. The only change is the character of the accumulation period. If the SPI is calculated on a monthly scale, the accumulated period is in average 30 days. We kept the accumulation period of 30 days, although we did not deal with monthly data, but we applied moving window on the daily data summing the daily precipitation totals or PET totals, respectively [8]. It means that the final value of the SPI (the SPEI) refers to the conditions of $n\text{-}29$ to n days, where n is a day at the end of the moving window. This principle was used for the 3-month SPI within the DROught adaPtation (DROP) project in Flanders [15], which is addressed for hydrological praxis. The 3-month time scale would be too long for agricultural purposes. Therefore, we limited the moving window to 30 days, and we applied this methodology not only on the SPI but the SPEI as well.

The Palmer's Crop Moisture Index was defined in 1968 [16], and it belongs to the group of agricultural drought indices. It takes into account week to week changes in simple water balance considering its state at the end of the previous week and soil characteristics such as available water content (AWC), which influence the soil moisture recharge. The CMI requires PET data as well. For its estimation originally used methodology by Thornthwaite is used [13].

The monitored area covered two agriculturally most important lowlands – the Danubian Lowland (DL) and the East Slovakian Lowland (ESL) in the first testing season 2015. At the moment, it covers the territory of the whole country. The monitoring is station based, and the data from 44 climatologic stations with available daily operational data access are used. The mountainous stations were excluded as the monitoring should be used primarily for agricultural purposes. The assessed period is from 1981 till the present, and the reference period for the SPI and the SPEI was fixed on 1981–2010. The historical data were homogenized for the period 1981–2014, and later data have operational character without homogenization. The monitoring is updated weekly each Monday from March to September at the official webpage of SHMI (http://www.shmu.sk/sk/?page=2161), and it consists of the assessment of the situation during the last 7 days as well as the expected changes in drought indices in the next 7 days. The forecast is based on the ECMWF model. The drought indices are visualized in figures, which are available after click on the station mark in the interactive map with figure preview. The colour of the mark represents drought intensity according to the SPEI (Fig. 1). Besides graphical visualization, we provide also text summarizing weather in the last week with an explanation, how it influenced the water balance in Slovakia and which changes are expected in the next week as well.

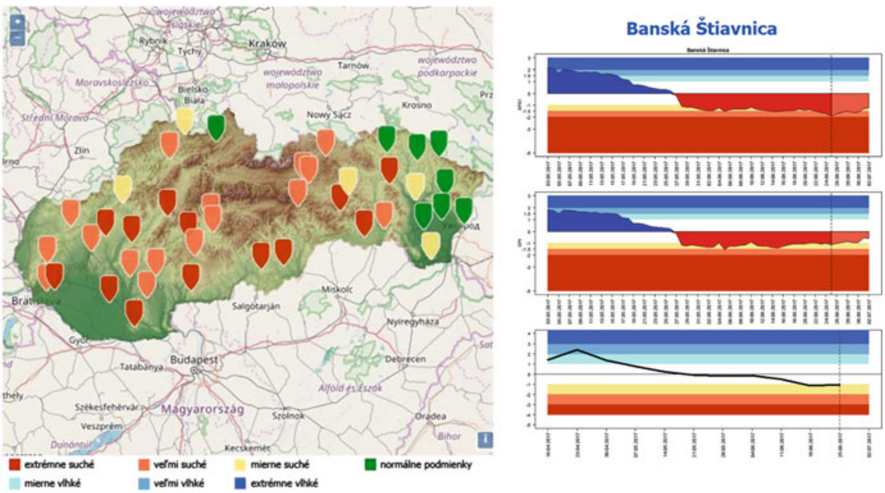


Fig. 1 The example of map graphics with figure preview on 26 June 2016. For clearer version for all stations, please visit this link (http://www.shmu.sk/sk/?dt=1498341600&page=2161)

2.2 *Operational Monitoring in Praxis*

2.2.1 Season 2015

As it was mentioned, the first drought monitoring season had testing character, and only two agriculturally most important lowlands were monitored. The initializing conditions were better in the Danubian Lowland (DL) than in the East Slovakian Lowland (ESL) due to drier winter conditions in the eastern part of Slovakia. A similar tendency was observed in March 2015, when the DL recorded values close to normal long-term precipitation totals, while the ESL observed only 11.8 mm in Milhostov. It resulted in the SPI values below −1 and in the south of ESL even below −1.5. The situation was getting worse at the end of the month at all monitored stations. Precipitation deficit continued in April, and the highest monthly precipitation total was observed in the southwestern part of the DL (26.1 mm), but the ESL experienced only 6.2 mm. It meant the deterioration in water balance, especially in the southeastern Slovakia. Besides the SPI and the SPEI, the CMI was also decreasing with an increasing air temperature. It reached the value −1 at the end of the month. The SPI showed even worse conditions with the values below −2. The SPEI stopped its decline closely above −2. In the DL, the indices were mostly positive and showed balanced (normal) conditions. However, they were slowly decreasing at the end of the month as well, especially in the central and southern part of the lowland.

Large regional differences also persisted in May 2015, when the DL had enough precipitation, especially in its southern locations. All three indices indicated moderate wet conditions. The month began as extremely dry according to the SPI and as very dry according to the SPEI in the ESL. The second half of the month brought the improvement of the situation, mainly after the passing of cold frontal zone on 26 and 27 May. The CMI was almost continuously decreasing as well due to rising daily air temperature, which increased the importance of evaporation in drought assessment. The CMI reached values around −1.5 in the last week of May.

The water balance in June 2015 was influenced by two main factors. The first one was a strongly deepening precipitation deficit, which was very rarely interrupted with thunderstorms connected with very intense rainfall. Such case occurred in Milhostov (ESL), where the total of 45 mm was observed. Heavy rainfall causes that surface runoff is higher than the infiltration into the soil, especially after long-lasting drought period, when the topsoil layer is quite solid. None of the used indices are able to exclude intense precipitation, which cannot finish the drought period very often. The lowest precipitation total (11.8 mm) was recorded in Somotor (southern ESL). The long-term values for June (1961–1990) are in the interval from 70 to 80 mm for these monitored stations. The second factor was high potential evapotranspiration due to very high air temperature, stable sunny weather and low relative air humidity. This factor strongly influenced the situation during whole summer and in the ESL also in September. The deviations of monthly average air temperature in summer months varied from +1.8°C up to more than +5°C. These factors caused the

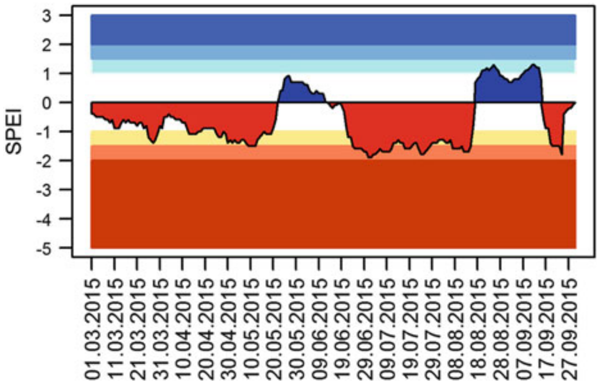


Fig. 2 The SPEI in the monitoring season 2015 in Žihárec

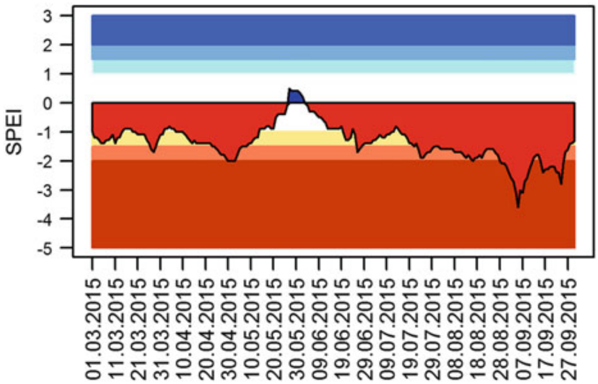
decrease of drought indices in both lowlands. The SPEI and the SPI were below −2 in Bratislava, Nitra, Piešťany, Žihárec (Fig. 2) and Somotor. The CMI was decreasing as well, and it reached values below −3 in Somotor and below −2 at other stations in the ESL except for the station Milhostov.

After a very dry June, even July did not bring long-desired precipitation. Moreover, the extremely high monthly average air temperature even deepened the drought. The SPI in Milhostov (ESL) decreased below −3, and both standardized indices varied around −2 in the DL. The same tendency showed the CMI as well, and all monitored stations recorded its values below −2, the stations Piešťany, Žihárec and Somotor even below −3. It has been the lowest recorded value of the CMI (−3.2) at the station Piešťany since 1961 as well as in Žihárec (CMI equal to −3.36). Comparable drought occurred in the central part of the DL only in 2012 with the minimum value equal to −3.35.

August brought a change for the DL, where the precipitation in the second half of the month finished drought period at all monitored stations. The SPEI showed normal to moderate wet conditions here. On the other hand, the water balance in the ESL was still worsening, and the stations recorded very dry to extremely dry conditions. The CMI reached its minimum values of the season. The station Vysoká nad Uhom recorded the value −4.40 (Fig. 3), which has been the lowest one since 1981. Similarly, the most southern station, Somotor, has not observed lower value than −4.19 before. In summary, the half of monitored stations have reached the lowest CMI since the beginning of their observation.

The last month of the monitoring season meant new drought period in the DL. The much worse situation was in the eastern part of Slovakia, where the SPEI decreased on −3.6 in Vysoká nad Uhom and other stations were approaching extreme low values as well. This long-lasting drought period was not interrupted till the end of monitoring season at the most of the ESL. The only exception was the station Milhostov. It can be concluded that the whole monitoring season was from very dry to extremely dry in the ESL as only a short interruption occurred in June.

Fig. 3 The SPEI in the monitoring season 2015 in Vysoká nad Uhom



2.2.2 Operational Meteorological Drought Monitoring and Relative Soil Humidity

The SPI and the SPEI began within the range of extremely wet values at the beginning of the second season (in 2016) due to very high precipitation totals in February. They were caused by repeating circulation situation, which enabled the flow of warm and wet oceanic air masses from the south and southwest. Both indices started to increase in the middle of the month, when they crossed +1.5, and they were evidently above +2 at the end of the month. The most extreme situation occurred in the south of Western and Central Slovakia. The eastern part of the country observed wet conditions approximately 1 month earlier than the rest of the country. The exception was the Spiš region, where conditions were closer to those in the Central Slovakia. The CMI showed very similar results as the SPI. The described situation resulted in much better water balance at the beginning of the monitoring season than in the previous year.

March was poor in the precipitation, which resulted in quite a steep decrease of the SPI and SPEI. The deficit was so high that we observed worse water balance in March and in the first half of April than in the previous year at the same time in the Western and Central Slovakia. It means that the situation changed from very/ extreme wet to very dry within 1 month. As the water balance in the eastern part of the country was much worse in 2015 than in other regions, this decrease meant "only" reaching the state from the previous year.

The drought development according to the SPI and the SPEI was in quite well agreement with the relative soil humidity, especially in the top 40 cm of the soil (Figs. 4 and 5), especially in the southern, lower located regions and in the northeast with the hilly land. The relative soil humidity was monitored within the project Intersucho [9].

Precipitation in April and May improved the water balance in almost all regions, except eastern Slovakia. The southeast experienced the same drought development as in the year 2015, and the situation was even worse in the Spiš region in comparison with season 2015, or a long-term mean. No change in regional

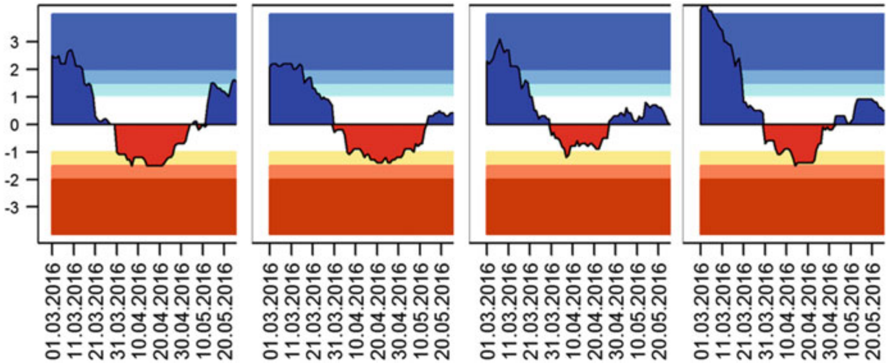


Fig. 4 The SPEI at the beginning of the monitoring season 2016 in Žihárec (1st panel), Milhostov (2nd panel), Bardejov (3rd panel) and Boľkovce (4th panel)

differentiation occurred in June, which was moderately wet in the Western Slovakia, but very dry to extremely dry in the northeast. Very good agreement was achieved between the SPEI and the relative soil humidity again. The operational SPEI caught developing drought in the topsoil layer in the northeastern Slovakia. Drought duration was not as long as in the previous year, and normal to moderate wet conditions prevailed from mid-July till the end monitoring season.

3 Case Study 2: Meteorological and Hydrological Drought in the Kysuca River Basin

The operational form of the SPI and SPEI described in the Case Study 1 also enables its utilization in interdisciplinary drought assessment. The Case Study 2 presents the assessment of meteorological drought as the prerequisite of a hydrological drought. The Kysuca river basin was chosen as the model area. This river basin is a quick responding river basin considering the precipitation-runoff relationship due to the flysch in the underground. Groundwater bodies are shallow, and groundwater storage is low in this type of sedimentary rock. Therefore, the flow in rivers varies according to precipitation conditions with short time shift.

3.1 Methods

3.1.1 Study Area

The Kysuca river basin is located in the northwestern part of Slovakia (Fig. 6). The surface has an upland character with a flysch as bedrock. Average air temperature in valley locations varies from 6 to 7.5°C, while surrounding mountains reach from

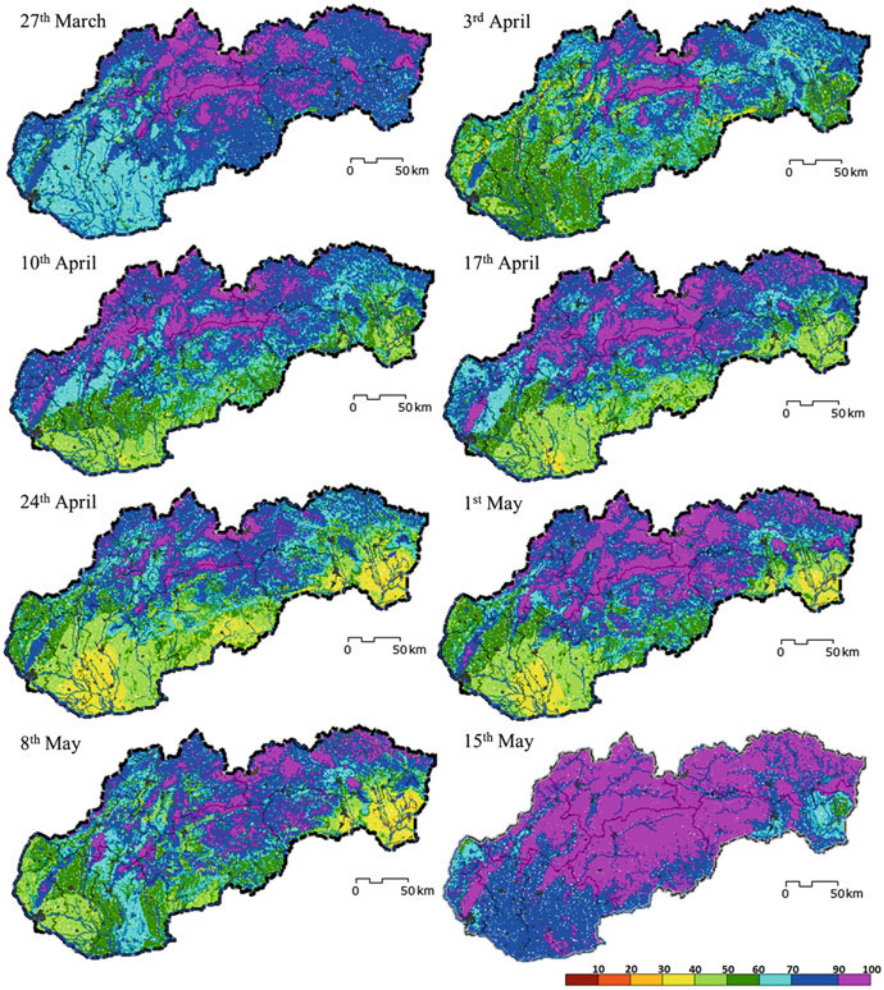


Fig. 5 Relative soil humidity in the top 40 cm of soil in Slovakia in the period 27 March to 15 May 2016 [9]

4.5 to 6°C in average. Average summer temperature reaches the values from interval 13.5 to 16.5°C. On the other hand, average winter temperature drops down to −4°C in average. Average precipitation total varies in the valleys from 950 to 1,000 mm, but the mountainous parts record from 1,000 mm up to 1,200 mm in average. The maximum precipitation falls in July; the minimum occurs in February. Average snow cover lasts in the lower parts of the basin from 80 to 90 days in average, in higher altitudes from 90 to 100 days. The snow cover occurs from 12 to 15 days in March in the most part of the river basin, but it can last up to 18 days in the highest altitudes [17].

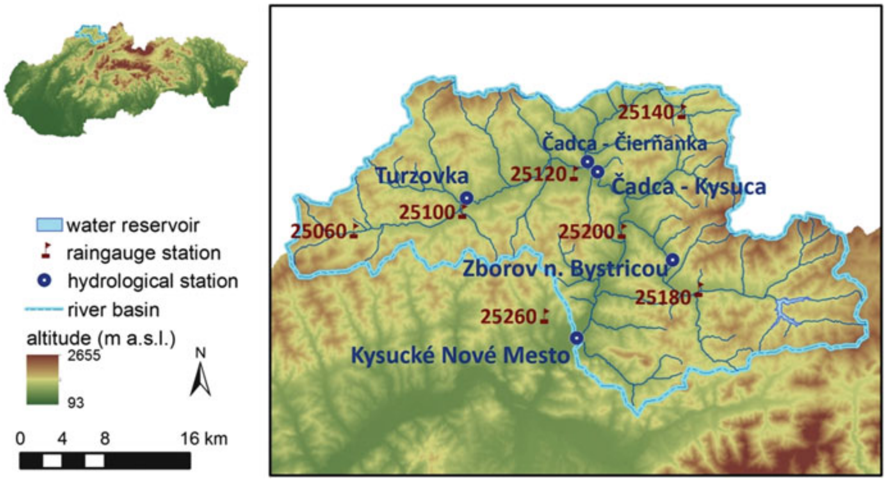


Fig. 6 Meteorological and hydrological stations in the Kysuca river basin

3.1.2 Meteorological Drought

As hydrological drought was assessed on a daily level, it was necessary to choose a daily indicator of meteorological drought. For this purpose, the operational form of the SPI and the SPEI was used. The detailed methodology was explained in the Case Study 1.

The daily station-based precipitation data were used to obtain spatial precipitation totals for each subbasin (the parts of the river basin belonging to each hydrological station) using the weighted average method. The list of rain gauge stations is in Table 1.

3.1.3 Hydrological Drought

The threshold level method is one of the most frequently used methods for the assessment of hydrological drought. Correctly chosen threshold enables to identify the beginning and the end of drought episodes as well as to compare their parameters such as deficit volume, intensity or duration. The threshold value usually varies between 70th and 95th percentile of flow duration curve (FDC), and most of the authors prefer 80th or 90th percentile ([4, 18, 19] a.o.). In this study, the threshold value was defined as the 90th percentile of the FDC. The discrete monthly threshold values were smoothed by applying a centred moving average of 30 days. The same methodology was used by Van Loon and Van Lanen [19], who created the process-based typology of hydrological drought, which was applied in this study.

Table 1 Rain gauge stations in the Kysuca river basin

ID	Station	Altitude	Latitude	Longitude
25060	Makov	574	49.373	18.486
25100	Turzovka	485	49.396	18.625
25120	Čadca	432	49.427	18.806
25140	Skalité	538	49.496	18.895
25180	Stará Bystrica	478	49.346	18.938
25200	Krásno nad Kysucou	384	49.384	18.832
25260	Nesluša	425	49.314	18.745

The dependent droughts were pooled applying the inter-event criterion of 10 days. The least duration of 10 days (a conservative value within usually used values) was used to eliminate the minor droughts in the evaluation.

3.1.4 Typology of Hydrological Drought

This typology was defined by Van Loon and Van Lanen [19]. It was based on a deep study of hydrometeorological variables in selected river basins, whereby each of them had different climatic conditions, geology and land cover. The following types were described:

- Classical rainfall deficit drought (CL)
- Rain-to-snow-season drought (RTSS)
- Wet-to-dry-season drought (WTDS)
- Cold snow season drought (CSS) with three subtypes (A, B and C)
- Warm snow season drought (WSS) with two subtypes (A and B)
- Composite drought (COM)

3.2 Linkage Between Meteorological and Hydrological Drought Occurrence

According to the SPI, the drought periods in the Kysuca river basins noted decreasing occurrence during the period 1981–2010. The same tendency was recorded in the length of the periods. The magnitude was without clear tendency, but some subbasins recorded slightly increase in the drought intensity in the last decade. It was not possible to exactly determine the months, which could be categorized as dry. However, it was possible to compare the drought occurrence in the warm (April to September) and cold half-year (October to March). In the 1980s, the number of drought periods in both half-years was equal, but the disproportionality was recorded in the next decades. The periods in warm half-year evidently prevailed (Table 2). It is in good agreement with the precipitation trend analysis. No

Table 2 Number of drought period in warm and cold half-year in the subbasins of the Kysuca river basin

Period		Kysucké N. M.	Zborov n. B.	Čadca – Čierňanka	Čadca – Kysuca	Turzovka
First decade	WH	15	14	12	15	18
	CH	16	16	14	15	16
Second decade	WH	14	15	15	16	16
	CH	8	9	7	8	9
Third decade	WH	20	15	19	20	20
	CH	14	13	13	13	14

CH cold half-year, *WH* warm half-year

significant trend was proved for the monthly precipitation totals. Nevertheless, some months experienced the changes. For example, the increase of precipitation was recorded in February, March, July and November. Average precipitation total increased about 5–11 mm/decade in February and about 6–16 mm/decade in March. The highest increase was located near the stations Stará Bystrica and Makov. The opposite tendency was noted in December.

There were only slight differences noticed in drought characteristics using the operational SPEI. The number of periods slightly increased on the contrary to the SPI. Climate conditions partially cause small differences between indices. The river basin lies in the northern, mountainous region in Slovakia, where the role of precipitation is higher than the role of potential evapotranspiration due to a lower temperature. The opposite situation could be found in the southern Slovakia, where the evapotranspiration has a key role in drought occurrence. Therefore, the importance of the increasing temperature does not lie in the changes of evapotranspiration, but it lies in the change of precipitation form as it will be explained later.

The operational SPI helped us to classify hydrological drought periods according to Van Loon and Van Lanen [19] and to identify the most frequently occurring or the most intensive drought type.

The highest intensity occurred by the type WSS-B and WSS-A (Table 3). Both types recorded increasing occurrence. The WSS-B was characterized by longer average duration (ca. 30 days), but the WSS-A accumulated high deficit volumes about 9 days shorter in average. Increasing temperature in the winter season (or in its part), which was proved by trend analysis, results in the occurrence of the most intensive hydrological drought periods. Both types can be strengthened by precipitation deficit in spring. Regarding only the deficit volume, the RSST type was the second in drought type ranking after the WSS-B. On the other hand, the RSST occurrence decreases due to the higher temperature at the beginning of snow season, which has been more frequently the case recently. Moreover, its duration is short due to quite regularly occurring temperature singularity called "Christmas warming", which causes partial snow melting subsidizing river flows. It is the same terminating factor for the CSS-A type.

Table 3 Drought types and their characteristics on the river Kysuca in Čadca in the period 1981–2010

Type	Count	*d*	*v*	*m*	1st decade	2nd decade	3rd decade
WSS-B	2	33	2,705.1	823.9	0	0	2
WSS-A	7	20.3	1,231.2	554.8	2	2	3
RTSS	1	23	1,373.8	597.3	1	0	0
CSS-C	5	23.4	972.8	431.0	1	2	2
CL	21	27.2	725.3	247.1	4	9	8
CSS-B	3	25	758.8	221.0	0	2	1

d average duration, *v* average deficit volume/1,000, *m* average intensity/100

The WSS-B type occurred only twice, in both cases at the end of the study period (1981–2010). Winter 2006/2007 was humid, but warm as well. Only several days with average daily temperature below 0°C were recorded. Under these conditions, precipitation was often in liquid form, and high discharges were observed during the whole season. Moreover, an intensive meteorological drought occurred from mid-April till mid-May (Fig. 7). It resulted in the second highest deficit volume and the third highest intensity of the hydrological drought period on the Kysuca river in Čadca. These drought parameters were even higher on the Čierňanka River. The rareness of this drought period is supported by the fact that the drought also occurred on the Bystrica River, which is anthropogenic influenced, and no drought period, except this one, has been observed since 1994.

Winter 2007/2008 had similar scenario considering air temperature. The difference was in precipitation. February and May were near normal compared to the long-term conditions, but the rest of months experienced precipitation deficit, which intensified hydrological drought (WSS-B type). This period was even more intensive than the previous one, because the deficit volume was high, but the duration was shorter.

The CL type is the most frequently occurring hydrological drought type. Therefore, the meteorological drought is the most common factor causing the hydrological drought in the Kysuca river basin. Regarding the deficit volume and the intensity, this type is not significant. It is caused by the fact that its duration is often longer than other's types, but the flows are just below the threshold value.

The temperature is the primary factor causing hydrological drought in the Kysuca river basin in the cold half-year. However, the precipitation as the secondary factor cannot be omitted. The influence of the precipitation deficit lies more in the intensifying of drought caused by too early or too late snow melting in winter. It is also supported by the fact that the hydrological drought occurring exclusively in winter is rare and hydrological drought dominates in spring, especially in April and May.

It is interesting to consider conditions, under which the hydrological drought did not occur even though the operational SPI indicated intensive meteorological drought. The impact of meteorological drought on discharges was strongly mitigated or fully eliminated in spring by melting snow, if the winter season was cold

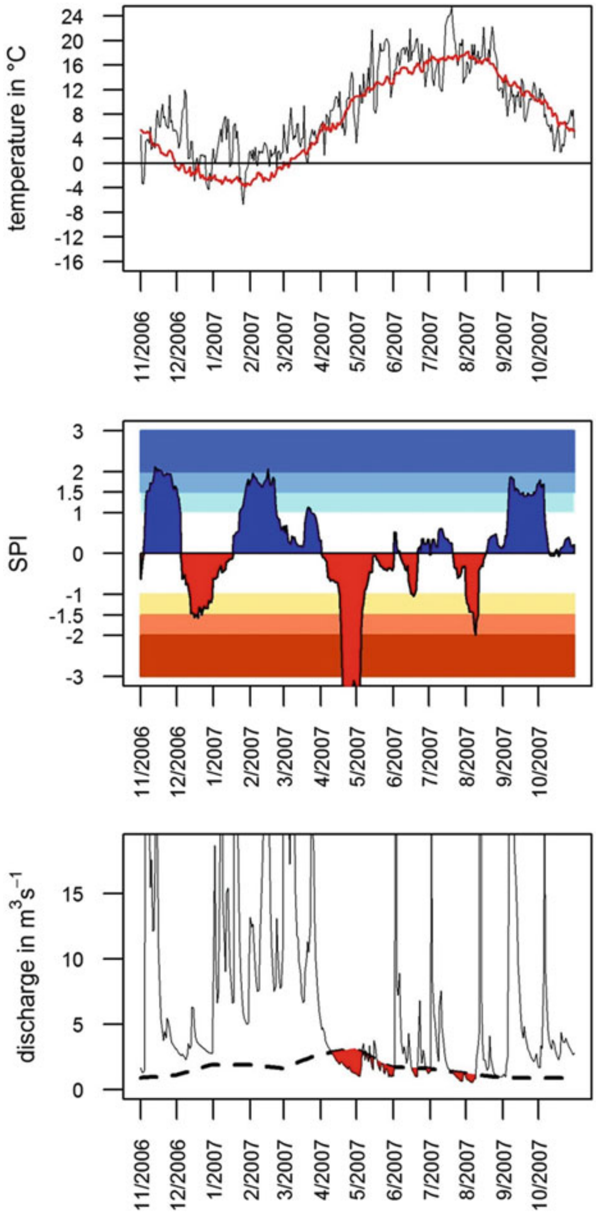


Fig. 7 Warm snow season drought (subtype B) on the Kysuca river in Čadca in the hydrological year 2007 (average daily air temperature, upper panel; operational SPI, middle panel; discharges, lower panel). Red line represented long-term average daily temperature and the dashed line represented threshold Q_{90}

and rich in precipitation and high snow cover was accumulated. Then spring precipitation deficit was less important than precipitation and temperature conditions in the snow season. For example, such case was noted in the hydrological year 1982.

Warm winter or earlier snow melting does not have to necessarily lead to hydrological drought if the operational SPI reaches positive values in April. Then naturally high discharges are not the result of snow melting, but the result of precipitation recorded in spring, e.g. such conditions were observed in the hydrological years 1983, 1990, 1994 a.o.

Meteorological drought in late summer or in autumn did not result in hydrological drought, if a natural precipitation maximum occurred from late June to mid-July as usual. This precipitation maximum improves the initiation discharges in the river and its tributaries before the meteorological drought occurring later (e.g. hydrological years 1987, 1997 a.o.).

The results of hydrological drought classification are slightly different for the Bystrica River behind the Nová Bystrica dam. The main reason has been almost no drought occurrence since 1994. Therefore, the final average parameters of drought periods were mainly based only on the earlier period. Despite that fact, the most intensive hydrological droughts were caused by warm snow seasons (both WSS-A and WSS-B). These periods were the only droughts occurring in the last decade on the anthropogenic influenced part of the river. Considering the whole study period, the most often occurring drought type was the CL type, but which was not at all observed in the last decade. It shows that water management can avoid the hydrological drought, which is primarily caused by precipitation deficit. On the other hand, the drought periods caused by changing temperature conditions in snow season point on the importance of temperature observation regarding the forecasting of hydrological drought.

4 Summary and Conclusion

The experience of the last years raised the attention of researchers and the general public in the topic of drought and its impacts in Slovakia. The need to monitor its development in near real time led to the launching of the operational meteorological drought monitoring by the Slovak Hydrometeorological Institute. The indicators used for the monitoring obtain a daily overview of changing water balance. The first two monitoring seasons brought sufficient results describing the development of meteorological drought in Slovakia in detail.

The advantage of modified SPI and SPEI, which are used for the monitoring, lies in the possibility to compare them to the indicators used in other research disciplines such as hydrology or soil science. The promising results were obtained by the comparison of the operational indices to the relative soil humidity. Therefore, the meteorological drought monitoring could be a good tool for early warning even on the sites, where the measurement or modelling of soil humidity is problematic due to the lack of measured data. Moreover, the recorded correlation between the SPI/SPEI results and crop yields in the Danubian Lowland supports the applicability of both indices for agricultural purposes. Their operational form enables to monitor drought on a daily basis during different phenological phases.

The application of the modified SPI helped to identify different hydrological drought types. On the other hand, the analysis pointed to the fact that precipitation deficit is not the only cause of the drought occurrence. The air temperature in snow season is sometimes more important than precipitation deficit in the river basin.

To avoid damages caused by drought, it is necessary to design integrated drought monitoring as the important part of early warning system. The meteorological conditions are the starting point of drought spreading within the hydrological cycle. Therefore, well-designed meteorological drought monitoring, bringing sufficient information in near real time, is an assumption for the effective early warning system.

5 Recommendations

Recently, drought research has been accelerated, and many studies have been published. Most of them is focused only on one sector: climatology, hydrology or agriculture. In the future, the emphasis should be put on interdisciplinary approach leading to integrated drought monitoring. Such monitoring would bring relevant information for all interested groups and would be sufficient basis for effective early warning system. Integrated drought early warning system is another necessary output of future research for mitigating drought impact in the changing climate.

Current drought monitoring methods have still had several weaknesses. The influence of snow cover on hydrological drought occurrence is very important, especially in spring season, when the snow cover is melting and increases discharges. Changing snow conditions due to the climate change result in hydrological drought occurrence after weak snow season. Therefore, it is important to implement monitoring of snow cover into hydrological drought monitoring according to regional dependencies between these two phenomena.

The weakness of meteorological drought monitoring is the absence of method, which could separate intense precipitation as the result of convection. Such precipitation has often only local effect, and most of them form only surface runoff. The established drought indices such as the SPI, SPEI or CMI do not consider low efficiency of intensive precipitation for soil moisture improvement or vegetation condition. Their values increase often above 0 value after such event, but dry conditions persist in the landscape, e.g. in the form of low soil humidity. For integrated drought monitoring, it will be important to establish a method, which could eliminate impact of intensive precipitation on the estimation of drought indices.

References

1. Šamaj F, Valovič Š (1972) Suché a vlhké obdobie na Slovensku. In: Balco M (ed) Malá vodnosť slovenských tokov. Veda, Bratislava
2. Patassiová M, Klementová E, Litschmann T, Čistý M (2002) Výskyt sucha a analýzy zrážok pri jeho výskyte v jarných mesiacoch. Acta Hydrologica Slovaca 3:61–69
3. Litschmann T, Klementová E (2004) Using palmer drought severity index to assess drought in the territory of Slovakia. Meteorologický časopis 7:67–72
4. Fendeková M, Ženišová Z (eds) (2010) Hydrologické sucho. Slovenská asociácia hydrológov and Katedra hydrogeológie, Prírodovedecká fakulta Univerzity Komenského v Bratislave, Bratislava
5. Skalský R, Nováková M, Mišková M (2012) Analýza sucha v krajine ako príklad využitia simulačných modelov v geografii. Geografický časopis 64:55–69
6. Takáč J (2015) Suchov poľnohospodárskej krajine. Národné poľnohospodárske a potravinárske centrum – Výskumný ústav pôdoznalectva a ochrany pôdy, Bratislava
7. Labudová L, Labuda M, Takáč J (2017) Comparison of SPI and SPEI applicability for drought impact assessment on crop production in the Danubian Lowland and the East Slovakian Lowland. Theor Appl Climatol 128:491–506
8. Labudová L, Turňa M, Nejedlík P (2015) Drought monitoring in Slovakia. In: Šiška B, Nejdlík P, Eliašová M (eds) International scientific conference "Towards Climatic Services". Slovak University of Agriculture, Nitra
9. CzechGlobe (2017) Intersucho. http://www.intersucho.sk
10. McKee TB, Doesken NJ, Kleist J (1993) The relationship of drought frequency and duration to time scales. In: 8th conference on applied climatology, American Meteorological Society, Anaheim
11. Bindoff NL, Stott PA, AchutaRao KM, Allen MR, Gillett N, Gutzler D, Hansingo K, Hegerl G, Hu Y, Jain S, Mokhov II, Overland J, Perlwitz J, Sebbari R, Zhang X (2013) Detection and attribution of climate change: from global to regional. In: Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013: the physical science basis. Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge
12. Vicente-Serrano SM, Begueria S, Lopéz-Moreno JI (2010) A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. J Clim 23:1696–1718
13. Thornthwaite CW (1948) An approach toward a rational classification of climate. Geogr Rev 38:55–94
14. Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration: guidelines for computing crop requirements. FAO Irrigation and drainage paper 56. FAO, Rome
15. Maetens W, Ingels B, Defloor W, Cauwenberghs K (2014) Optimalization of the Standardized Precipitation Index (SPI) for operational drought monitoring. In: EGU Leonardo conference series on the hydrological cycle: 6th Leonardo conference 2014: HYPER droughts: hydrological, precipitation, evaporation, runoff droughts (book of abstracts), Prague
16. Palmer WC (1968) Keeping track of crop moisture conditions, nationwide: the new crop moisture index. Weatherwise 21:156–161
17. Climatic Atlas of Slovakia (2015) Slovenský hydrometeorologický ústav. Bratislava
18. Demeterová B, Škoda P (2009) Malá vodnosť vybraných vodných tokov Slovenska. J Hydrol Hydromech 57:55–69
19. Van Loon AF, Van Lanen HAJ (2012) A process-based typology of hydrological drought. Hydrol Earth Syst Sci 16:1915–1946

Hydrological Drought Occurrence in Slovakia

M. Zeleňáková, T. Soľáková, P. Purcz, and D. Simonová

Contents

Abstract The chapter presents the problem of drought and describes its classification and methods of assessing this risk. The aim of this chapter is to identify statistically significant trends in streamflow characteristics of low water content in the Eastern Slovakia, which are used in the evaluation of hydrological drought. In this thesis is presented a new methodology for evaluating hydrological drought based on statistical analysis of observed minimal flows at selected 63 gauging stations in Eastern Slovakia for a 32-year period. Mann-Kendall statistical test identifies the frequency of minimal flow trends: in individual gauging stations, in river basins (Poprad, Hornád, Bodva, Bodrog to throughout Eastern Slovakia), and also in groups of gauging stations with the same physicogeographical parameters. Size of the flow trends is identified by directives of the trend lines. The procedure is also applied in assessing the impact of human activities and the impact of physicogeographical factors for the emergence of hydrological drought.

M. Zeleňáková (✉), T. Soľáková, and P. Purcz
Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia
e-mail: martina.zelenakova@tuke.sk

D. Simonová
Slovak Hydrometeorological Institute, Branch Office Košice, Košice, Slovakia

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 69–90,
DOI 10.1007/698_2017_225,
Published online: 27 April 2018

Obtained results from the statistically significant trends in the flows are established prediction of hydrological drought risk in each month of the hydrological year in Eastern Slovakia.

Keywords Hydrological drought, Minimal streamflows, Statistical tests, Trend analysis

1 Introduction

In principle, the concept of drought is a deficiency of water in the atmosphere, soil, and plants. Depending on where it shows a lack of water by the World Meteorological Organization (WMO) [1] classifies four basic types of drought, including meteorological, hydrological, agricultural, and socioeconomic droughts [2]. The drought has a devastating impact on fauna and flora, human society, and all sectors of national economy; for this, it is recognized as an environmental disaster. Its effects have been observed on all continents, and over the past decade, the frequency of drought increases [3].

Hydrological drought is a phenomenon which rises with the existence of occurrence of no-precipitation period coupled with extreme temperatures. The genesis of hydrological drought also affects the morphological conditions of origin, climatic factors, geological and hydrogeological conditions, and anthropogenic activities. This type of drought is defined by a long-term decrease in levels of surface water bodies (e.g., rivers, lakes, reservoirs, and others) and drops in groundwater levels [4]. Low water content is proof of this type of drought [5]. For the mathematical-statistical evaluation of low water content are used the flow and no-flow characteristics [6].

A distinction is made between streamflow droughts and low flows (minimal flows). The main feature of a drought is said to be the deficit of water for some specific purpose. Low flows are typically experienced during a drought, but they feature only one element of the drought, i.e., the drought magnitude. Low flow studies are described as being analyses aimed at understanding the physical development of flows at a point along a river at a short-term (e.g., daily). Hydrological drought analyses in terms of streamflow deficits are said to be studies over a season or more extended time periods and in a regional context. A streamflow drought event definition quantitatively defines whether the flow can be regarded as being in a drought situation or not and gives the duration of a drought, whereas low flow indices characterize specific features of the low flow range [7, 8].

The primary objective of the chapter is to identify minimal streamflow trends in the selected 63 gauging stations in Eastern Slovakia in the time interval 1975–2010. The Mann-Kendall nonparametric test has been used to detect trends in hydrological time series. Statistically significant trends have been determined from the trend lines, and the prediction of hydrological drought risk in each month of the hydrological year for the whole territory of Eastern Slovakia has been made [8].

Slovakia is a rich country in water resources. Both the surface and the groundwater resources ensure the present and also the prospective needs of the country. However, they are distributed unequally over the Slovak territory. The distribution depends on natural conditions – mostly on geomorphologic, geological, hydrogeological, and climatic ones.

2 Study Area

The study area is situated at the eastern part of Slovakia (Fig. 1). It includes two major river basins – Bodrog river basin and Hornád river basin. Bodrog River is 15.2 km long at Slovak Republic but its basin area is 7,272 km^2. The territory of Bodrog basin is located in two orographic subassemblies, which are the Carpathians and Pannonian Basin. The morphological type of the relief is predominantly plane in the southern part and hilly in the northern part. Bodrog river valley has varied climatic conditions. Precipitations are highly differentiated. The highest annual totals are mainly at east border mountains and Vihorlat where rainfall totals are about of 1,000 mm. The decrease of total precipitation is quite intense direct to the south – annual totals fall to below 800 mm. Lowland part of the Michalovce – Lastomír and Medzibodrožie – belongs to among the driest in the eastern region (550 mm rainfall per year). Hornád river basin area is 4,414 km^2. Annual precipitation is 700 mm in Hornád river basin. The morphological type of terrain in Hornád river valley is dominated by rolling hills, highlands, and lower highlands. The southern sub-basin is part of a plane and Slovak Kras and is formed by moderately higher rugged highlands. Well-drained rocks with high permeability are only in Spiš and Gemer areas and in Slovak Kras near Košice.

In this territory, 63 gauging stations are located. List of gauging stations is shown in Tables 1, 2, 3, and 4, where the stations affected by human activity are highlighted in gray.

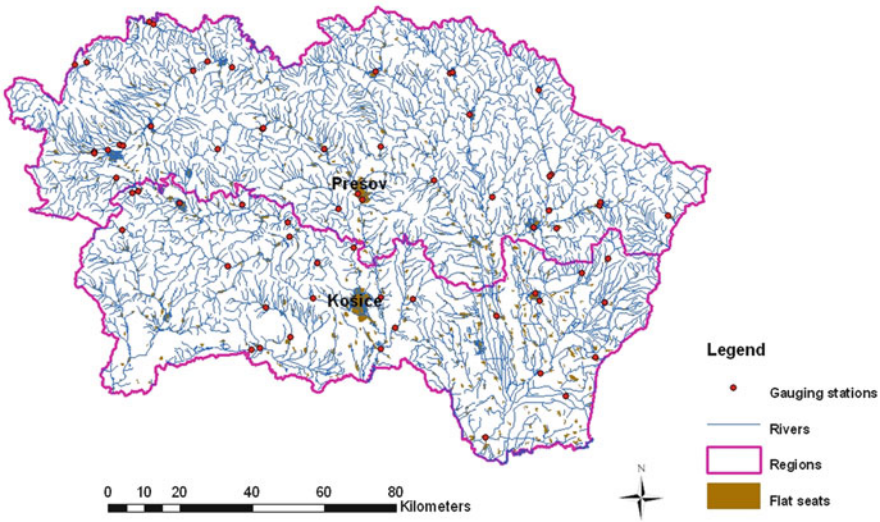


Fig. 1 A spatial distribution of river stations

Table 1 Basic statistical characteristics in river stations in Poprad basin

No	River station	Period			Kurtosis	Skewness	Median	Number of extreme values
		From	To	Total				
1	Ždiar–Lysá Poľana	1972	2010	39	1.554026	2.579875	1.235	16
2	Ždiar–Podspády	1961	2010	50	1.385817	2.07331	0.76	16
3	Červený Kláštor–Kúpele	1968	2010	43	1.89943	6.041278	0.41	17
4	Červený Kláštor	1968	2010	43	0.931166	0.816089	13.8	4
5	Svit	1966	2010	45	1.35799	1.653051	0.579	26
6	Svit	1963	2010	49	1.769929	3.811689	0.237	41
7	Poprad–Veľká	1963	2010	49	1.507696	4.297559	0.46	19
8	Poprad–Matejovce	1962	2010	49	1.131653	1.919848	0.279	16
9	Kežmarok	1972	2010	39	2.000563	5.511457	0.36	25
10	Nižné Ružbachy	1974	2010	37	1.248576	1.67138	5.899	17
11	Hniezdne	1972	2010	39	1.436049	2.549134	0.124	17
12	Chmeľnica	1931	2010	80	1.598901	3.609744	7.11	34

The affected hydrometric stations are considered as a station where the hydrological regime altered the flow by the interference of human activities (by water works, by excessive water abstraction, etc.).

3 Material and Methods

The first step in the evaluation was to obtain values of the minimal monthly flow for selected hydrometric stations. Hydrological data were provided by the Slovak Hydrometeorological Institute, Regional Centre Košice. Hydrological data files obtained were processed and statistically analyzed with the following sequence:

1. Creating a database and determining the fundamental characteristics of statistical series
2. Modifying existing files with respect to further processing
3. Testing the statistical files

   The methodology of the evaluation can be seen from Fig. 2.

Essential datasets were created by collecting and organizing the values of minimal streamflows to the statistical files. One set of values is for one gauging station. Each station was assigned by the statistical characteristics, namely, mean, median, skewness,

Table 2 Basic statistical characteristics in river stations in Hornád basin

No	Station	Period			Kurtosis	Skewness	Median	Number of extreme values
		From	To	Total				
13	Hranovnica	1965	2010	45	2.044337	6.020411	0.3315	27
14	Hrabušice	1967	2010	44	2.88779	15.51134	0.774	19
15	Hrabušice–Podlesok	1972	2010	39	1.204042	2.990362	0.248	11
16	Spišská Nová Ves	1972	2010	39	2.068367	7.152126	1.317	14
17	Spišské Vlachy	1975	2010	36	1.954649	6.447947	0.28	18
18	Margecany	1972	2010	39	2.361353	9.367487	3.5995	26
19	Stratená	1954	2010	57	1.929821	4.994504	0.479	35
20	Švedlár na Hrabliach	1931	2010	80	1.842699	3.956677	1.5535	66
21	Jaklovce	1931	2010	80	2.080526	5.453678	2.589	72
22	Košická Belá	1974	2010	37	2.060845	5.618473	0.087	23
23	Kysak	1929	2010	82	2.344298	7.271084	7.3	85
24	Nižné Repaše	1975	2010	36	2.351989	8.744696	0.0935	31
25	Brezovica	1973	2010	38	1.990774	5.837077	0.1475	20
26	Sabinov	1973	2010	38	1.742292	3.969851	1.18	20
27	Prešov	1970	2010	41	1.724631	4.083802	1.65	22
28	Demjata	1973	2010	38	1.238889	1.343055	0.3055	29
29	Prešov	1961	2010	50	2.052677	6.349703	0.6445	32
30	Košické Olšany	1931	2010	80	1.984643	6.990796	3.02	29
31	Svinica	1973	2010	38	2.124086	5.476892	0.06	40
32	Bohdanovce	1966	2010	45	2.383099	8.955003	0.3265	30
33	Ždaňa	1958	2010	53	2.364586	7.426313	11.915	54

Table 3 Basic statistical characteristics in river stations in Bodva basin

No	Station	Period			Kurtosis	Skewness	Median	Number of extreme values
		From	To	Total				
34	Nižný Medzev	1941	2010	70	2.162925	6.137853	0.251	64
35	Moldava nad Bodvou	1965	2010	46	2.146241	5.762377	0.341	41
36	Hýľov	1965	2010	46	3.727486	23.54098	0.1475	28
37	Turňa nad Bodvou	1966	2010	45	2.328922	7.631559	0.9375	45
38	Hosťovce	1968	2010	43	2.628787	9.080273	0.2025	43

Table 4 Basic statistical characteristics in river stations in Bodrog basin

No	Station	Period			Kurtosis	Skewness	Median	Number of extreme values
		From	To	Total				
39	Medzilaborce	1975	2010	36	1.969083	5.43406	0.223	23
40	Jabloň	1975	2010	36	1.590893	3.095441	0.2705	18
41	Kokošovce	1961	2010	50	7.232974	101.9174	1.062	33
42	Udavské	1975	2010	36	1.663648	4.150873	0.52	14
43	Snina	1957	2010	54	1.695406	3.443234	0.797	40
44	Snina	1975	2010	36	1.46199	2.463163	0.126	13
45	Kamenica nad Cirochou	1961	2010	50	2.923875	12.89779	0.26	43
46	Humenné	1967	2010	44	2.480386	13.64994	3.5825	20
47	Michalovce–Stráňany	1962	2010	49	1.927579	4.563265	2.4865	40
48	Jovsa	1970	2010	41	2.104789	6.216189	0.086	31
49	Michalovce–Meďov	1955	2010	56	1.172373	1.319246	5.25	16
50	Ulič	1972	2010	39	2.774549	11.53484	0.307	18
51	Lekárovce	1951	2010	60	1.905658	5.0883	7.543	30
52	Remetské Hámre	1955	2010	56	2.546627	9.075364	0.294	45
53	Sobrance	1970	2010	41	1.702476	3.742496	0.22	28
54	Ižkovce	1975	2010	36	2.220385	6.096453	20.545	34
55	Veľké Kapušany	1951	2010	60	2.086689	5.389429	11.59	55
56	Bardejov	1967	2010	44	1.681923	3.603626	1.1205	23
57	Hanušovce nad Topľou	1931	2010	80	2.116909	7.988851	2.9	38
58	Svidník	1962	2010	49	9.318237	149.7023	0.34	23
59	Svidník	1962	2010	49	2.138821	7.177429	0.405	21
60	Stropkov	1967	2010	44	4.074425	36.50911	1.245	22
61	Jasenovce	1957	2010	54	1.589772	2.876338	0.3	25
62	Horovce	1931	2010	80	3.032593	19.04556	7.79	37
63	Streda nad Bodrogom	1951	2010	60	2.599394	9.194828	43.285	56

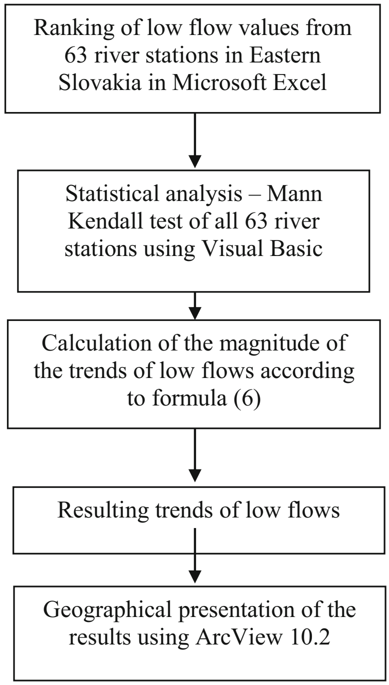
kurtosis, and extremes. These characteristics were used in choosing the right modification files and in choosing a statistical test.

The calculated median was used in ranking stations and their hydrological data in the database and also in modification (1) of these files. Calculation of relative values was conducted for each gauging station by relation [9]:

$$y_i = x_i/\tilde{x} \tag{1}$$

where x_i the value of the minimum streamflow, $\tilde{x}$ median

Fig. 2 Flowchart of the methodology



The median is the middle digit range of variation that is created from the values of minimal flows from one gauging stations arranged in ascending order for the entire period:

$$x_{(1)} < x_{(2)} < \ldots < x_{(n)} \tag{2}$$

Modification (1) was necessary because each gauging station had a different potential of water and in this case, it was not possible to establish one comprehensive set of statistics.

The skewness describes the form of distribution of the random variables and measures both the direction and the degree of asymmetry of the distribution of the random variables. Positive values (as measured in our case) cause the mean to be higher than the median. It follows from this fact that the majority of the values (in all studied data files) are lower than the mean.

The kurtosis measures the "peakedness" of the distribution of the random variables, which shows the potential occurrence of extreme (outlet) data. Mostly this coefficient is compared to the coefficient of kurtosis in the normal distribution, which equals 3. Using this statistical analysis, it was demonstrated that all entry data files contain more extreme (outlet) values. The graphs for all of the data files show log-normal distribution of low flow values with large positive coefficients for both skewness and kurtosis.

The existence of extreme values in the data file may be determined, e.g., using the box plot method.

For statistical tests were used relative streamflow values y_i as random variables Y.

Mann-Kendall test is used as a rule by which it is possible to decide whether the tested hypothesis H_0 is rejected or not rejected [9]. The test is based on the statistical value S. Comparing any two values y_i, y_j $(i > j)$, a random variable Y can be determined if $y_i > y_j$ and $y_i < y_j$. The number of pairs of the first type is denoted as P and the number of pairs of the second type as M. Then S is defined as [10, 11]

$$S = P - M \tag{3}$$

Mann-Kendall following statistics based on standard normal distribution (Z), where

$$\begin{aligned} Z &= (S-1)/{\sigma_s}^{1/2} && \text{if } S > 0 \\ Z &= 0 && \text{if } S = 0 \\ Z &= (S+1)/{\sigma_s}^{1/2} && \text{if } S < 0 \end{aligned} \tag{4}$$

where the variance is defined as

$$\sigma_s = n(n-1) \cdot (2n+5)/18 \tag{5}$$

and n is a size of sample

Hypothesis H_0 no trend is accepted if the following applies: $Z < Z_{\alpha/2}$ or refused, if applies, that $Z > Z_{\alpha/2}$, then is accepted H_1-exist a statistically significant trend. The significance level is chosen as $\alpha = 0.05$, and $Z_{\alpha/2}$ is a value for normal distribution; in this case, $Z_{\alpha/2} = 1.645$. The sign of Z statistic indicates whether the trend is growing ($Z > 0$) or decreasing ($Z < 0$). Estimate of the magnitude of the trends obtained cannot be determined with this test, and therefore, the magnitude of the trends in the streamflow was calculated using relation (6) [12, 13].

For $x_2 \neq x_1$ applies

$$K = tg\varphi = D_{ij} = \left(y_j - y_i\right)/\left(x_j - x_i\right) \quad \text{for } i > j \tag{6}$$

where y_i is the relative value of the minimum monthly streamflow in year x_i.

All mathematical relations from (1) to (6) were programmed in Visual Basic in Microsoft Excel 2003. Using ArcView GIS 10.2 was created a graphical representation of analysis results.

4 Results

4.1 Descriptive Statistical Analysis

The first step in the evaluation was to obtain values of the minimal monthly flow for selected river stations. Hydrological data, provided by Slovak Hydrometeorological Institute, Regional Centre Košice, at monthly intervals during years 1975–2010 were used for the creation of essential datasets. Datasets were created by chronologically ranking the values of low flows to the statistical files. One set of values is for one river station in the mentioned 36-year period.

Essential statistical characteristics of the data files are presented in Tables 1, 2, 3, and 4. Stations affected by human activity are highlighted in dark color.

After the statistical analysis, each river station is assigned trends of low flow in each month.

4.2 Trends of Low Flows in River Stations

In analyzing the results, it is considered that there is a decreasing trend when normalized test statistics Z is negative and the obtained probability is higher than the adopted level of significance. Conversely, when the normalized test statistics Z is positive, and the obtained probability is higher than the adopted level of significance, it is considered that there is an increasing trend. If the obtained probability is less than the adopted level of significance, it is accepted that there is no trend.

Tables 5, 6, 7, and 8 present statistically significant trends in the months with the favorable development of water levels shown in double plus sign, prevailing water levels drop are shown in double minus sign.

The results of analysis of a possible trend shown in Tables 5, 6, 7, and 8 indicate that it is not possible to determine, with reasonable certainty, the existence of a trend in time series of low flows at evaluated river stations. There has been detecting a trend in 16 river stations which is 25% of all river stations. In ten river stations has appeared a decreasing trend (marked in tables by doubled minus $- -$) of low flows mainly in the smallest river basin – Bodva. In six cases from the all river stations have been found an increasing trend of low streamflows. It is interesting that, at 7 river stations (50%) from a total of 14 river stations located in parts of watercourses where there is an influence of man and its activities, a significant trend was noted. It is where hydraulics structures are situated. At four river stations (Švedlár na Hrabliach, Jaklovce, Brezovica, and Hosťovce) from mentioned seven stations influenced by human activities, this significant trend is decreasing. River stations Švedlár na Hrabliach and Jaklovce are located upstream of the sizeable Ružín dam. At the remaining seven stations, there is no trend, based on the results of the test.

4.3 Trends of Low Flows in River Basins

The next analysis was devoted to investigations of trends in river basins. River stations were grouped to sub-basins and ranked according to the increasing median. They create one statistical file within one sub-basin, which was created from values of low flows arranged according to (1). This statistical file was tested by Mann-Kendall nonparametric test, for the period 1975–2010. The magnitude of the statistically

Table 5 Statistically significant trends in river stations in river basin Poprad

No	Hydrological year											
	XI	XII	I	II	II	IV	V	VI	VII	VIII	IX	X
1	+	–	+	+	++	+	+	– –	–	– –	– –	–
2	–	–	–	–	+	+	+	–	–	– –	– –	–
3	++	+	+	+	+	+	+	++	++	+	+	+
4	+	+	+	++	+	–	–	–	–	–	–	+
5	–	–	–	+	+	+	+	–	–	– –	–	–
6	+	+	+	++	+	–	–	– –	– –	–	–	–
7	++	+	+	+	+	+	+	+	+	+	+	+
8	+	+	+	+	+	++	+	+	+	+	+	+
9	++	++	++	++	+	+	++	+	+	++	+	++
10	+	–	–	–	–	–	+	–	–	–	–	–
11	++	+	++	++	++	+	+	++	++	+	+	+
12	+	–	–	+	–	–	–	–	–	–	–	–

Table 6 Statistically significant trends in river stations in river basin Hornád

No	Hydrological year											
	XI	XII	I	II	II	IV	V	VI	VII	VIII	IX	X
13	++	++	+	+	+	+	+	+	+	++	++	++
14	+	+	+	+	–	–	– –	–	+	+	++	+
15	++	+	+	+	+	+	–	–	+	++	++	++
16	+	+	+	+	+	–	–	– –	–	+	+	+
17	++	++	++	++	+	+	+	++	++	++	++	++
18	+	–	–	–	–	–	– –	–	–	+	+	+
19	+	+	+	++	+	–	–	– –	+	+	+	+
20	+	+	+	+	+	+	–	–	–	+	+	++
21	–	–	–	–	–	– –	– –	– –	– –	–	–	–
22	++	+	+	+	+	+	+	+	+	+	+	++
23	–	–	–	–	–	–	–	–	–	+	–	–
24	++	++	++	++	+	+	+	++	++	++	+	++
25	+	+	– –	–	+	+	–	–	–	+	+	+
26	+	+	+	+	+	+	–	–	+	+	+	+
27	–	–	–	–	–	–	– –	– –	– –	–	–	–
28	++	+	+	–	–	–	–	– –	–	+	–	+
29	+	+	–	–	–	–	–	–	–	+	+	+
30	–	–	–	–	– –	–	– –	– –	– –	–	–	–
31	+	+	+	+	+	+	–	–	–	– –	–	+
32	+	+	+	+	–	–	–	–	–	–	–	+
33	–	–	–	–	–	–	–	– –	–	–	–	–

significant trend was calculated from Eq. (4) for each month of the hydrological year. Statistical analysis in river basin was done for all river stations and separately for river stations not influenced by human activity to compare the results and characterize the

Table 7 Statistically significant trends in river stations in river basin Bodva

No	Hydrological year											
	XI	XII	I	II	II	IV	V	VI	VII	VIII	IX	X
34	–	+	+	–	–	–	–	–	– –	–	–	–
35	–	+	+	–	–	–	– –	– –	–	–	–	–
36	+	++	+	+	+	–	–	–	–	–	+	++
37	–	–	–	–	–	–	– –	– –	–	–	–	–
38	–	–	–	–	–	– –	– –	– –	– –	–	–	– –

Table 8 Statistically significant trends in river stations in river basin Bodrog

No	Hydrological year											
	XI	XII	I	II	II	IV	V	VI	VII	VIII	IX	X
39	+	–	+	+	+	–	–	–	– –	–	–	+
40	+	+	+	++	+	+	+	+	+	–	–	+
41	–	–	–	–	–	–	–	– –	– –	– –	–	–
42	+	–	+	+	+	+	–	–	–	–	–	+
43	+	+	+	–	–	+	–	+	–	++	+	+
44	+	+	+	–	+	+	+	+	–	–	–	–
45	++	++	++	++	++	+	++	++	++	++	++	++
46	+	+	+	–	–	+	–	+	–	–	+	+
47	–	–	–	–	+	– –	– –	– –	– –	– –	–	– –
48	+	+	++	+	+	+	+	–	+	+	+	++
49	–	–	–	+	+	–	–	–	–	+	– –	– –
50	+	+	+	++	+	++	+	–	–	–	–	+
51	–	–	–	–	–	–	–	–	– –	– –	– –	–
52	+	–	+	+	+	–	–	–	–	–	–	–
53	+	+	+	+	+	+	+	+	+	+	+	+
54	–	+	–	+	+	+	–	– –	– –	–	– –	– –
55	–	–	–	–	–	–	– –	– –	– –	– –	– –	–
56	+	+	++	++	+	+	–	–	+	+	+	+
57	–	–	–	–	–	– –	– –	– –	– –	– –	– –	– –
58	+	–	+	+	+	++	+	+	–	+	+	+
59	+	–	+	+	+	+	+	–	–	–	–	–
60	–	–	–	–	–	–	– –	– –	– –	–	– –	– –
61	+	+	+	++	+	+	+	–	–	+	+	+
62	+	+	+	+	+	+	–	+	+	+	+	+
63	–	–	–	–	–	–	–	– –	– –	–	–	–

influence of human activities to the hydrological regime. The results are presented in Tables 12, 13, 14, and 15.

Influenced river station Červený Kláštor in Dunajec was not included in the second assessment (column: Non-influenced river stations). Influence of human activity was proved in March when the significant trend has occurred in non-influenced river stations.

It means that significant decreasing trends of low river flows are not occurring in March as a result of human activity in river basin Poprad. Based on Table 9, we can say that significant decreasing trends in low river flows are occurring in winter months – December and January. Vice versa significant increasing trend is occurring in May which is in coincidence with precipitation trend analysis.

Trends in river basin Hornád are depicted in Table 10.

River stations influenced by human activity in river basin Hornád are Švedlár and Jaklovce in Hnilec River; Margecany, Kysak, and Ždaňa in Hornád River; and Brezovica in Slavkovský potok. These river stations were not considered in trend detection within non-influenced river stations. The difference has occurred in August; the significant increasing trend of low flows is not occurring in non-influenced river stations. Based on Table 10, it is clear that significant decreasing trend is occurring in winter and spring seasons – from December to June.

Evaluation of trends of low flows during 1975–2010 in river basin Bodva is depicted in Table 11.

In Bodva river basin was proved the difference in trends of low flows between all river stations and by human activity non-influenced river stations (without river station Hosťovce in Turňa) in months January and May. There is a statistically significant decreasing trend of low flows during the whole year. In Table 11, a negative influence of hydrological regime of human activity is evident.

There is introduced the occurrence of trends of low flows in river basin Bodrog in Table 12.

The trend analysis in Bodrog river basin includes 25 river stations: 20 river station not influenced by human activity and 5 river stations influenced by human activity (Snina in Cirocha River, Michalovce and Ižkovce in Laborec River, Streda nad Bodrogom in Bodrog River, Horovce in Ondava River). The significant decreasing trend of low flows was proved in December, February, June, and July; in

Table 9 Statistically significant trends in river basin Poprad

	All river stations		Non-influenced river stations	
Months	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – not exist	−0.0016	H_0 – not exist	−0.00157
X – December	**H_1 – exist**	**−0.0078**	**H_1 – exist**	**−0.00835**
I – January	**H_1 – exist**	**−0.00635**	**H_1 – exist**	**−0.00735**
II – February	H_0 – not exist	0.002481	H_0 – not exist	0.00121
III – March	H_0 – not exist	−0.00756	**H_1 – exist**	**-0.00904**
IV – April	H_0 – not exist	0.001853	H_0 – not exist	0.002392
V – May	**H_1 – exist**	**0.013847**	**H_1 – exist**	**0.014733**
VI – June	H_0 – not exist	−0.00397	H_0 – not exist	−0.0047
VII – July	H_0 – not exist	0.000805	H_0 – not exist	0.000411
VIII – August	H_0 – not exist	0.002425	H_0 – not exist	0.002629
IX – September	H_0 – not exist	0.002781	H_0 – not exist	0.002534
X – October	H_0 – not exist	−0.00291	H_0 – not exist	−0.00298

Bold values: Significance level is 95%

Table 10 Statistically significant trends in river basin Hornád

Months	All river stations		Non-influenced river stations	
	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – not exist	−0.0116	H_0 – not exist	−0.01188
X – December	**H_1 – exist**	**−0.01897**	**H_1 – exist**	**−0.02119**
I – January	**H_1 – exist**	**−0.01417**	**H_1 – exist**	**−0.01461**
II – February	**H_1 – exist**	**−0.01463**	**H_1 – exist**	**−0.01525**
III – March	**H_1 – exist**	**−0.03008**	**H_1 – exist**	**−0.03076**
IV – April	**H_1 – exist**	**−0.01532**	**H_1 – exist**	**−0.01755**
V – May	**H_1 – exist**	**−0.01917**	**H_1 – exist**	**−0.02044**
VI – June	**H_1 – Exist**	**−0.01413**	**H_1 – exist**	**−0.0163**
VII – July	H_0 – not exist	−0.00455	H_0 – not exist	−0.00252
VIII – August	**H_1 – exist**	**0.011176**	H_0 – not exist	0.011107
IX – September	H_0 – not exist	0.003095	H_0 – not exist	0.002666
X – October	H_0 – not exist	0.000724	H_0 – not exist	0.000567

Bold values: Significance level is 95%

Table 11 Statistically significant trends in river basin Bodva

Months	All river stations		Non-influenced river stations	
	Trend	Magnitude	Trend	Magnitude
IX – November	**H_1 – exist**	**−0.03706**	**H_1 – exist**	**−0.03498**
X – December	**H_1 – exist**	**−0.03715**	**H_1 – exist**	**−0.03303**
I – January	**H_1 – exist**	**−0.02164**	H_0 – not exist	**−0.01926**
II – February	**H_1 – exist**	**−0.04673**	**H_1 – exist**	**−0.04173**
III – March	**H_1 – exist**	**−0.0535**	**H_1 – exist**	**−0.05171**
IV – April	**H_1 – exist**	**−0.05966**	**H_1 – Exist**	**−0.05091**
V – May	**H_1 – Exist**	**−0.04591**	H_0 – not exist	−0.03768
VI – June	**H_1 – exist**	**−0.01386**	**H_1 – exist**	**−0.01085**
VII – July	**H_1 – exist**	**−0.03503**	**H_1 – exist**	**−0.03329**
VIII – August	**H_1 – exist**	**−0.01144**	**H_1 – exist**	**−0.01219**
IX – September	**H_1 – exist**	**−0.01213**	**H_1 – exist**	**−0.01335**
X – October	**H_1 – exist**	**−0.01495**	**H_1 – exist**	**−0.01346**

Bold values: Significance level is 95%

other months, any statistically significant trend was not proved (Table 12). In this river basin is the course of flows the most stable.

4.4 Trends of Low Flows in Eastern Slovakia

The statistical file was created from the values of low streamflow in the gauging stations, monitored for a 36-year period and modified by relation (1). In this file were

Table 12 Statistically significant trends in river basin Bodrog

Months	All river stations		Non influenced river stations	
	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – not exist	−0.01314	H_0 – not exist	−0.01393
X – December	**H_1 – exist**	**−0.02115**	**H_1 – exist**	**−0.02388**
I – January	H_0 – not exist	−0.00869	H_0 – not exist	−0.0086
II – February	H_0 – not exist	−0.00552	**H_1 – exist**	**−0.00742**
III – March	H_0 – not exist	−0.0002	H_0 – not exist	−0.0028
IV – April	H_0 – not exist	0.009796	H_0 – not exist	0.00701
V – May	H_0 – Not exist	−0.00351	H_0 – not exist	−0.00555
VI – June	**H_1 – exist**	**−0.01136**	**H_1 – exist**	**−0.01382**
VII – July	**H_1 – exist**	**−0.00685**	**H_1 – exist**	**−0.00831**
VIII – August	H_0 – not exist	−0.00027	H_0 – not exist	−0.002
IX – September	H_0 – not exist	−0.00234	H_0 – Not exist	−0.00352
X – October	H_0 – not exist	−0.00356	H_0 – Not exist	−0.00313

Bold values: Significance level is 95%

included the 63 gauging stations (red color in Fig. 3). The second sets of statistics were created like the previous one but only from stations not affected by human activities (blue color in Fig. 3). Results of statistical analysis are recorded in the chart (Fig. 3) and in Table 13.

In both sets of statistic were detected significant statistical trends by Mann-Kendall test in these months: from December to July and October. All trends are decreasing. Low streamflow trends are slightly different in sizes. It was not proven the statistically significant impact of human activities for the hydrological regime of rivers.

Using ArcView GIS 10.2 was created the thematic map (Fig. 4) from the geographical map of Eastern Slovakia (Fig. 1) and were calculated relative magnitudes of the low streamflow trends in individual river stations. For each gauging station was assigned the streamflow histogram (Fig. 4).

In general, there was a statistically confirmed long-term decreasing trend of low streamflows in most of the monitored river stations in Eastern Slovakia.

4.5 *Trends Dependent to Geographical Parameters*

The next analysis was devoted to the evaluation of the interaction between the altitude of the river station and low flows in the river station. The results are documented in Table 14.

Statistically significant decreasing trends of low flows in river station with altitude up to 800 m asl. were proved in almost all the months of the hydrological year: November, April, August, and September. For river stations with altitude above 800 m were proved statistically significant trends from December till April and in June (Table 14).

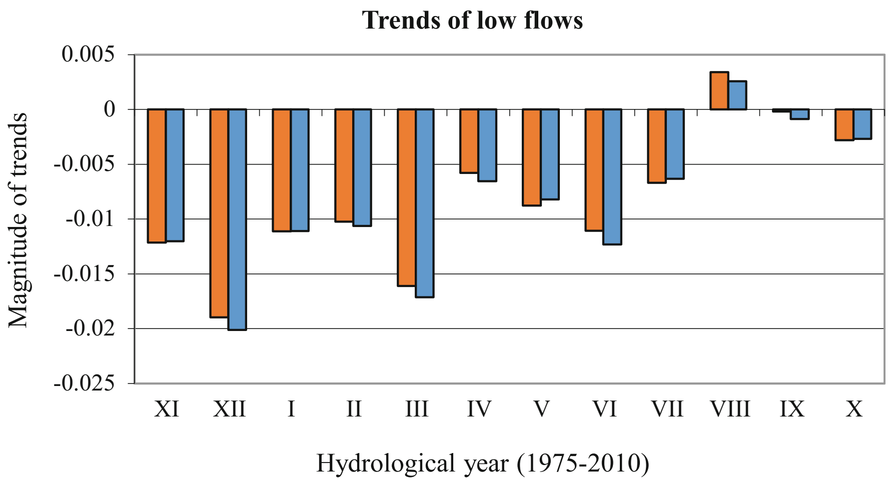


Fig. 3 Statistically significant trends throughout the territory of Eastern Slovakia

Table 13 Results of statistically significant trends

	All river stations		Non-influenced river stations	
Months	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – no exist	−0.01214	H_0 – no exist	−0.01203
X – December	**H_1 – exist**	**−0.01897**	**H_1 – exist**	**−0.02012**
I – January	**H_1 – exist**	**−0.01112**	**H_1 – exist**	**−0.01109**
II – February	**H_1 – Exist**	**−0.01014**	**H_1 – exist**	**−0.01063**
III – March	**H_1 – exist**	**−0.01610**	**H_1 – exist**	**−0.01714**
IV – April	**H_1 – exist**	**−0.00578**	**H_1 – exist**	**−0.00654**
V – May	**H_1 – exist**	**−0.00876**	**H_1 – exist**	**−0.00821**
VI – June	**H_1 – exist**	**−0.01106**	**H_1 – exist**	**-0.01230**
VII – July	**H_1 – exist**	**−0.00668**	**H_1 – exist**	**−0.00633**
VIII – August	H_0 – no exist	0.00340	H_0 – no exist	0.00257
IX – September	H_0 – no exist	−0.00018	H_0 – no exist	−0.00086
X – October	**H_1 – exist**	**−0.00280**	**H_1 – exist**	**−0.00268**

Bold values: Significance level is 95%

In the next analysis was investigated the interaction between low flows and the slope of the river basin. The results are documented in Table 15.

In the first group, formed from partial river basins with a slope lower than 15°, the low flow rate is expected to occur mainly in December, January, February, March, and in the summer months: May and June. For partial basins with a basin slope above 15°, the occurrence of the low water regime is predestined throughout the year except November, May, and August.

Physicogeographical factors in the river basin can suppress the influence of climatic factors, and therefore we also evaluated the natural hydrological flow regime depending

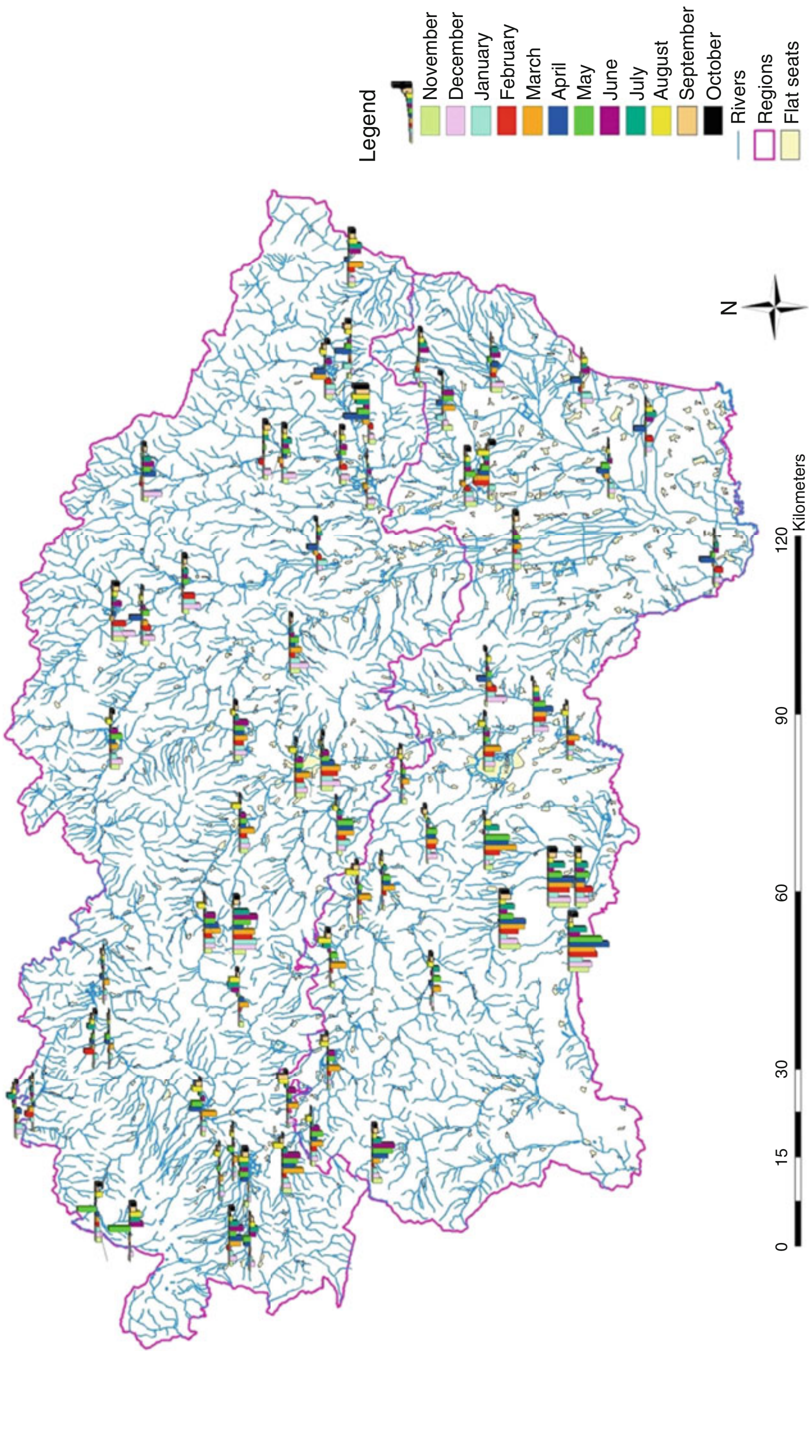


Fig. 4 Histograms from trends of low streamflow

Table 14 Results of the influence of the altitude to low flows

Months	Altitude up to 800 m asl.		Altitude up above 800 m asl.	
	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – no exist	−0.01533	H_0 – no exist	−0.00597
X – December	**H_1 – exist**	−0.02566	**H_1 – exist**	−0.01062
I – January	**H_1 – exist**	−0.01353	**H_1 – exist**	−0.00805
II – February	**H_1 – exist**	−0.01459	**H_1 – exist**	−0.00306
III – March	**H_1 – exist**	−0.01673	**H_1 – exist**	−0.01767
IV – April	H_0 – no exist	−0.00865	**H_1 – exist**	−0.00604
V – May	**H_1 – exist**	−0.01287	H_0 – no exist	0.002033
VI – June	**H_1 – exist**	−0.01153	**H_1 – exist**	−0.0126
VII – July	**H_1 – exist**	−0.0082	H_0 – no exist	−0.00209
VIII – August	H_0 – no exist	0.00078	H_0 – no exist	0.00646
IX – September	H_0 – no exist	−0.00287	H_0 – no exist	0.002704
X – October	**H_1 – exist**	−0.00384	H_0 – no exist	−0.00164

Bold values: Significance level is 95%

Table 15 Results of the influence of the slope of the river basin to low flows

Months	Basin slope up to 15°		Basin slope above 15°	
	Trend	Magnitude	Trend	Magnitude
IX – November	H_0 – no exist	−0.01239	H_0 – no exist	−0.01193
X – December	**H_1 – exist**	−0.02265	**H_1 – exist**	−0.01549
I – January	**H_1 – exist**	−0.01272	**H_1 – exist**	−0.00903
II – February	**H_1 – exist**	−0.0108	**H_1 – exist**	−0.01089
III – March	**H_1 – exist**	−0.01463	**H_1 – exist**	−0.02371
IV – April	H_0 – no exist	−0.00381	**H_1 – exist**	−0.01885
V – May	**H_1 – exist**	−0.00781	H_0 – no exist	−0.00852
VI – June	**H_1 – exist**	−0.00972	**H_1 – exist**	−0.01786
VII – July	H_0 – no exist	−0.00315	**H_1 – exist**	−0.01466
VIII – August	H_0 – no exist	0.005789	H_0 – no exist	−0.0061
IX – September	H_0 – no exist	0.000586	**H_1 – exist**	−0.00557
X – October	H_0 – no exist	−0.00157	**H_1 – exist**	−0.0074

Bold values: Significance level is 95%

on physicogeographical parameters by the regression analysis. We have determined the type of the regression function inductively, based on the empirical dependence of the evaluated values in the graph. We have evaluated the relative total amount of water in the river basin for the period 1975–2010 and the altitude/slope of the river basin. The grouping of points into a line or curve indicates that the relationship between the studied variables exists. The relationship is expressed by a coefficient of linear regression *R*. If *R* is less than ±0.4 is an important relationship, *R* up to ±0.7 means prognostic relation, and *R* up to ±1 expresses a high degree of dependence, a functional relationship [5]. The evaluation of this analysis is shown in Figs. 5 and 6.

The linear regression dependence (Fig. 5) identifies that the increasing altitude increases the occurrence of low streamflows.

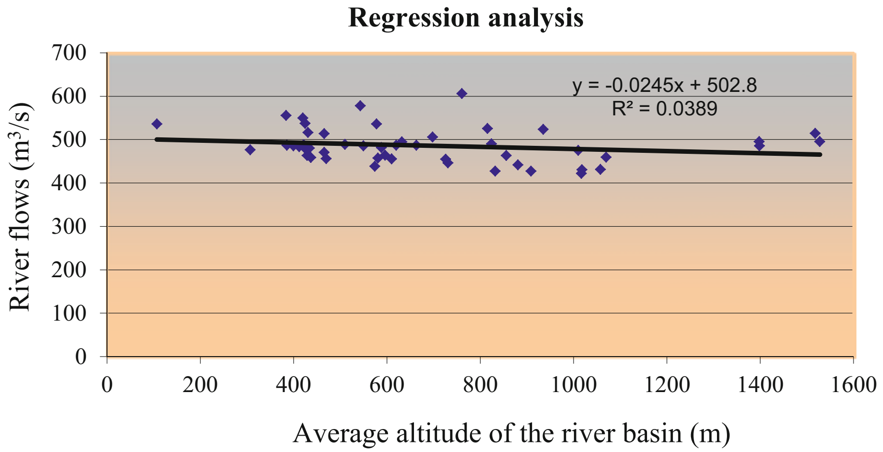


Fig. 5 Dependency of the altitude of the river basin and rate low streamflows

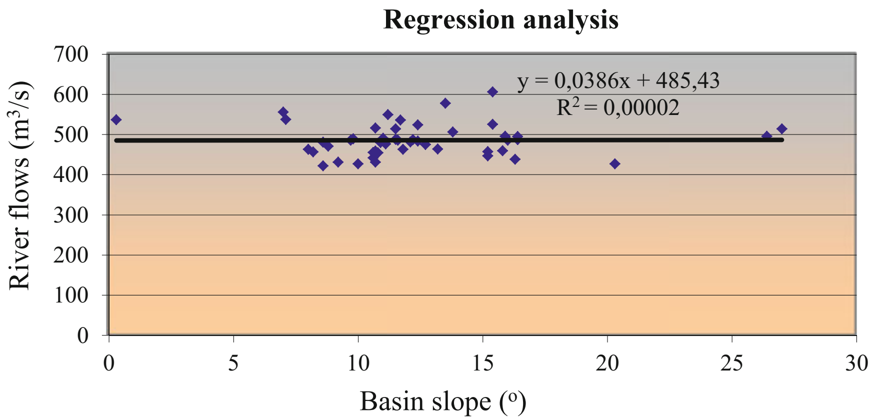


Fig. 6 Dependency of the slope of the river basin and rate low streamflows

Between the average slope of the basin and the relative amount of the streamflow, only a slight linear regression dependence is shown. With the increasing slope of the basin, the water quantity in the river stations increases only in a minimum.

It is important to note that in both cases (the dependency of the altitude and the slope of the river basin on the low flow), the regression analysis leads to a slight or almost no impact of the physicogeographical conditions of the basin on the low flow. The results were affected by taking into account (for simplicity) the total flow rate for the selected 36-year period. Unconstrained dependence can be obtained if only a proportionate amount of water per month of the evaluated period is taken as a variable and the regression analysis is performed for each month.

4.6 Spatial Analysis

The basis for the spatial analysis of hydrological drought analysis was the magnitude of the statistically significant flow trends obtained from the statistical analysis of the occurrence of trends in river stations. The spatial distribution map of the statistically significant trends for months during the year is shown in Fig. 7.

The spatial analysis was done for the period 1975–2010 and for each month separately by mapping the trend magnitude in the map of Eastern Slovakia. The maps were created using the kriging method in the ArcView GIS 10.2.

The results of the hydrological drought risk analysis confirm the more frequent occurrence of the low water season, especially in the locality of the Eastern Slovakia Lowlands.

A similar analysis can also be done for these parameters: temperatures, precipitation, and groundwater levels that significantly affect droughts. By covering all these maps, a comprehensive risk assessment of this phenomenon would arise.

5 Conclusion and Recommendations

Hydrological drought analyses in terms of streamflow deficits are said to be studies over a season or more extended time periods and in a regional context. A streamflow drought event definition quantitatively defines whether the flow can be regarded as being in a drought situation or not and gives the duration of a drought, whereas low flow indices characterize specific features of the low flow range.

The task of this chapter was to identify statistically significant trends in streamflow characteristics of low water content in Eastern Slovakia, which are used in the evaluation of hydrological drought. These data were obtained from the Slovak Hydrometeorological Institute, branch office Košice, at monthly intervals during the years 1975–2010. The methodology is based on statistical analysis of observed low streamflows at river stations. Mann-Kendall statistical test identifies the frequency of low streamflow trends. The hydrological drought is defined by a long-term decrease in levels of surface water bodies (e.g., rivers, lakes, reservoirs, and others) and drops in groundwater levels. Low water content is proof of this type of drought. Hydrological drought analyses in terms of streamflow deficits are said to be studies over a season or more extended time periods and in a regional context.

The main objective is to identify low streamflow trends in the selected 63-five river stations in Eastern Slovakia in the time interval from 1075 to 2010. The Mann-Kendall nonparametric test has been used to detect trends in hydrological time series. Some of streamflow records in rivers in Eastern Slovakia are affected by human activities, and another is without influence. Statistical tests can detect the existence of trends in hydrological time series. The purpose of the tests is to detect a statistically significant trend of decrease or increase of the low flow values. The nonparametric Mann-Kendall test has wide application in the testing of hydrometeorological characteristics. On the

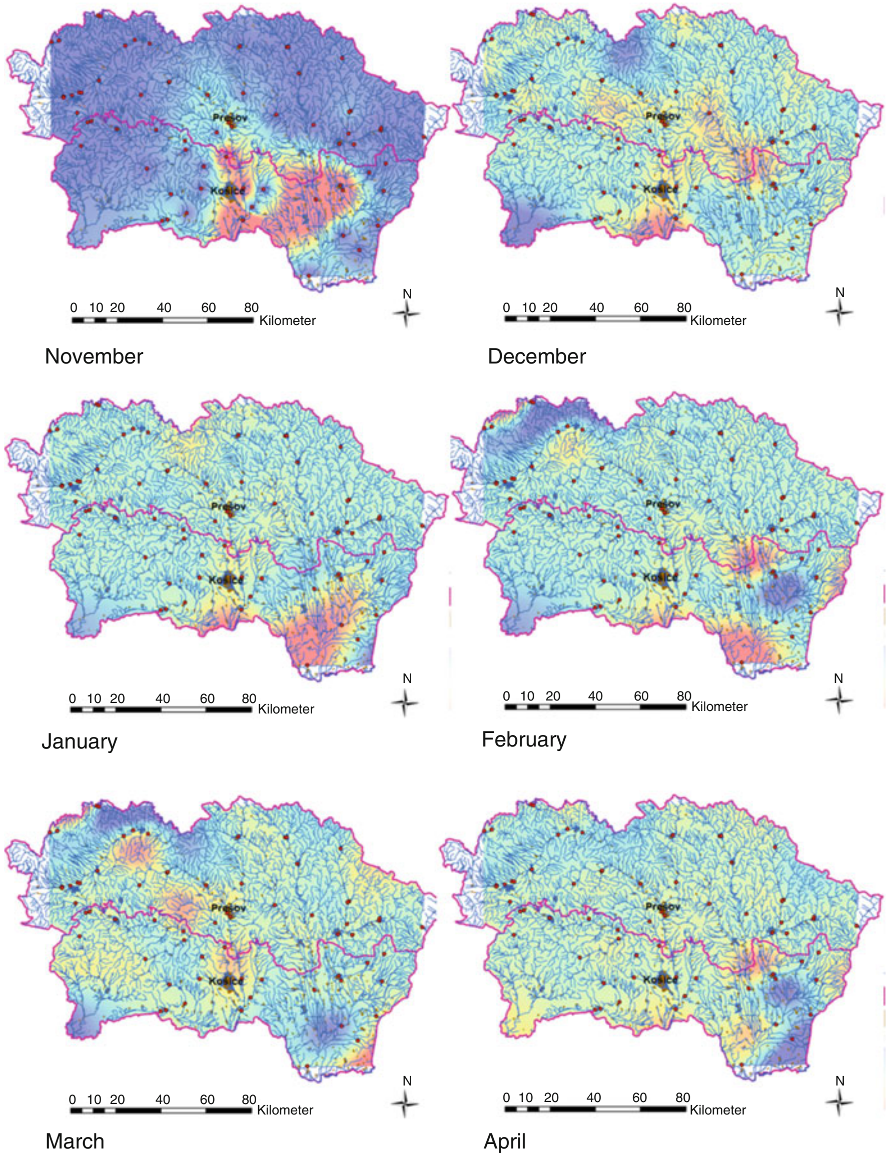


Fig. 7 Spatial distribution of the size of statistically significant trends in flows (*blue* color, wetter conditions; *red* color, drier conditions)

basis of the applied methodology, the existence of a trend in most of the evaluated river stations was not recorded. Only a small number of cases depict the decreasing trend in the time series of low flows. It was proven the slightly statistically significant impact of human activities for the hydrological regime of rivers.

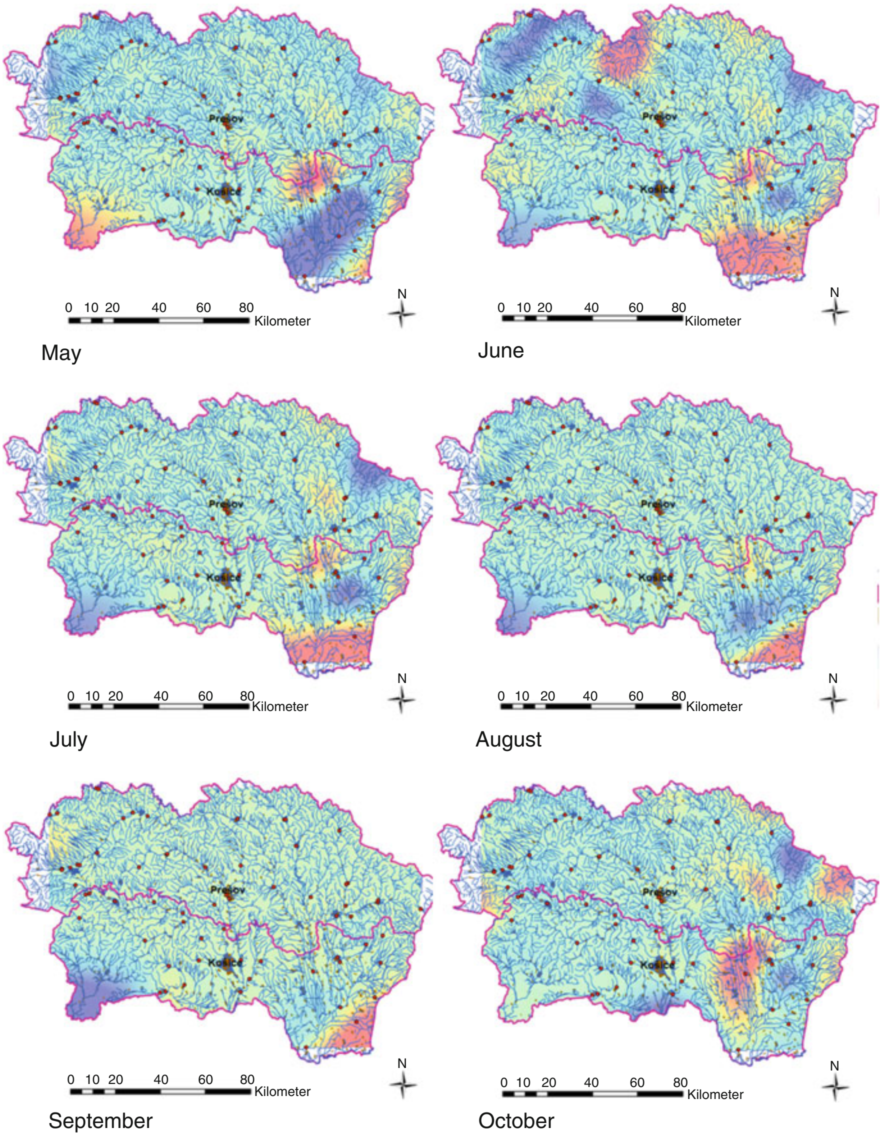


Fig. 7 (continued)

The results confirm the rising incidence trends of decreasing of low flows in the streams in Eastern Slovakia in river catchments Poprad, Hornád, Bodva, and Bodrog. Hydrological drought can be expected in almost summer months during the year – May, June, July, and August. In the complex vulnerability assessment of territory owing to drought, it is essential to take into account also the parameters as temperature, precipitation, and groundwater levels. Using ArcView GIS was created a graphical representation of hydrological drought risk regionalization in each month of the hydrological year.

Statistical tests can only indicate the significance of the observed test statistics and do not provide unequivocal findings. It is therefore essential to clearly understand the interpretation of the results and to corroborate findings with physical evidence of the causes, such as land use changes or river stations influenced by human activities. Changes in streamflow drought severity and frequency might occur as a result of changes in climate (mainly precipitation and temperature) and artificial influences in the catchment such as groundwater abstraction, irrigation, and urbanization [14]. Even so, low flow data are especially prone to artificial influences in a catchment, and the results presented in this paper may have been affected by this. The causes of a change in river flow behavior often do not have a simple explanation, and a further study would require a detailed analysis at the catchment scale, which is beyond the scope of this chapter. However, the spatial consistency in the results does indicate some systematic factors that can be evaluated at a qualitative, regional level.

References

1. WMO (2008) World Meteorological Organization, Guide to hydrological practices No 1211/168 on hydrology – from measurement to hydrological information, vol 1. World Meteorological Organization, Geneva
2. Mishra K, Singh P (2010) A review of drought concepts. J Hydrol 263:203–212
3. Wilhite DA (2000) Drought: a global assessment. Routledge, New York
4. Demeterová B, Škoda P (2008) Low flow in selected streams of Slovakia (in Slovak). J Hydrol Hydromech 57:55–59
5. Szolgay J, Dzubák M, Hlavčová K (1994) Hydrology. Runoff process and hydrology of surface water (in Slovak). Slovak Technical University, Bratislava
6. Demeterová B, Škoda P, Magulová R, Gápelová V, Síčová B, Liová S (2006) Hydrological limits. Low water content. Analysis of water balance in drought year with a new flow limits (in Slovak). Task of SHMI 6321-00, Final report – part 2, Slovak Hydrometeorological Institute, Bratislava
7. Hisdal H, Tallaksen LM (2000) Impact of droughts in Europe. Drought event definition. Technical Report No. 6
8. Zeleňáková M, Soľáková T, Purcz P, Simonová D, Kuzevičová Ž (2014) Drought regionalization based on low flow trends in selected river basins in Slovakia. Int J Environ Sci Dev 5(6):581–585
9. Šťavina P (2010) Algoritms of scientific and technical computations (in Slovak). Comenius University, Bratislava
10. Kendall MG (1975) Rank correlation measures. Charles Griffin, London
11. Mann HB (1945) Non-parametric tests against trend. Econometrica 13:245–259
12. Önöz B, Bayazit M (2003) The power of statistical tests for trend detection. Turk J Eng Env Sci 27:247–251
13. Santos JF, Pulido-Calvo I, Portela MM (2010) Spatial and temporal variability of droughts in Portugal. Water Resour Res 46:W03503
14. Hisdal H, Stahl K, Tallaksen H, Demuth S (2001) Have streamflow droughts in Europe become more severe or frequent? Int J Climatol 21:317–333

Groundwater Drought Occurrence in Slovakia

Miriam Fendeková

Contents

Abstract Groundwater regime and drought occurrence studies are very important for Slovakia, where groundwater is preferentially used for drinking water supply. It was shown by several studies that the groundwater drought occurs in Slovakia more often since the 1980s, causing problems in various sectors of the Slovak economy. Groundwater drought can be described either through groundwater heads, baseflow, groundwater storage or by the spring yield change. As the main reasons for groundwater drought occurrence, the natural factors and human activities can be mentioned. The amount of groundwater stored in the rock environment primarily depends on the water availability in the area and on the storage capacity of the rock environment itself. The lack of precipitation, high air temperature and the unfavourable storage properties of the rock environment belong to the main natural factors conditioning the groundwater drought occurrence. The groundwater over-abstraction also could increase the sensitivity of the local hydrological system to drought development. The groundwater drought studies for the Slovak territory were first published in the 1990s as a result of drought which hit the territory in the 1982–1984 period. After that, several important scientific works were performed to

M. Fendeková (✉)
Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Bratislava, Slovakia
e-mail: miriam.fendekova@uniba.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 91–104,
DOI 10.1007/698_2018_269, © Springer International Publishing AG 2018,
Published online: 15 May 2018

analyse the factors of drought development, occurrence and impacts on nature and social sphere. Baseflow drought, groundwater head drought and spring yield decrease were studied as presented in the chapter.

Keywords Baseflow, Drought, Groundwater, Groundwater head, Over-abstraction, Spring yield

1 Introduction

Drought belongs to major natural hazards together with floods, tornadoes, hurricanes, blizzards, volcanic eruptions and earthquakes. However, the perception of drought as a hazard was less intense in the past. The reason for the smaller public awareness of drought was [1] that droughts develop slowly and imperceptibly and may thus remain unnoticed for a long time. The series of drought events occurring since the 1980s of the last century attracted more attention to drought phenomenon in the scientific community, state authorities and also public. Meteorological, soil moisture and hydrological droughts were widely described in many studies. The fundamental works were published already in 1967 [2], later in 1987 [3] and in 2004 [1], among many others. The authors showed that there could not be one unique definition of drought because of manifold effects of drought in various parts of the climate system of the Earth, either in the system of its natural spheres (atmosphere, biosphere, lithosphere and pedosphere) or in the noosphere, ruled by the society. One of the first lists of definitions was published in 1985 [4] when the interest in drought issue started to rise, and one of the latest drought definition list was published in 2010 [5].

The meteorological drought is accepted as the initial input for the soil moisture and hydrological droughts development. The lack of precipitation or its presence in solid form (snow), in combination with other climatic factors, different in various parts of the year (the cold and the warm seasons) conditions the meteorological drought development. The lack of water starts in the atmosphere and propagates further through the soil up to the surface and subsurface part of the hydrosphere. Its influence reaches in the end the societal life and manifests itself in the socio-economic sphere.

Hydrological drought in the majority of studies includes drought in the two parts of the hydrosphere – the surface and the subsurface ones. The surface water drought concerns the streamflows (river stages or discharges), and lake or water reservoirs heads. The subsurface water drought includes: the (1) soil moisture and (2) groundwater droughts. Therefore, the groundwater drought is often considered as a type of hydrological drought.

Groundwater drought can be described either through groundwater heads, baseflow, groundwater storage or spring yield changes [1]. However, taking into account the influence of hydrogeological conditions on groundwater run-off formation, groundwater level and spring yield fluctuation, as well as the changes in physical properties and chemical composition of groundwater during the period of drought,

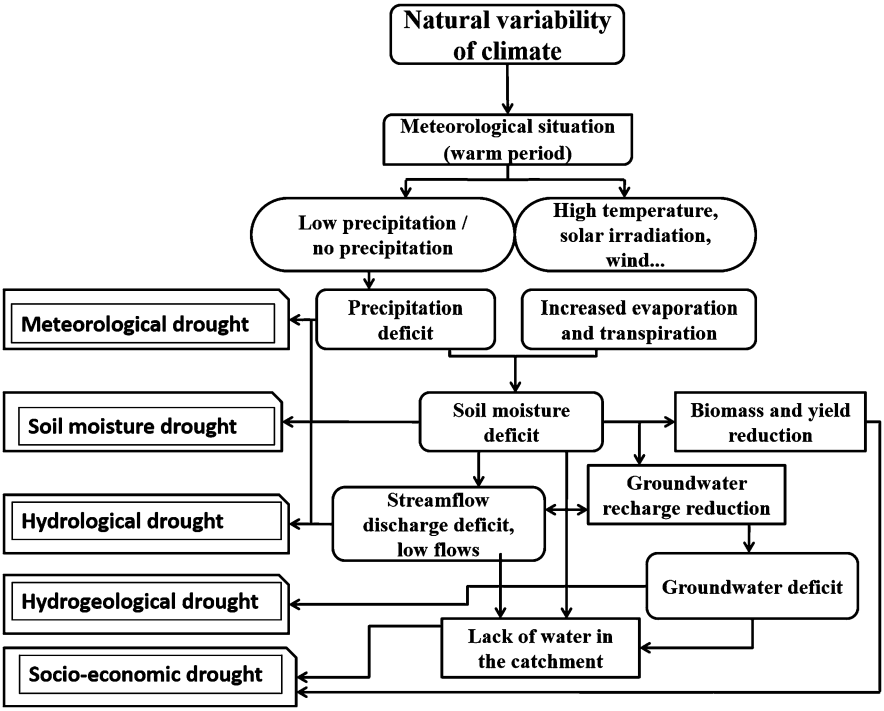


Fig. 1 Drought propagation through the hydrosphere – warm period conditions (modified from [7])

it is correct to regard this type of drought as hydrogeological drought [6]. The scheme of drought propagation modified from [7] is in Fig. 1 for the warm period conditions and in Fig. 2 for the cold period conditions.

Discussion on climate change effects in hydrological balance elements on the Slovak territory is being lasted among specialists in climatology, hydrology, hydrogeology and water economy mainly since the 1980s of the last century. Increasing air temperature was proved for the majority of the Slovak catchments, changes in precipitation amounts differ spatially [8, 9]. It was concluded [10] that there is still no significant decrease of water amount in Slovak catchments because decreasing interflow compensates the increasing evapotranspiration (due to the air temperature increase). The most serious affecting was documented for discharge values on surface streams in the southern, eastern and southeastern part of Slovakia [11].

2 Groundwater Drought

Groundwater regime and drought occurrence studies are very important for Slovakia, where groundwater is preferentially used for drinking water supply [12]. The amount of groundwater is affected by many factors among them the most important role play: the

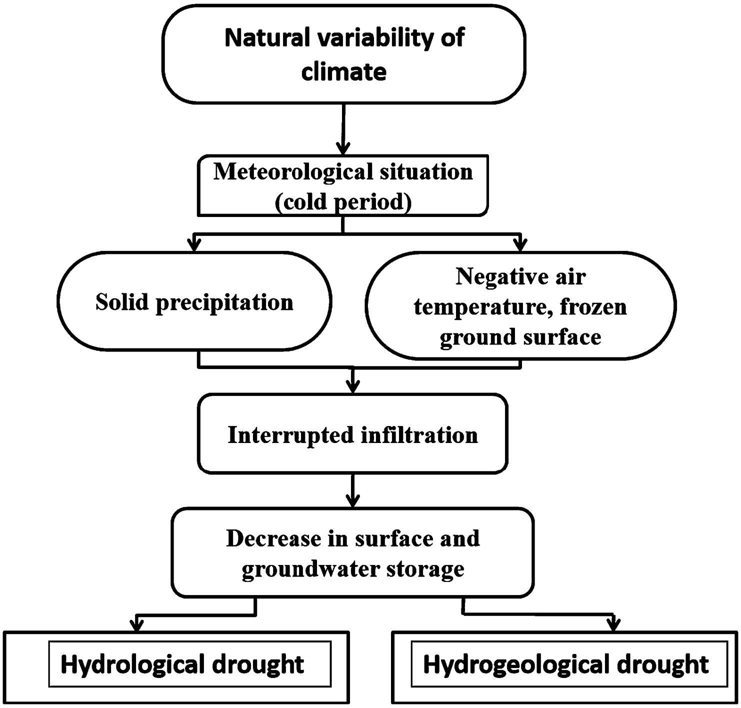


Fig. 2 Drought propagation through the hydrosphere – cold period conditions

(1) natural factors, among them the climatic, geomorphological, geological and hydrogeological conditions, and (2) artificial factors as the result of human influencing of the natural regime.

2.1 Natural Factors of Drought Occurrence

The amount of groundwater stored in the rock environment primarily depends on the water availability in the area and on the storage capacity of the rock environment itself. The water availability is conditioned by the climatic parameters – precipitation and evapotranspiration depths. Both parameters are altitude dependant – the precipitation depth increases with the increasing altitude. On the contrary, the air temperature, conditioning the evapotranspiration depth, decreases with the increasing altitude.

The storage capacity of the rock environment is conditioned by the rock type and kind of the rock permeability. The unconsolidated rocks with the larger grain size have larger storage capacity expressed by the storage coefficient. The best storage capacity is typical for porous fluvial sediments – alluvial deposits consisting of sands and gravels with various ratios of the sandy and gravelly compounds.

The lesser amount of water is stored in the loamy and clayey sands, and gravels where also the groundwater flow velocity is lower than in pure sand or gravel (see the chapter titled “an overview of water resources in Slovakia”, in volume I of this book). Larger amounts of groundwater can also be stored in certain types of consolidated rocks, being represented by carbonates – limestones and dolomites. Particularly, karstified limestones can store huge amounts of groundwater in the underground spaces (small and large fissures, canals, caves, etc.). Good storage properties also have certain types of dolomites (see the chapter titled “an overview of water resources in Slovakia”, in volume I of this book).

During the warm periods of the year with low precipitation and high air temperature (summer season), the precipitation is consumed mostly by vegetation for its growth and the recharge of the rock environment is decreasing rapidly (see Fig. 1). Therefore, the summer season is very typically the season during which the groundwater drought occurs. The spring yields, having their maxima in the end of the snow melting period, start to decrease with the minimum values occurring during the summer and early autumn period, often continuing also during the next winter period. The soil and rock permeability type and groundwater circulation depth play also the important role in groundwater storage depletion and drought occurrence. The groundwater levels react in most cases slower on the lack of precipitation than springs. The decrease of groundwater table depends on the existence of the hydraulic connectivity between the groundwater and streamflows, and the distance from the stream, and also on the depth of groundwater table below the surface. If the groundwater table is close to the surface (within 1–2 m), the water consumption by the plant roots through the capillary rise could lead to high evapotranspiration and thus to soil moisture and groundwater drought development.

There were several types of the winter droughts distinguished for streamflows [13, 14]. However, the groundwater winter drought was not studied in such details yet. Winter drought in the baseflow, groundwater storage, groundwater level and spring yields is connected to the interrupted groundwater recharge because of below zero air temperatures, frozen ground surface and precipitation in the solid form (snow cover).

2.2 *Groundwater Over-Abstraction*

The over-abstraction of groundwater also could lead to the development of the groundwater drought, at least increasing the hydrosphere sensitivity to possible drought occurrence locally. The over-abstraction of groundwater can be caused either by groundwater pumping from wells or by tapping of springs which followingly do not recharge the surface streams. In both cases, there are consequences endangering and damaging the stability of the aquatic ecosystems and also, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems [15].

The primary negative consequences of the groundwater over-abstraction are mostly:

- The decrease of groundwater levels in the surroundings
- Interruption of hydraulic connectivity between the surface and groundwater
- The decrease of streamflows, mainly during the low flow periods, in the worst cases leading to drying of the small surface streams
- The disappearance of the natural springs

The secondary consequences are mostly connected to surface water quality deterioration during the low flow period, damaging of aquatic habitats, the disappearance of valuable aquatic species and others.

The lack of water caused by natural factors of groundwater drought occurrence is often strengthened by the increased water consumption in the household, tertiary sphere, industry and agriculture during the drought period.

The natural systems are able to recover after the over-abstraction is ended. However, it could take even several years. The over-exploitation of groundwater resources could become a major problem in a foreseeable future when some slowly rechargeable aquifers become exhausted [16].

3 Groundwater Drought in Slovakia

The groundwater drought studies for the Slovak territory were first published in the 1990s as a result of drought which hit the territory in the 1982–1984 period [17, 18]. Later on, they were followed by a complex study of trends of 98 springs and 99 monitoring wells of the groundwater monitoring network of the Slovak Hydrometeorological Institute (SHMI) [19] in the period since the beginning of observation (mostly from the late 1960s) up to 2009. The results documented that the climate changes after 1980 negatively influenced the stage of groundwater resources and reserves. It was documented that 70% of the Slovak territory was hit by groundwater resources decrease. However, the impact does not cover the whole territory homogeneously. The most serious impact was found in the central and southern part, the moderate one in the northern and north-eastern part of Slovakia. The intensity of the negative changes was stronger after 1991. The decrease in groundwater resources in the most affected areas reached 25%, locally up to 35%. The total decrease in groundwater resources was calculated totally on $-250{,}000\ m^3\ km^{-2}$. On the other hand, the surprising moderate increase in groundwater resources (both, spring yields and groundwater levels) was documented for the area of the south-eastern part of Slovakia (Eastern Slovakian Lowland, Košice basin), and for the central part of the Váh River Basin (Turiec Basin, Veľká Fatra Mts.) [19].

The baseflow drought was studied in the upper Torysa River sub-basin [6, 20], in the upper Nitra River sub-basin [21] and also in the Topľa River Basin [22, 23]. Groundwater drought studies were performed for different parts of Slovakia. The comparative study of the streamflow and groundwater drought was performed in the Topľa River Basin (north-eastern part of Slovakia) [22, 23].

Topľa River (Fig. 3) belongs to Bodrog River Basin. Topľa has its spring in Čergov Mts., north-eastern Slovakia. The altitude changes from 1,152.2 m.a.s.l. (Minčol, the highest point of the catchment) to 160.4 m.a.s.l. (Hanušovce nad Topľou, closing profile of the studied area). The average annual air temperature and annual precipitation totals are altitude dependant. The average annual air temperature reaches 4–8°C, and annual precipitation totals vary between 700 and 900 mm. The catchment belongs to the less permeable ones, being built of flysch sediments (alteration of sandstone and claystone) and covered by Quaternary alluvial deposits and slope sediments. Run-off is dominated by rainfall; high flow periods are predominantly in March–April, and low flow periods occur in September.

Following data were used for surface and groundwater drought evaluation (Fig. 4):

- Daily precipitation at Bardejov station
- Daily discharges at Bardejov and Hanušovce nad Topľou stations
- Weekly groundwater levels at Tarnov (1,308), Komárov (1,311), Dubinné (1,313), Marháň (1,359), Hanušovce nad Topľou (3,317), Vyšný Žipov (1,318), Hlinné (1,321) and Parchovany (1,160) villages

The hydrological drought was evaluated using the method of sequent peak algorithm (SPA) [1]. The fixed threshold of the 90th percentile of the long-term flow–duration curve and variable threshold based on the 80th percentile of the long-term monthly flow–duration curves were used.

It was documented [23] that the short-term drought prevailed in stream discharges. Results also showed that only three periods of the discharge drought longer than 100 days occurred during the evaluated period: in 1986–1987, 1997 and 2003–2004. Discharge drought at Bardejov gauging station usually lasts longer

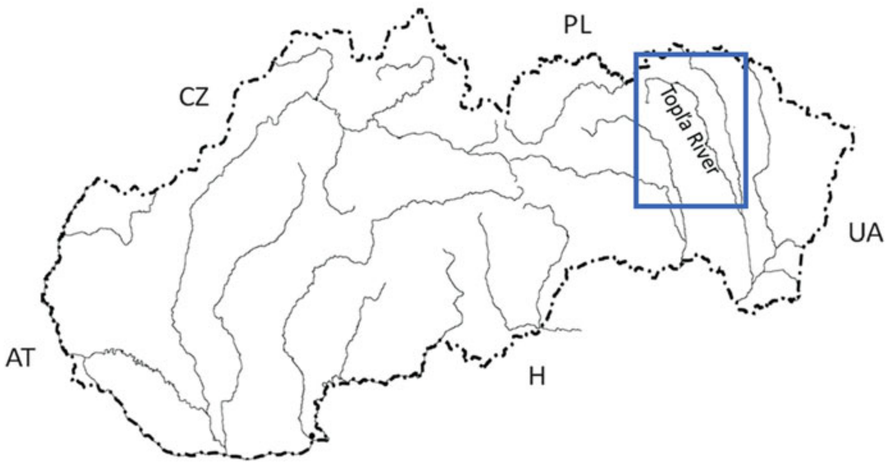


Fig. 3 Location of the Topľa River Basin

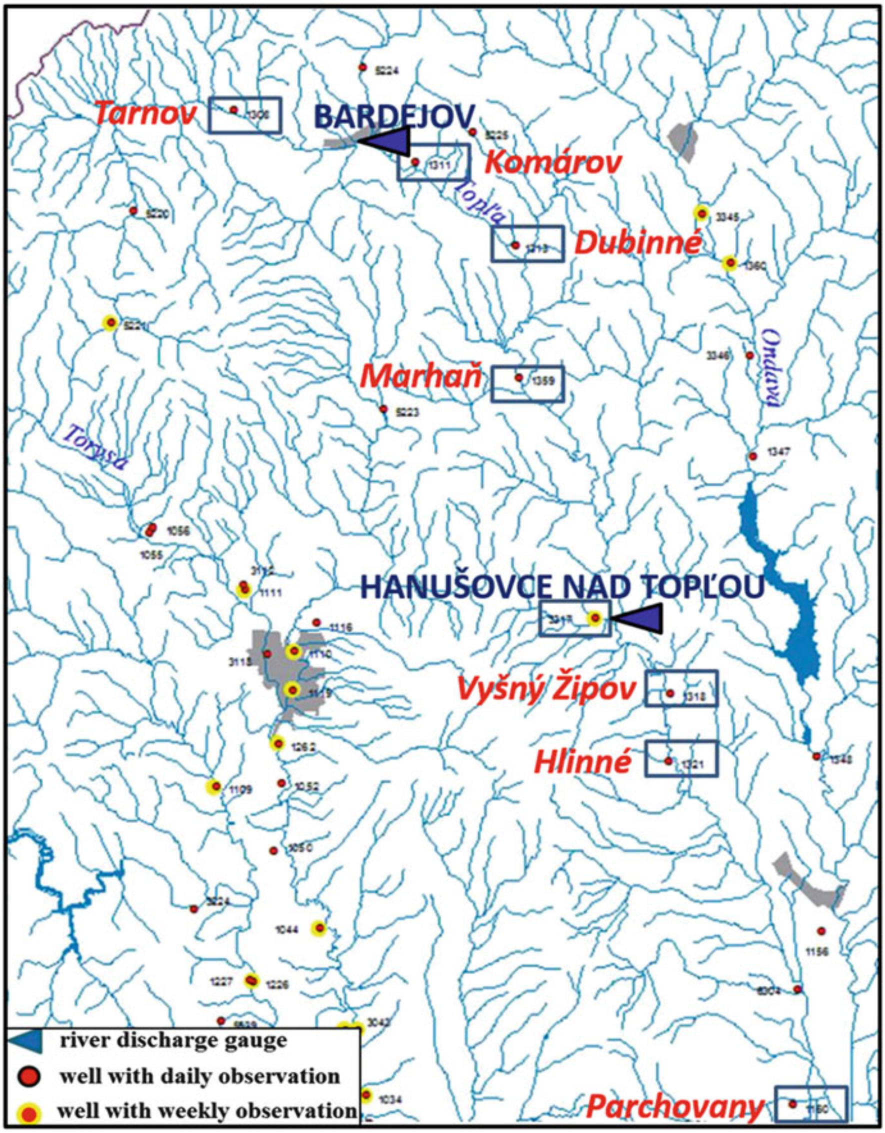


Fig. 4 Location of evaluated objects of the State monitoring network of the Slovak Hydrometeorological Institute (SHMI) (adopted from [22])

than in Hanušovce nad Topľou station being located downstream of the Bardejov station (see Fig. 4). More long-term droughts were estimated by all methods for groundwater levels. Those droughts lasted for tens of weeks since summer until the spring of the next year. No regularity in temporal groundwater level drought propagation downstream the Topľa River was discovered. However, results of the cluster analysis showed some common features of long-term drought periods (more than 100 days) occurrence for two groups of wells. The first one includes three wells in the upper part of the basin (Tarnov, Komárov and Dubinné, see Fig. 4), and the second one four other wells in the middle part of the basin. Specific conditions for groundwater drought occurrence were found in the well at Parchovany, which is the southern-most located and deepest well among all, with the highest amplitude of the level fluctuation. A higher number of short-term droughts were also estimated for groundwater level in Marháň, which has the smallest depth of groundwater table below the surface. In this case, the influence of evapotranspiration can be the reason.

Areal groundwater drought occurrence evaluation was performed by Slivová, Gavurník and Kullman for 123 objects of the State groundwater monitoring network of the SHMI in 2017 [11]. The drought intensity was evaluated using the SANDRE method [11] – see Table 1.

The results showed that the majority of dry years within the evaluated period 1981–2015 occurred before 1993, even with the 5-year drought between 1989 and 1993. The most intense drought among these 5 years occurred in 1990 and 1993. The results of groundwater drought occurrence evaluation correspond very well with the results of the discharge trends evaluation which also documented the important share of the period before 2001 on the identified discharge decreasing trends in Slovakia [11]. After the 1993 water year, the drought occurred only in 2003 and 2004, 2007, 2012 and 2015. The most intense was the 2012-year drought. September was the month with the most intense drought in the years 2003, 2012 and 2015 (see Fig. 5).

The occurrence of drought in the groundwater regime for different hydrogeological conditions in Slovakia was studied in [25]. Vrablíková in [26] evaluated the spring yields seasonality. Seasonality of the yields of 78 springs

Table 1 Categories of groundwater drought evaluation according to SANDRE method (http://www.sandre.eaufrance.fr/)

Groundwater level and spring yield	Distinctly lower than the long-term average (1981–2010) $<\varphi_{10\%}$, $<Q_{10\%}$	Lower than the long-term average (1981–2010) $\varphi_{10\%}$–$\varphi_{40\%}$, $Q_{10\%}$–$Q_{40\%}$	Matching the long-term average (1981–2010) $\varphi_{40\%}$–$\varphi_{60\%}$, $Q_{40\%}$–$Q_{60\%}$	Higher than the long-term average (1981–2010) $\varphi_{60\%}$–$\varphi_{90\%}$, $Q_{60\%}$–$Q_{90\%}$	Distinctly higher than the long-term average (1981–2010) $>\varphi_{90\%}$, $>Q_{90\%}$
Value	1	2	3	4	5

Explanation 1 – groundwater level (quantile value lower than $\varphi_{10\%}$) and spring yield (quantile value lower than $Q_{10\%}$) is distinctly lower than the long-term average of the reference period (drought), 2 – groundwater level (quantile value lower and equal to $\varphi_{40\%}$) and spring yield (quantile value lower and equal to $Q_{40\%}$) is lower than the long-term average of the reference period, 3 – groundwater level (quantile value lower and equal to $\varphi_{60\%}$) and spring yield (quantile value lower and equal to $Q_{60\%}$) are equal to long-term average of the reference period, 4 – groundwater level (quantile value lower and equal to $\varphi_{90\%}$) and spring yield (quantile value lower and equal to $Q_{90\%}$) is higher than the long-term average of the reference period and 5 – groundwater level (quantile value higher than $\varphi_{90\%}$) and spring yield (quantile value higher than $Q_{90\%}$) is distinctly higher than the long-term average of the reference period (wetness)

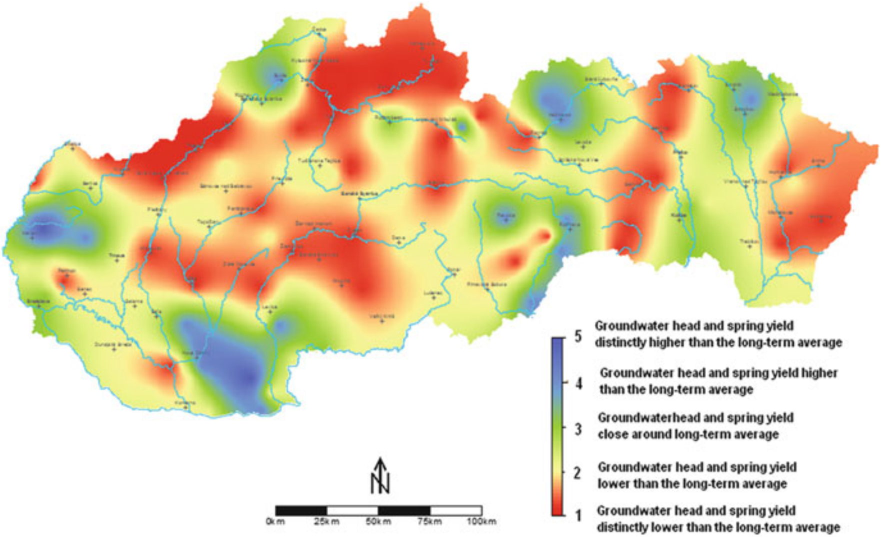


Fig. 5 Groundwater drought in September 2015 on the Slovak territory (adopted from [24])

in the mountainous areas of Slovakia was studied in detail. The study period included the years 1980–2012. The special attention was devoted to minimum yield occurrences. The minimum yield parameters were represented by $Q_{90\%}$ and Q_{Amin}. The $Q_{90\%}$ yield was calculated from the long-term yield–duration curve, representing the yield which was reached and overstepped during the 90% of the whole observed period 1980–2012. The Q_{Amin} represented the absolute minimum spring yield within the evaluated period. Seasonality of the average and minimum spring yields was evaluated using the Burn's vector and frequency histograms. The seasonality evaluation was followed by the regionalisation of the minimum spring yields based on a combination of physical–geographical factors (precipitation, air temperature, spring discharge area altitude, slope orientation and hydraulic properties of the rock environment expressed by transmissivity coefficient), the Burn's vector values and the frequency histogram values. The best results were reached using the physical–geographical parameters and the Burn's vector for both, the $Q_{90\%}$ and Q_{Amin} yields, respectively. Results of regionalisation for both of the minimum spring yield parameters are similar to each other, reflecting the dominant influence of the spring discharge area altitude. Three regions were delineated. The first regional type includes all evaluated springs with the discharge area altitude between 100 and 460 m (in a few cases in 550 m). Minimum yields occurred mostly from August to the first half of November. The discharge areas of the springs belonging to the second regional type are concentrated at the altitudes of 700 m and more. The minimum spring yields occur during the winter months – from December until February. The third regional type of springs spatially stretches between the first two regions; the spring yields are typical by minimum discharges during the summer–autumn period. So, the assessment showed that the spring yield droughts in the low to mid-altitudes occur in Slovakia in the summer-autumn months and those with the discharge area at the altitudes over the 700 m in the winter period – from December till February.

The over-abstraction causing groundwater drought occurrence can be illustrated on the example of the Podzámčok water-supply source. The water-supply source is located in the southern part of central Slovakia in the Neresnica brook catchment. The Neresnica brook catchment has an area of 139.33 km^2, the stream flows in the south-north direction towards the Hron River. The catchment area is built of Neogene volcanic rocks of the Štiavnické vrchy Mts. (western part of the catchment) and Javorie Mts. (eastern part of the catchment). The Neresnica stream follows the tectonic line dividing the Štiavnické vrchy Mts. and the Javorie Mts., acting at the same time as the deep drainage zone. The deep circulation of groundwater, coming from the depth of 150–200 m is demonstrated by the increased groundwater temperature reaching up to 16.9°C [27]. The average annual precipitation in the area reached 666 mm in the period 1963–2015, and the average annual air temperature varies around 8°C. Further information on the natural conditions can be found in [28] and in the chapter titled "an overview of water resources in Slovakia", in volume I of this book).

The groundwater abstraction in the catchment is documented since 1973 when the first wells were drilled in the area. The amount of abstracted water has been increasing gradually, reaching the highest amounts of more than 200 L s^{-1} since the 1980s up to the early 1990s, see Fig. 6 in which the course of precipitation amounts, average annual discharges and abstraction amounts during the evaluated period 1963–2015 are shown.

Such amount was too high for the natural recharge of the area, and the streamflows of the Neresnica reacted on the over-abstraction by an enormous decrease together with the groundwater heads. The groundwater heads decreased

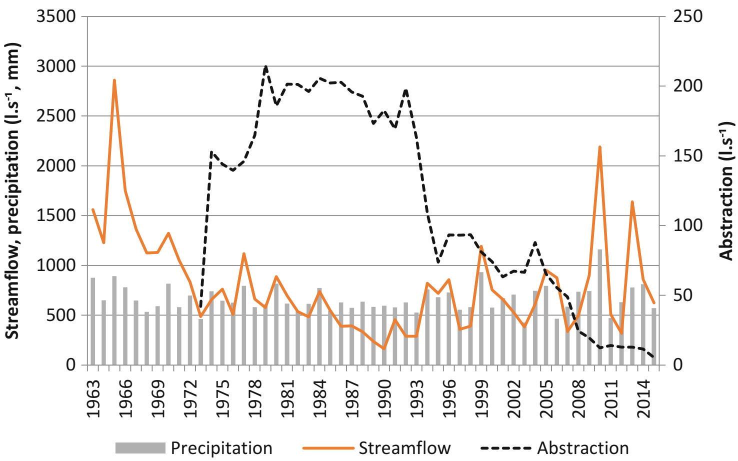


Fig. 6 Course of precipitation, average annual discharges and abstraction amounts in the Neresnica brook in the period 1963–2015

from the previous 1.5–3 m below the surface up to 15–23 m below the surface. The hydraulic connection of the surface and groundwater was interrupted, and the minimum annual discharges of the surface stream decreased from 180 L s^{-1} in 1964 to 20–10 L s^{-1}, reaching the absolute minimum of 9 L s^{-1} on August 30, 1990.

The decrease in groundwater abstraction since the mid-1990s had a positive influence not only on groundwater heads, which after approx. 5 years reached the previous values but also on the streamflow discharges, which increased importantly (see Fig. 6).

4 Conclusions and Recommendations

Groundwater is preferentially used for drinking water supply in Slovakia. However, the groundwater resources are endangered by increasing frequency of drought events, occurring also on the territory of Slovakia. These events, as the result of the climate changes, already caused the decrease in groundwater resources in $-250{,}000$ m^3 km^{-2} since 1981 as documented by the results of the study performed by the SHMI. Therefore, the possibility of groundwater drought occurrence on the territory of Slovakia should be continuously studied and the operational monitoring and warning system should be put into operation, as it was already done for the flood warning.

The European Water Framework Directive [15] put the strong accent not only on water quality in all parts of the hydrological cycle but also on prevention of deterioration of the good ecological status of the surface water bodies and good quantitative status of groundwater bodies. Therefore, the adoption of measures for mitigation and prevention of the groundwater drought impacts on the groundwater quantity should be one of the primary actions of the sustainable water policy. The groundwater over-abstraction and over-exploitation should be restrained because of possible undesirable impacts on surface and groundwater systems on which the natural ecosystems are dependent. This recommendation is in full agreement with the European legislation, e.g. European Water Framework Directive, which request to ensure the full implementation and enforcement of existing environmental legislation for the protection of waters [15].

References

1. Tallaksen LM, van Lanen HAJ (eds) (2004) Hydrological drought: processes and estimation methods for streamflow and groundwater. Developments in water science, vol 48. Elsevier Science B.V, Amsterdam, 579 p
2. Yevjevich V (1967) An objective approach to definition and investigation of continental hydrologic droughts. Hydrology papers, vol 23. Colorado State University, Fort Collins
3. Zelenhasic E, Salvai A (1987) A method of streamflow drought analysis. Water Resour Res 23:156–168

4. Wilhite DA, Glanz MH (1985) Understanding the drought phenomenon: the role of definitions. Water Int 10(3):111–120
5. Mishra A, Singh V (2010) A review of drought concepts. J Hydrol 391(1–2):202–216
6. Fendeková M, Ženišová Z, Demeterová B, Fendek M, Fľaková R, Gavurník J, Krčmář D, Macura M, Némethy P, Slivová V (2010) Hydrogeological drought. Slovak Association of Hydrogeologists, Bratislava. 190 p (in Slovak with English Summary)
7. Stahl K (2001) Hydrological drought - a study across Europe. PhD thesis, Albert-Ludwigs-Universität Freiburg. Freiburger Schriften zur Hydrologie, Freiburg. https://freidok.uni-freiburg.de/data/202. Accessed 15 Sept 2017
8. Szolgay J, Hlavčová K, Mosný V, Parajka J (1997) Temporal and spatial changes of the hydrological balance in the territory of the eastern Slovakia. STU, Bratislava. 213 p (in Slovak with English Summary)
9. Škvarenina J, Szolgay J, Šiška B, Lapin M (eds) (2010) Climate change and landscape. Study of the Slovak Bioclimatic Society at SAS, vol 22, 25. SAS, Bratislava, 114 p
10. Pekárová P, Szolgay J (eds) (2005) Scenarios of changes in selected elements of the hydrosphere and biosphere in the Hron and Váh River Basins due to climate change. VEDA, Publishing House of the SAS, Bratislava. 496 p (in Slovak)
11. Fendeková M, Poórová J, Slivová V (eds) (2017) Hydrological drought and prognosis of its development in Slovakia. Publishing House of the Comenius University in Bratislava, Bratislava. 300 p (in Slovak with English Summary)
12. Act No. 364/2004 Coll. on Water and amendments of Slovak National Council Act No. 372/1990 Coll. on Offences as amended (Water Act)
13. Van Loon AF, Van Lanen HAJ, Hisdal H, Tallaksen LM, Fendeková M, Oostervijk J, Horvát O, Machlica A (2010) Understanding hydrological winter drought in Europe. IAHS Publ 340:189–197
14. Van Loon AF, Van Lanen HAJ (2012) A process-based typology of hydrological drought. Hydrol Earth Syst Sci 16:1915–1946
15. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy. Off J L 327, 22/12/2000, pp 0001–0073. http://data.europa.eu/eli/dir/2000/60/oj
16. Dimkic M, Brauch H-J, Kavanaugh M (eds) (2008) Groundwater management in large river basins. IWA Publishing Alliance House, London, 706 p
17. Fendeková M., Gavurník J, Kullman E Jr, Sadloňová K (1995) Influence of global climate change on spring yields on Slovak territory. In: Proceedings of the conference AQUA′95, Trenčín, pp 8–18 (in Slovak)
18. Majerčáková O, Fendeková M, Lešková D (1997) The variability of hydrological series due to extreme climate conditions and possible change of the hydrological characteristics with respect to potential climate change, vol 246. IAHS-AISH, Wallingford, pp 59–66
19. Kullman E (2011) Evaluation of spring yield and groundwater level changes in the state hydrological network monitoring objects. In: Bottlik F, Malík P (eds) Proceedings of the conference: research of the climate change impacts on available groundwater amounts in Slovak Republic and compilation of the expert GIS, State Geological Institute of D. Štúr, Stará Lesná, 14–16 Nov 2011, pp 61–121
20. Fendeková M, Demeterová B, Slivová V, Macura V, Fendek M, Machlica A, Gregor M, Jalčovíková M (2011) Surface and groundwater drought evaluation with respect to aquatic habitat quality applied in Torysa river catchment, Slovakia. Ecohydrol Hydrobiol 11(1–2):49–62
21. Fendeková M, Fendek M (2012) Groundwater drought in the Nitra River Basin - identification and classification. J Hydrol Hydromech 60(3):185–193
22. Fendeková M, Vrablíková D, Fendek M, Gavurník J, Blaškovičová L, Kapolková H (2015) Inter-relation of meteorological and hydrological droughts in the upper and middle part of the Topľa River Basin. Acta Hydrol Slovaca 16(2):138–145
23. Fendeková M, Fendek M, Vrablíková D, Blaškovičová L, Slivová V, Horvát O (2016) Response of surface and groundwater on meteorological drought in Topla River catchment, Slovakia. Geophysical research abstracts, vol 18, EGU2016–6921. EGU General Assembly, Vienna. http://meetingorganizer.copernicus.org/EGU2016/EGU2016-6921.pdf

24. Fendeková M, Fendek M, Vrablíková D, Gauster T, Danáčová Z, Slivová V, Horvát O (2016) Comparison of the 2003, 2012 and 2015 drought in the Kysuca River Basin. Poster. In: 18th Slovak hydrogeological conference, Demänovská dolina, 18–21 October 2016
25. Stojkovová D (2014) Identification and classification of drought in the groundwater regime. Dissertation thesis, Comenius University in Bratislava, 183 p
26. Vrablíková D (2017) Regionalisation of the spring yields seasonality. Dissertation thesis, Comenius University in Bratislava, 110 p
27. Makišová Z, Ženišová Z (2004) Hydrogeochemical characteristics of the water-supply source Podzámčok. Podzemná voda 10(1):106–114
28. Fendeková M, Ženišová Z, Némethy P, Fendek M, Makišová Z, Kupčová S, Fľaková R (2005) Environmental impacts of groundwater abstraction in Neresnica brook catchment (Slovak Republic). Environ Geol 48(8):1029–1039

Drought as Stress for Plants, Irrigation and Climatic Changes

Ľ. Jurík and T. Kaletová

Contents

Abstract Drought by itself cannot be considered a disaster. However, if its impacts on local people, economies and the environment are severe and their ability to cope with and recover from it is difficult, it should be considered as a disaster. Droughts and floods are a recognizable category of natural risk. Hydrological assessments of drought impacts require detailed characteristics. We propose a new conceptual framework for drought identification in landscape with agricultural use. We described hydrological drought characteristics with impacts at the agricultural landscape and food security and the issues related to drought water management. In the past, the Slovak Republic was not considered a country immediately threatened with drought. The situation had changed at the turn of the millennium, especially after the extreme weather conditions in 2014 and also in 2015, when, for example, the historical minima were recorded.

Ľ. Jurík (✉) and T. Kaletová
Department of Water Resources and Environmental Engineering, Faculty of Horticulture and Landscape Engineering, Slovak University of Agriculture in Nitra, Nitra, Slovakia
e-mail: lubos.jurik@uniag.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 105–124,
DOI 10.1007/698_2018_271, © Springer International Publishing AG 2018,
Published online: 15 July 2018

Keywords Anthropogenic influences, Climate change, Disposable water resources, Ecosystem, Landscape evapotranspiration, Moisture demand of crops, Stress, Water deficit

1 Introduction

A settlement of countryside and population growth places emphasis on the increasing demands on exploitation of resources, including land, soil and water. On the first place, it is landscape—authentic forest vegetation was changed on an agriculture landscape with agriculture production. Authentic ecosystem with wide biodiversity was changed on the sort of plants which were selected in the aim of an increasing yields and resistance to diseases and pests by the millennium. A proper selection of crops, as has been found in archeologically excavations in China from 2000 years BC, helped several communities to survive impact of the extreme weather seasons—drought and floods (wheat, barley, millet, rice, sorghum, vegetables). They used to grow crops with high water demand and crops resistant to drought in the same time. Therefore, they always reach the needed minimum for human nutrition without the weather impact. High-performance crop varieties in order to achieve high yields require proper agrotechnics, nutrition, protection and optimum water regime. Landscape as itself is connected to the same water regime which ensures the safety for the people living in it. The extremes of water regime in the landscape are floods and drought. The drought in the landscape is a complicated and socially very important problem. We can relatively exactly determine and evaluate a beginning and end of flood. A beginning and end of the drought is hardly determined; therefore, it is important to know its progress and consequences.

Drought is one of the natural disasters. The area affected by drought increases from 6 to 18% in last 30 years according to data from European Commission [1].

1.1 Soil and Water

Soil is one of the most important non-renewable resources for the agriculture crop production. All of these basic components have undergone profound changes over the years as a result of anthropogenic activity that has adversely affected their state. The effects were mainly the destruction of the authentic ecosystems, the reduction of biodiversity and the creation of conditions for the intense growth of weed communities as accompanying vegetation of cultural plants, often with higher resistance than the cultural plants themselves. No lesser influence on potential plant production also has climatic conditions. Over the past 20 years, climate change has become increasingly apparent in Slovakia and surrounding countries. We are witnessing an increase in average temperatures and the impact of precipitation, both in terms of quantity and distribution over the year, and an increase in extreme phenomena (drought on one side and torrential rain on the other). Equally water consumption in different areas of economy needs optimization of its use. It is apart important accumulation capacity of natural landscape in Slovakia. Available water in the catchment during the whole year depends upon that accumulation capacity. Accumulation capacity is a function of the soil vegetation cover, soil properties and its subsoil and terrain configuration in the landscape.

The water balance draws the hydrological cycle quantitatively. The water balance looks at the balance between inputs and outputs. One can look at the water balance at a global level (hydrological cycle), at a local level (drainage basin cycle) or even just as an investigated site.

The general water balance equation is

$$P - R - G - E - T = \mathrm{DS} \tag{1}$$

where P precipitation [mm] or [$\mathrm{m}^3\ \mathrm{s}^{-1}$], R runoff, [mm] or [$\mathrm{m}^3\ \mathrm{s}^{-1}$], $R = R_{\mathrm{out}} - R_{\mathrm{in}}$, R_{out} = runoff as outflow from the water body × hydrologic region, R_{in} = runoff as influx into the water body × hydrologic region, G groundwater flow, [mm] or [$\mathrm{m}^3\ \mathrm{s}^{-1}$], $G = G_{\mathrm{out}} - G_{\mathrm{in}}$, G_{out} = groundwater as outflow from the water body ÷ hydrologic region, G_{in} = groundwater as influx into the water body ÷ hydrologic region, E evaporation [mm] or [$\mathrm{m}^3\ \mathrm{s}^{-1}$], T transpiration [mm] or [$\mathrm{m}^3\ \mathrm{s}^{-1}$], DS change in storage [mm] or [$\mathrm{m}^3\ \mathrm{s}^{-1}$].

For water sustainability in the landscape, DS should be greater than zero. Storage may be in the form of the soil water, groundwater or surface resources in the reservoirs. The drought is when the change in storage is negative. Potentially evapotranspiration is usually higher than precipitation and cannot be achieved not only to ensure it but also to redistribute the water, e.g. to surface runoff or underground drains. The distribution of balance components is very different.

1.2 Water Resources and Drought

Water in the landscape is evaluated by resources and its division or consumption. It is expressed by the quantitative water management balance.

The evaluation of the drought in the landscape is by balance equation not only by the evaluation of actual and potential evapotranspiration but also the state of resources—local, regional or international—available in the area of evaluation. The sufficient available water may eliminate the local natural conditions during the evaluation of the drought.

The precipitation is the local parameter. Each square metre is covered by water from precipitation in particular time, and value significantly changes in the distance of 1 km; therefore, we are based on the data from meteorological stations. Also, data from different amateurs' stations of high quality are used, nowadays.

The soil moisture and the soil water content in depth of 1 m are also a local parameter, and the differences in the values may be in the distance of 100 m. We used data from the stations which network is minor. The Faculty of Horticulture and

Landscape Engineering operated a Centre of Excellence with its own network of stations for the Nitra river basin. The data are available from 2014. More information about the centre and monitoring network are available in Tárnik and Igaz [2].

The water resources in the landscape are also water in the streams or rivers and water in the reservoirs. The water runoff in the streams is the local parameter and is connected with the soil and groundwater and current precipitation. Its values vary a lot, and it is not possible to use as the water source during the drought because of low or zero discharge without a possible usage.

River flow is a sum of outflows from subbasins and does not respond to local precipitation in a small part of the area. It is affected more by the stock of soil and groundwater in the area (base flow). Therefore, rivers can be used as a source of irrigation water even at the beginning of the dry season, as the base flow provides the resources from previous periods. Large transboundary rivers crossing the borders can bring water from areas with sufficient rainfall to drought areas and are thus an important source of water in dry periods.

The local water source for the dry season is the water in the reservoirs in which we create water reserves over a period with excess rainfall for a period with a lack of precipitation. The volume of water in the water reservoir creates the conditions for temporally bridging the current shortage of water resources for use for irrigation or production. The problem of water reservoirs is siltation and decreasing the capacity (volume) of reservoirs, nowadays [3].

The current processed water balance forecast considers irrigation water needs for the horizon of 2010 and also provides views of the years, 2030 and 2075. On the side for water sources are considered the natural average monthly flow rates with high security and on the other side are used minimum residual flows values MQ. The balance is processed by evaluating the discharge profiles of individual subbasins. The results only for 2010 are declared through the capacity of water sources (flows). A negative number means the shortage of water sources (Table 1) [4].

Table 1 Forecast of water balance in river basins in selected months for the year 2010 in $m^3 s^{-1}$ [4]

	Month						
River subbasin	4	5	6	7	8	9	10
Bodrog	26.85	18.71	9.801	0.383	0.196	3.604	6.140
Hron	6.461	6.042	3.072	1.165	**−1.554**[a]	0.961	**−0.111**
Ipeľ	0.763	0.110	**−0.686**	**−0.972**	**−0.792**	**−0.053**	0.311
Slaná	1.894	3.496	1.480	0.476	0.221	0.549	0.550
Nitra	2.456	0.575	**−0.833**	**−1.018**	**−1.453**	**−0.026**	0.567
Váh	47.42	17.95	13.64	4.707	**−2.042**	0.529	**−1.365**
Morava	30.99	22.93	9.396	3.022	2.013	5.314	3.219
Dunaj	888.5	828.4	824.1	890.8	437.5	276.7	13.6
Bodva	**−0.005**	0.339	0.306	**−0.249**	**−0.299**	**−0.318**	**−0.178**
Poprad	5.386	6.261	8.239	3.874	2.923	2.137	1.381
Hornád	2.047	3.396	2.024	1.745	1.035	0.126	0.604

[a]Bold cells mean a lack of resources in the balance sheet

The basis for water balance is the determination of the monthly potential evapotranspiration because we know the monthly rainfall.

Monthly totals have significant regional differences in Slovakia. As an example, we will show values from two stations on the lowland. Different are not only the sums of precipitation but also their distribution during the year (Fig. 1).

To create properly the local balance is the evapotranspiration basis for the real determination. The value of evapotranspiration is not usually measured but is determined from the measured meteorological and climatological parameters. There is a network of climatological stations with evaporation measurement in Slovakia (Fig. 2).

For direct measurement of soil vapour, equipment called lysimeter is used; in the case of soil with vegetation, they are called evapotranspirometer. These are containers filled with soil monolith and covered with a crop identical to the assessed environment. Lysimeters and evapotranspirometers are soil and plant water evaporation analysers that also allow the measurement of the amount or the chemical composition of water sprayed into the vessels that are part of the lysimeter.

The direct measurement of evaporation from plants is the most accurate determination of transpiration and, therefore, in the scientific institutions, is seeking new measuring devices. In the year 2017, Iowa State University researchers have developed new "plant tattoo sensors" (Fig. 3) to take real-time, direct measurements of water use in crops. "With a tool like this, we can begin to breed plants that are more efficient in using water," he said. "That is exciting. We could not do this before. However, once we can measure something, we can begin to understand it." [7]

1.3 Soil and Drought

The main factors determining agricultural production are landscape, soil and water. The landscape creates conditions for the distribution of precipitation water and provides space for the accumulation of that precipitation water and its outflow

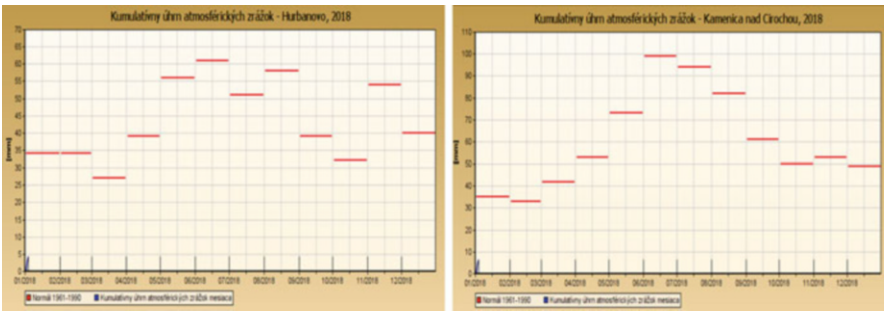


Fig. 1 Average monthly precipitation totals (red lines—normal 1961–1990) for Hurbanovo (left) and Kamenica nad Cirochou in mm month^{-1} [5]

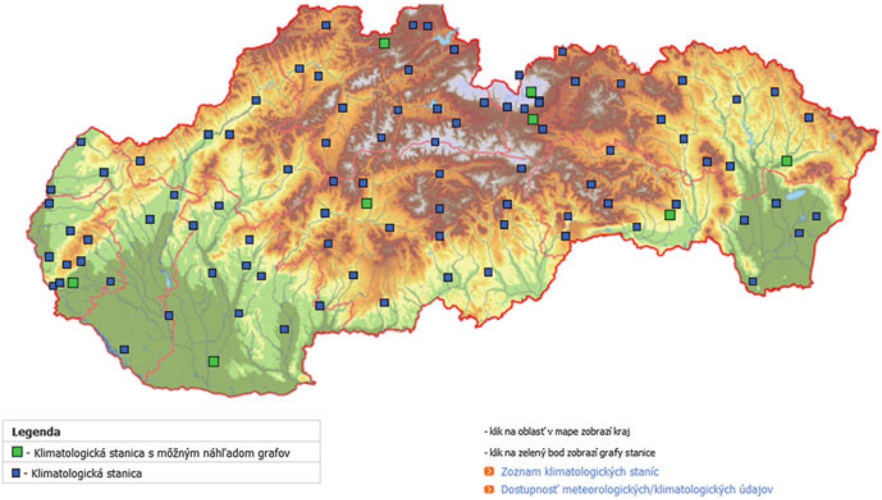


Fig. 2 Climatological stations measuring the evaporation in Slovakia [6]

Fig. 3 Plant sensors for direct measurements of water use in crops [7]

from the territory. The soil is a habitat for plants and creates for them the storage space for those substances necessary for plant growth, namely, nutrients, air and water. The main axis of the whole water dynamics in the landscape is the river network, which has to manage the regulation of all processes in the water. Agricultural production and plant biodiversity in the landscape are determined just by the basic constituents of the natural environment and their mutual interactions.

In many regions of the world, biomass production and water safety are at the risk level of overexploiting water resources and soil degradation. Climate change will increase this risk, especially in the environment with limited water sources and in the border regions.

The society can be gained from an improved understanding of the connection between soil, water and landscape. Improving the interconnection of soil management and land use requires regional specific management options that can help:

– To protect and develop land and water resources
– To enhance food and water security
– To improve the efficiency of water use and maintain and improve the soil and water associated with ecosystem services
– To enable the production of biomass in a variable climate and degrading and waning soil [8]

1.4 Drought Identification

There are hundreds of definitions, adding to the confusion about the existence of drought and its degree of severity. Drought may be defined as a period of a deficit with respect to the expected rain (normal), which occurs during the season [9]. Definitions of drought should be region and application specific or impact specifically. Drought is a natural disaster that is characterized by a lower-than-expected or lower than normal precipitation that, when the season is extended or a longer period, is insufficient to meet the demands of human activity and the environment. If we evaluate the effects of drought, problems can be combined into three common areas: economic, environmental and social problems [10]. Their effect and significance are usually different according to the location that we recognize. Expressions of drought are associated with looking at his assessment—we say about the drought meteorological, agronomical, hydrological, etc.

Drought is a regional phenomenon, and its characteristics differ from one climate regime to another. It is often difficult to know when a drought begins. Likewise, it is also difficult to determine when a drought is over and according to what criteria this determination should be made. Droughts have three distinguishing features: intensity, duration and spatial coverage. Intensity refers to the degree of the precipitation shortfall and/or the severity of impacts associated with the shortfall [11].

The difficulty for a drought assessment and identifying are, for example, quantification of intensity and determining its length. Because normal precipitation and water use expectations vary, the specific definition of drought is more a matter of where the water comes from and how it is being used [12].

Drought may be defined as a period of a deficit with respect to the expected rain (normal), which occurs during the season [9]. Normal shows about the long-term balance between precipitation and evapotranspiration for a specific site (meteorological drought concept). About the agronomic drought, one can say if the amount of soil moisture does not meet the needs of the plants. Agronomic drought correlates to the water deficit in the soil. It occurs after meteorological drought but before the hydrological drought. Agriculture and forestry are the first sectors of the economy, which are significantly affected by the drought. Then it can follow in the water supply to the population and the industry. Therefore, definitions of drought are of a qualitative nature, and extent of drought is expressed by words such as "water scarcity", "less water" and "low amount of precipitation" [13]. Water deficits are the result of a multifaceted interaction between human inflows and outflows, meteorological anomalies, landscape processes at the surface and changes of total water storage (see Fig. 4) [14, 15].

In Slovakia, it is drought classification based on the water balance which consists of the difference between precipitation and evapotranspiration. The occurrence of drought in the country in recent years can be also connected with the methods of land use—surface changes, changing the classic crop rotation, regional changes in water abstraction, etc. [16]. In semiarid areas during the 3-year experiment, the vegetation strongly controlled water loss even when daily climatic evaporative demand was high, and soil water availability was expected to be non-limiting [17].

For the evaluation of drought, currently, not only many definitions but also a number of evaluation indexes are used. For agricultural landscape, Palmer Index (Palmer Hydrological Drought Index—PHDI, Table 2) is suitable to use, among others. It takes into account not only climatic characteristics of the area but also the basic soil hydro limits [19]. This means that the same value of Palmer's Index in the different areas in them should have approximately the same economic impact on

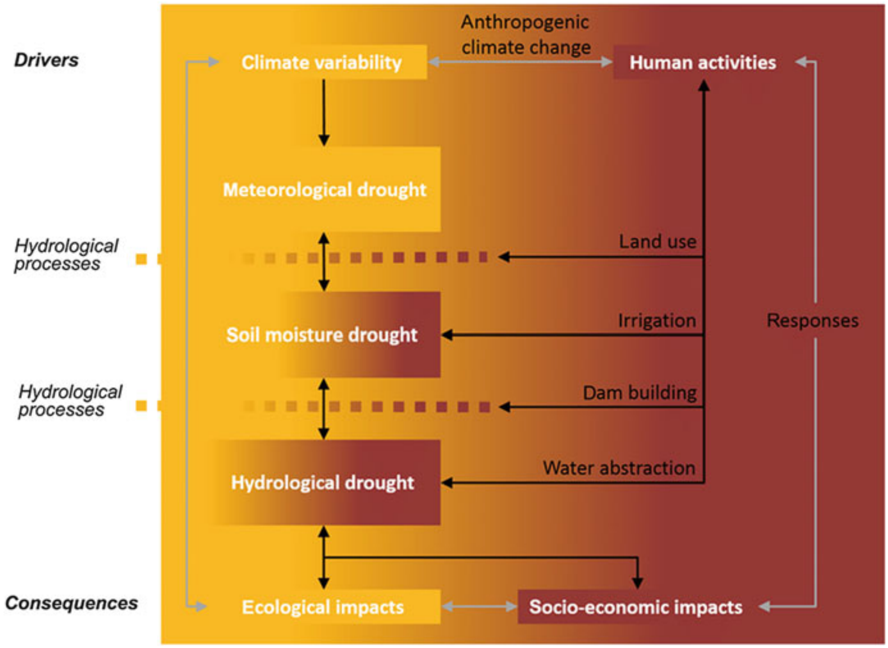


Fig. 4 Natural and human drivers and feedbacks (grey arrows) of drought; black arrows—direct influences [18]

Table 2 The Palmer drought severity index classifications for dry and wet periods

Value	Description	Value	Description
4.00 or more	Extremely wet	−0.50 to −0.99	Incipient dry spell
3.00 to 3.99	Very wet	−1.00 to −1.99	Mild drought
2.00 to 2.99	Moderately wet	−2.00 to −2.99	Moderate drought
1.00 to 1.99	Slightly wet	−3.00 to −3.99	Severe drought
0.50 to 0.99	Incipient wet spell	−4.00 or less	Extreme drought
0.49 to −0.49	Near normal		

crop production. The definition of drought in official documents is affecting reaction to drought. It is very important that the definition of drought allows the gradual implementation of the planned measures for its elimination. It is important to know and understand the diversity of drought definitions and the different needs of the perception of the drought phenomenon [20].

Drought impacts (Fig. 5) are most eye-catching in the agricultural sector. Dried crops, abandoned farmland and withered and yellow pastureland are the common signs of drought [12].

The sequence of drought occurrence has impacts for commonly accepted drought types. All droughts originate from a deficiency of precipitation or meteorological drought, but other types of drought and impacts cascade from this deficiency (Figs. 4, 5 and 6).

1.5 Water in the Landscape

Water in the Slovak landscape is the result of precipitation with a different character. We know the water balance equation in a landscape, where the water outflow from the territory is equal to rainfall, reduced by the amount of precipitation captured in the landscape, either through interception or infiltration into the soil profile.

The precipitation interaction in the soil profile creates two basic conditions. The first, the soil is with a partially saturated soil profile where the water content is smaller than the total porosity. The second, soil saturation is up to the porosity value, i.e. the state of saturation of the soil with water. These values have a significant impact on hydrological conditions in the area.

Tasks, given for the agricultural landscape, are currently:

- Create and maintain potential for crop harvesting.
- Create a place for social activities of the inhabitants of the given municipality, area, etc.
- Create conditions to maintain the optimal water cycle.
- Create conditions to maintain the optimal cycle of substances.
- Create conditions to maintain the optimal energy cycle.

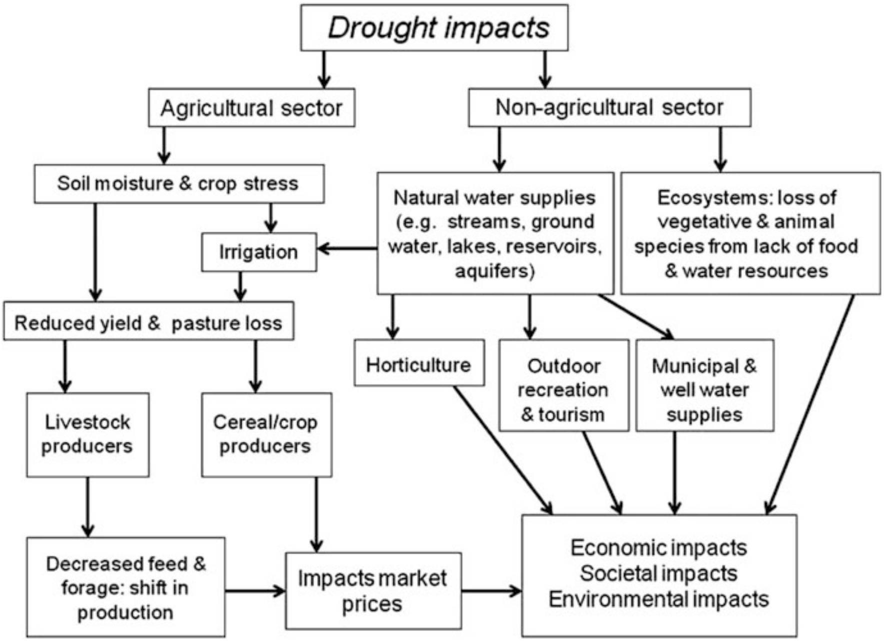


Fig. 5 Drought impacts on the economy, societies and the environment moving through time from the top to the bottom of the chart [21]

There is no clear and precise definition of the agricultural landscape in the literature. It is unclear whether or not only agricultural areas are concerned or the total cadastre of municipalities together with the parts of the residential area and, e.g. part of the forest fund. For its correct understanding, it is necessary to systematically analyse it. Water can significantly change soil properties—albedo, thermal conductivity and plant cover. Water has the largest thermal capacity of all known substances and can, therefore, influence the rate of change in the ambient temperature—soil and ground atmosphere [23].

Mostly, the course and direction of the fulfilment of functions taking place in the landscape are ensured by the water cycle in nature. Landscape and agricultural hydrology is the most fundamental analysis of landscape creation and development processes. Names of the landscape forms have been stabilized primarily by sufficiency respectively lack of the water in the country. Current climate change redistributes the water cycle and the amount of water in the country, and as in history, even today, it will be necessary to reassess the names of the forms of the landscape. The speed of changes in natural hydrological processes is affecting by the economy interests of land use the economy. In the agricultural landscape, by changing cultures from economic interests, we can fundamentally change the water consumption in the country. Experiments in semiarid conditions in Australia show that total evaporation was less than rainfall, as would be expected, but there were periods when

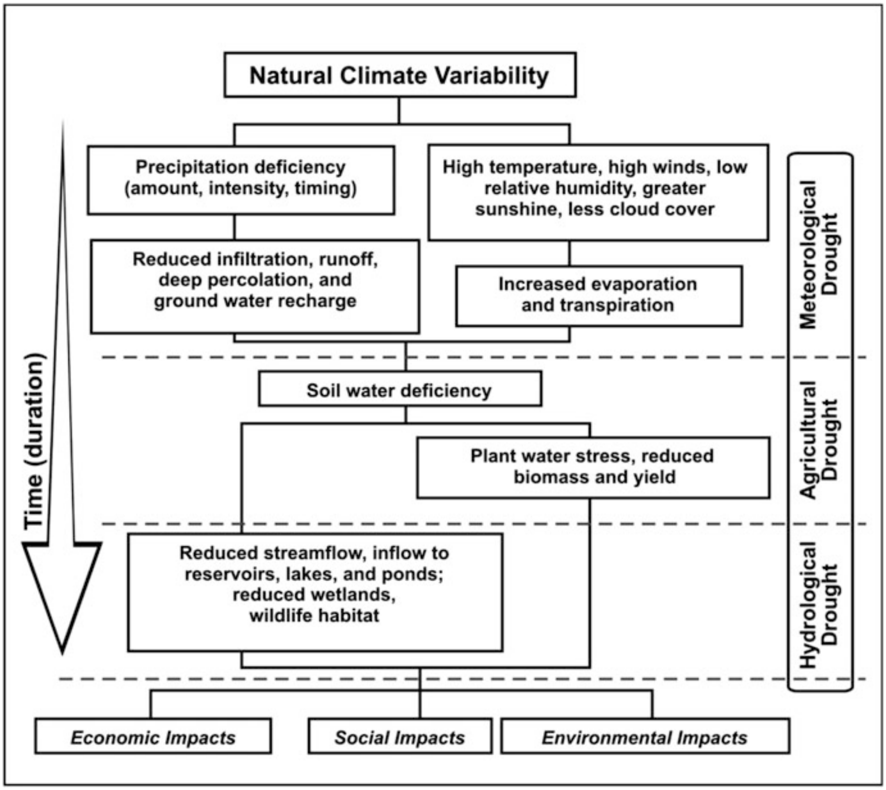


Fig. 6 Types of drought and their impacts [22]

evaporation exceeded rainfall for the period indicating that vegetation was using stored soil water from previous wetter periods [17].

For the classification of the landscape, its hydroclimatic regime is often used, balancing the ratio of evapotranspiration and precipitation (Table 3). With excess rainfall and small evapotranspiration, the landscape mode is wet and vice versa; when the evapotranspiration is greater than the rainfall, the mode is dry.

2 Drought in Agriculture in Slovakia

In Slovakia, more than one-third of the incident energy is used for evaporation, the part is heating the biosphere and part is radiated back into space. When the energy of the Earth is balanced over a period of 1 year, then there is a balance between the amount of energy received and the radiated energy [25]. From Slovak teritory on average about two-thirds of annual rainfall will evaporate, and one-third rainwater

Table 3 Review of evaluation of landscape hydroclimatic regimes [24]

ET/P	0–0.33	0.33–0.66	0.66–1.0	1.0–1.5	1.5–3.0	>3.0
Hydroclimatic regime	Very wet	Wet	Moderate wet	Moderate dry	Dry	Very dry

flows away. The average annual rainfall is 768 mm and layer of water that evaporates is 497 mm. Due to the varied morphological structure of our territory, the distribution of evapotranspiration also varied—up to 95% of the precipitations evaporate from southern Slovakia but only about 30% of the annual precipitation from mountain areas. Also, calculations in 2009 show that the increase in evapotranspiration for particular crops ranged from 9 to 57% in comparison with consumptive water usage calculated according to valid Slovak Technical Standard (STN no. 83 0635) [26]. Therefore, it is necessary to determine the exact value of the evaporation for a selected area.

Today there are several models to solve the soil-water-plant relationship. All of them are working with relatively different values for quantification of the surface condition of the land used by the territory. It is necessary to clarify these input data, in particular about the crop plants and their absolute or time-dependent water needs for the conditions of Slovakia. Models from other countries include data from other climate and soil databases. There are also different crops of the grown plants. Models from Belgium or the Netherlands are based on crops about 100% higher than in our country. Moreover, so it is clear that in Slovakia the absolute and time-divided need of the water is different.

The assessment ratio A for classification of soil humidity regime into types according to the agronomic classification for the vegetation period can be calculated in Slovakia according to the relationship [27]:

$$A = \frac{1}{n} \sum\nolimits_{i=1}^{n} \frac{\Theta_i - \Theta_w}{\Theta_{FC} - \Theta_w} \qquad (2)$$

where Θ_i the average moisture content of the active root zone of the i-th day of the balance sheet for period [$m^3\ m^{-3}$], Θ_w wilting point of the active root zone [$m^3\ m^{-3}$], Θ_{FC} field water capacity of the active root zone [$m^3\ m^{-3}$].

To evaluate the type of the groundwater regime, the ratio in Table 4 is used [28].

The calculation and evaluation are seemingly simple. However, the problem is that current soil moisture is measured only on a few research grounds. We do not know such a simple relationship to count for specific locations in Slovakia. Therefore, there are projects focused on the spatial modelling of soil moisture, soil water availability or water storage capacity of agricultural soils within the catchment [29, 30].

The calculation comes from the time when the soil moisture values were solved on the soil sample. There was no distinction between soil layering and different moisture ratios at different depths of soil. The water is naturally moved by gravity in

Table 4 Types of moisture regime according to agronomic classification of soil moisture regime [28]

Part of soil water content	Type of soil moisture regime in the balance period
<0.10	Completely dry, lack of soil water for plants
0.11–0.20	Very dry
0.21–0.30	Substantially dry
0.31–0.40	Dry
0.41–0.50	Alternately dry
0.51–060	Alternately wet, optimum water content for plants
0.61–0.75	Wet
0.76–0.90	Very wet
0.91–1.00	Wet, surplus of soil water
>1.00	Waterlogged

the soil profile, and we know a lot of the works, reporting on the redistribution in the soil profile after irrigation or collision (Fig. 7).

2.1 Drought Monitoring

The drought and soil water content calculation and evaluation are often simple. In practice, however, it looks different. Problem is data measurement for larger regions. The Faculty of Horticulture and Landscape Engineering has the group of automatic soil moisture measurement stations available [2]. Soil moisture is continuously measured at depths of 10, 20, 30, 40, 50, 75, 100, 150 and 200 cm. Changes in soil moisture are usually not the same at all measured depths. Using measurement devices, we recorded drought in previous years. The significant drought was in 2014 and 2015. Soil moisture fell to a wilting point in both years.

From the records for the Mužla village, it is possible to evaluate the actual humidity and its deficit and the likely development in the coming days without precipitation or after the expected rain. In Figs. 8 and 9, it is possible to see the fundamental difference in the soil moisture development at individual depths (10, 40 and 50 cm) of the soil profile in 2014 and 2015. In 2014, the soil had been with plenty of winter moisture and gradually was replenished with new rainfalls. The 2015 growing season began with a lack of moisture and period without rains; this condition deteriorated critically at all depths.

2.2 Drought Evaluation

More interesting is the evaluation of the changes of soil moisture after a long drought (Fig. 10) and subsequent precipitation at the end of May 2015 and June 2015. Even

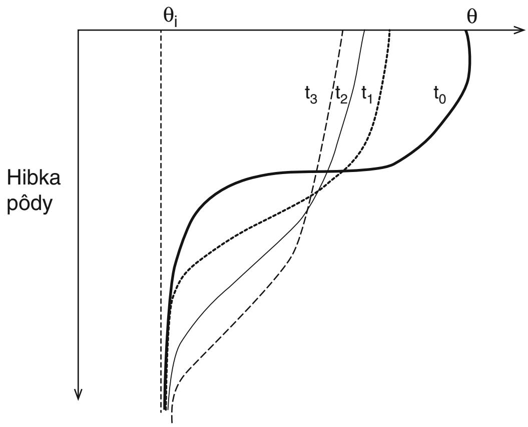


Fig. 7 Change of soil moisture after the redistribution of applied irrigation water

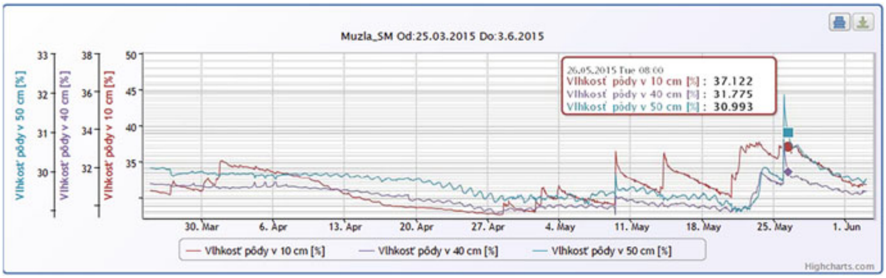


Fig. 8 Graph of soil moisture in March and June 2015

Fig. 9 Graph of soil moisture in March and June 2014

with significant water infiltration after precipitation is moisture descending on the value after the long dry period very quickly.

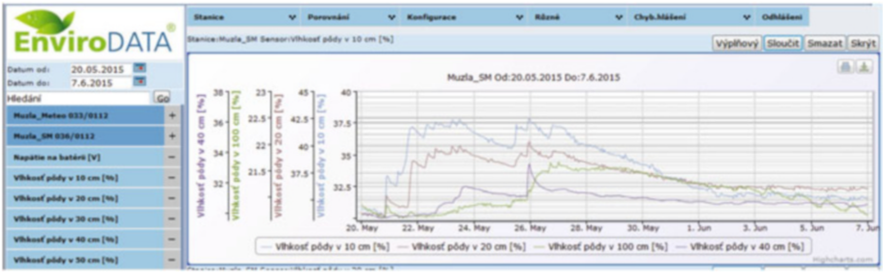


Fig. 10 Evaluation of soil moisture progress after the long-term drought in 2015

For Hurbanovo station Palmer index was calculated [31] for the entire measurement period, and the results are in the following Fig. 11. Palmer index in the last two decades was moved into the negative values and often below −4, which are already extremely dry years. Therefore, the use of long-term series for evaluation is important because the comparison data for the period since 2000 is then drought rated moderately [27]. These values are related to changes in temperature in the northern hemisphere (see Fig. 12).

In the recent times, SHMU introduced freely available output from modelling drought—integrated system for drought monitoring ("Monitor sucha"). This output is focused on meteorological and agricultural drought, with a view to their more frequent occurrence and that of the economic consequences for Slovakia.

3 Conclusion

Slovakia wants to achieve greater protection from drought in the landscape, also for the reason of the security by the self-sufficiency in agricultural production. A supply of crops will be critical with sufficient soil moisture. Current climate change and state of the irrigation structures in Slovakia show that this goal can not be achieved if we do not provide better soil and water management and we do not have enough sources of the information.

The measuring stations measure tens and hundreds of surface water parameters, but the soil water information network is not yet planned in Slovakia. Current weather developments and changes in cultivated crops, however, indicate the importance of this water source for the future.

A basic conceptual document for addressing drought and water scarcity issues will be the river basin plans, in particular, plans for subbasins where this issue is dealt with at the most detailed level.

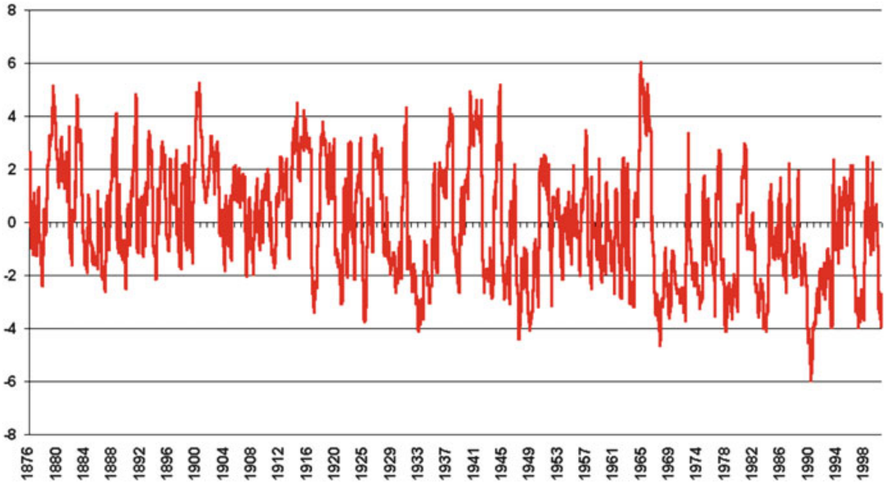


Fig. 11 Palmer index of monthly values for station Hurbanovo (1876–2000) [32]

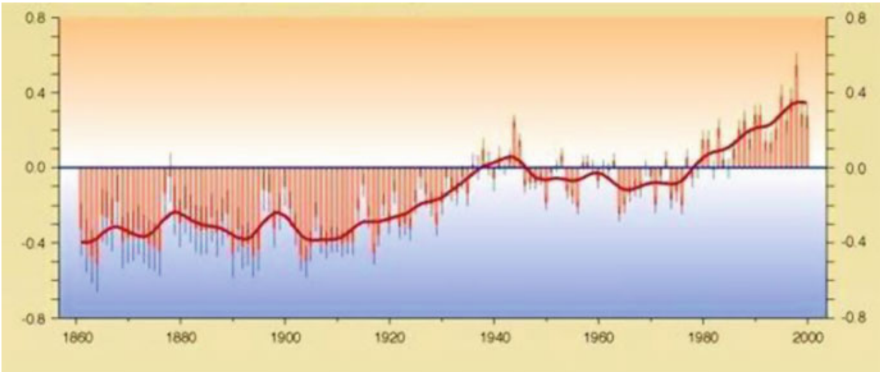


Fig. 12 Average annual temperatures in the period 1861–2004 in the northern hemisphere. The red line is the 5-year moving average for temperature [33]

It is not yet determined how the surplus water can be estimated in the landscape, and, conversely, we cannot estimate water consumption from other areas. It is not even determined what could be the maximum water consumption in the smallest basins or what maximum deficiency can be acceptable from the point of view of the water cycle in nature and its sustainability. The occurrence of drought leads to a fundamental influence on the outflow from the river basin and causes changes in the flow regime to be discontinuous, characterized by a reduction in flow often to zero.

4 Recommendations

To mitigate the impact of drought, which will occur more often in the future, it is necessary to re-examine the theoretical and practical approaches that are being used today. It should seek to respond to the basic challenges of protecting the country and its users from droughts in the future:

- Development of methods to forecast droughts using existing resources
- Ensuring quality drought monitoring and related phenomena (state of the agricultural land, water quality, state of aquatic ecosystems, state of forest stands)
- Determining the distribution of the precipitation (water resource creation) in a country that can be described as sustainable
- Creating the methodology for quantifying the production and non-production functions of the landscape (including water resources) as a basis for optimizing measures
- Addressing the assessment of the excessive water resource creation in the small river basin and excessive water consumption in another neighbouring river basin—the relation between the upper and lower part of the basin
- The interaction between human economic activities and natural processes and possibilities of using this interaction in designing effective measures especially in the field of agricultural and forestry management
- Evaluating the effectiveness of the measures that influence the energy and water balance at a local, regional and supra-regional level under normal and extreme conditions
- Real reallocation of the precipitation in the soil and quantification of the contribution of groundwater to the creation of groundwater reserves and to increase its level

Prioritizing the above tasks and their mutual relations is important.

Acknowledgements This chapter was supported by the following grants and projects:

- APVV-16-0278: Use of hydromelioration structures for mitigation of the negative extreme hydrological phenomena effects and their impacts on the quality of water bodies in agricultural landscapes
- KEGA 028SPU-4/2017: Monitoring of elements of environment—practical course

References

1. Čimo J, Igaz D, Bárek V (2008) Hodnotenie sucha na základe agroklimatických a pôdnych faktorov. In: Rožnovský J, Litschmann T (eds) Bioklimatologické aspekty hodnocení procesů v krajině, Mikulov 9. 11.9.2008, ISBN 978-80-86690-55-1
2. Húska D, Jurík Ľ, Tátošová L, Šinka K, Jakabovičová J (2017) Cultural landscape, floods and remote sensing. J Ecol Eng 18(3):31–36

3. Jurík Ľ, Húska D, Halászová K, Bandlerová A (2015) Small water reservoirs—sources of water or problems? J Ecol Eng 16(4):22–28
4. Fekete V (2013) Výhľadová VHB množstva a kvality povrchovej vody k časovému horizontu 2021 vrátane prehodnotenia výhľadových vodných nádrží. VÚVH Bratislava
5. SHMU (2018) http://www.shmu.sk/sk/?page=1784&id=
6. SHMU (2018) http://www.shmu.sk/sk/?page=1604
7. https://www.news.iastate.edu/news/2018/01/03/planttattoosensors
8. Hettiarachchi H, Reza A (eds) (2016) Safe use of wastewater in agriculture: good practice examples cUNU-FLORES
9. Wilhite DA (1991) Drought planning: a process for state government. Water Resour Bull 27 (1):29–38
10. Freire-González J, Decker C, Hall JW (2017) The economic impacts of droughts: a framework for analysis. Ecol Econ 132:196–204. https://doi.org/10.1016
11. WMO (2006) Drought monitoring and early warning: concepts, progress and future challenges. http://www.wmo.int/pages/publications/showcase/documents/1006_E.pdf
12. Ding Y, Hayes MJ, Widhalm M (2010) Measuring economic impacts of drought: a review and discussion. Papers in Natural Resources 196:1–23
13. Novák V (2012) Evapotranspiration in the soil–plant–atmosphere system. Springer Science + Business Media, Dordrecht. 253 p
14. Van Loon AF (2015) Hydrological drought explained. WIREs Water 2:359–392. https://doi.org/10.1002/wat2.1085
15. Wanders N, Wada Y (2015) Human and climate impacts on the 21st-century hydrological drought. J Hydrol 526:208–220
16. Ondráček P (2014) Vyhodnocení trendů k vysychavosti vodních toků: Projekt TA ČR BIOSUCHO a databáze SALAMANDER—Hydrogeologické hodnocení povodí. Zpráva. Brno, 2014, 16 s
17. Meyer WS, Kondrlová E, Koerber GR (2015) Evaporation of perennial semi-arid woodland in southeastern Australia is adapted for irregular but common dry periods. Hydrol Process 29:3714–3726
18. Van Loon AF, Stahl K, Di Baldassarre G, Clark J, Rangecroft S, Wanders N, Gleeson T, Van Dijk AIJM, Tallaksen LM, Hannaford J, Uijlenhoet R, Teuling AJ, Hannah DM, Sheffield J, Svoboda M, Verbeiren B, Wagener T, Van Lanen HAJ (2016) Drought in a human-modified world: reframing drought definitions, understanding, and analysis approaches. Hydrol Earth Syst Sci 20:3631–3650. https://www.hydrol-earth-syst-sci.net/20/3631/2016/hess-20-3631-2016.pdf
19. Newman JE, Oliver JE (2005) Palmer index/Palmer drought severity index. In: Oliver JE (ed) Encyclopedia of world climatology. Springer, Dordrecht, The Netherlands, pp 571–573
20. Urquijo J, Pereira D, Dias S, De Stefano L (2016) A methodology to assess drought management as applied to six European case studies. Int J Water Resour Dev. https://doi.org/10.1080/07900627.2016.1174106
21. Kellner O, Niyogi D (2014) Forages and Pastures symposium: assessing drought vulnerability of agricultural production systems in context of the 2012 drought. J Anim Sci 92(7):2811–2822. https://doi.org/10.2527/jas.2013-7496. https://www.animalsciencepublications.org/publications/jas/articles/92/7/2811
22. National Drought Mitigation Center, University of Nebraska-Lincoln, USA. http://drought.unl.edu/DroughtBasics/TypesofDrought.aspx
23. Lapin M, Melo M (2004) Methods of climate change scenarios projection in Slovakia and selected results. J Hydrol Hydromechan 52(4):224–238
24. Weiskel PK, Vogel RM, Steeves PA, Desimone LA, Zarriello PJ, Ries KG (2007) Water-use regimes: characterizing direct human interaction with hydrologic systems. Water Resour Res 43. https://doi.org/10.1029/2006WR005062
25. Novák V (1995) Evapotranspiration and its estimation. Veda, Bratislava. 260 p

26. Bárek V, Halaj P, Igaz D (2009) The influence of climate change on water demands for irrigation of special plants and vegetables in Slovakia. In: Bioclimatology and natural hazards. Springer, Dordrecht, pp 271–282
27. Benetin J, Šoltész A (1988) Hydrologické charakteristiky vodného režimu pôd a ich výpočet. In: Agromelio. ČSVTS, Nitra, pp 12–20
28. Gomboš MJ, Ivančo R, Mati D, Pavelková D (1999) Výsledky meraní pôdnej vlhkosti v ťažkých pôdach na Východoslovenskej nížine. In: III. Zborník z konferencie "Vplyv antropogénnej činnosti na vodný režim nížinného územia". ÚH SAV Bratislava, Michalovce, s. 258–261
29. Tárník A, Tárníková M (2017) Analysis of the development of available soil water storage in the Nitra river catchment. IOP Conf Ser Mater Sci Eng 245:9
30. Orfánus T (2005) Spatial Assessment of Soil Drought Indicators at Regional Scale: Hydrolimits andSoil Water Storage Capacity in Záhorská nížina Lowland. J Hydrol Hydromechan 53 (3):164–176
31. Tate EL, Gustard A (2000) Drought definition: a hydrological perspective. In: Vogt JV, Somma F (eds) Drought and drought mitigation in Europe. Kluwer Academic Publishers, Dordrecht, The Netherlands, pp 23–48
32. Lapin M, Faško P, Kveták Š (1988) Metodický predpis 3-09-1/1. Klimatické normály. SHMÚ, Bratislava, 25 pp
33. European Environmental Agency (2012) Climate change, impacts and vulnerability in Europe 2012. An Indicator Based Report. EEA Report No. 12/2012. EEA, Copenhagen, 300 pp

Major Droughts in Slovakia in the Twenty-First Century

M. Fendeková

Contents

Abstract It is supposed that because of the climate change, the extreme hydrological events are going to be more pronounced and more frequent in the future also on the territory of Slovakia. The occurrence, duration and severity of hydrological droughts in Slovakia were studied during 3 years of the twenty-first century – 2003, 2012 and 2015. Mainly the 2003 and 2015 belong to the warmest years of the twenty-first century with the occurrence of hydrological drought on the Pan-European scale. Data on average daily discharges at twelve discharge gauging stations across Slovakia were used. The data covered the period 1981–2016. Hydrological drought in discharges was evaluated using the sequent-peak algorithm (SPA) method; the fixed threshold value of the 80th percentile was applied. The threshold value was estimated for the reference period of 1981–2010. The theoretical Weibull and GEV frequency distributions were used for drought parameters calculation, their evaluation and comparison of the 2003, 2012 and 2015 droughts. Data calculated for the evaluated years were compared with the reference period of 1981–2010. Spatial distribution of hydrological drought occurrence was discussed in connection to meteorological drought occurrence analysis.

M. Fendeková (✉)
Department of Hydrogeology, Faculty of Natural Sciences, Comenius University in Bratislava, Bratislava, Slovakia
e-mail: miriam.fendekova@uniba.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 125–144,
DOI 10.1007/698_2018_272,
Published online: 13 May 2018

Keywords Average daily discharge, Deficit volume, Drought duration, Drought intensity, Hydrological drought, Minimum value

1 Introduction

Drought is a natural phenomenon, which is defined as the sustained and extensive occurrence of below-average water availability, caused by climate variability [1]. The drought has hit Europe hard over the last decades [2]. The increased attention paid to drought could be observed since the 1990s of the last century when the extreme meteorological drought occurrence and its consequences in the early 1980s and early 1990s attracted the attention of the scientific community, both the climatologic and the hydrological ones. The attention paid to drought further increased in the first decade of the twenty-first century after the Pan-European drought in 2003 which hit almost the whole Europe.

The interest in drought is also reflected in the number of publications which could be found in scientific databases. The keyword "drought" inserted into the search engine of the Scopus database (https://www.scopus.com/results) identified 244,559 documents, within them 62,326 scientific papers with the word drought in the title. There were 1,637 papers already published in 2017, belonging to various scientific disciplines. The highest number of publications belonged to hydrology; water economics; water resources; landscape ecology; geochemistry; atmospheric, soil, agricultural and forestry sciences; and also eco-toxicology, vegetable and zoological physiology, molecular genetics or anthropology.

It is generally supposed that because of the climate change, the extreme hydrological events, including drought, are going to be more pronounced and more frequent in the future also on the territory of Slovakia. Therefore, the Slovak hydrologists led by the author participated actively in hydrological drought research within the frame of the VIII International Hydrological Programme of UNESCO, FP5 and FP6 EU projects and the projects of the Slovak Agency for Research and Development (APVV). The three most intense droughts of the twenty-first century, 2003, 2011–2012 and 2015 droughts, which hit Slovakia were studied. These years belong to the warmest years of the twenty-first century with the occurrence of meteorological and hydrological droughts on the Pan-European scale. Part of the research results is presented in this chapter.

2 Data and Methods

Data on daily discharges at 12 discharge gauging profiles were used as the input data. The time series of daily discharges of the period 1 January 1981–30 June 2016 was used. The discharge data were provided by the Slovak Hydrometeorological Institute within the solution of the APVV-0089-12 project: Prognosis of the hydrological drought development in Slovakia (principal investigator Miriam Fendeková). The necessary information on discharge gauging profiles is in Table 1. The item river km in Table 1 refers to the distance of the gauging profile from the river mouth, which has the value of the river km equal to zero. The location of the evaluated river basins is in Fig. 1.

The river km values (Table 1) for the Váh and Ipeľ streams indicate that only the upper parts of the river basin are represented by the discharges in the respective gauging profile. The reason for selection of these two gauging profiles was as follows. The Váh River is the stream at which a number of water works are operated; therefore, the discharges in the downstream gauging profiles do not represent the natural conditions. There is one water reservoir also over the Liptovský Mikuláš gauging profile (Čierny Váh water reservoir at the Čierny Váh tributary), but the area of the water reservoir is not very large in comparison with the downstream reservoirs, and there are other essential tributaries mouthing into the Váh River downstream the Čierny Váh tributary. Selection of the Holiša gauging profile at the Ipeľ River was conditioned by the fact that there are tributaries from the Hungarian side downstream the Holiša profile and Ipeľ River starts to create the state boundary along its whole course up to the river mouth to the Danube River.

Data were processed statistically using the Statgraphics Centurion 17 software package [5]. The statistical processing included calculation of necessary statistical parameters, analysis of the seasonal component and analysis of the interrelationships among the discharge time series. The seasonal component was assessed using the seasonality index. A seasonal index represents the expected percentage of "normal value" in a given month. The normal value is defined by the monthly average for the whole surrounding year.

Table 1 Basic data on discharge gauging profiles [3]

Database no.	Gauging station	River	River km	Gauge zero [m a.s.l.]	Area (km^2)
5030	Šaštín-Stráže	Myjava	15.18	164.25	644.89
5550	Liptovský Mikuláš	Váh (upper)	346.60	567.68	1107.21
5840	Trstená	Oravica	3.55	585.49	129.95
6200	Kysucké Nové Mesto	Kysuca	8.00	346.09	955.09
6730	Nitrianska Streda	Nitra	91.10	158.27	2093.71
6820	Vieska nad Žitavou	Žitava	34.20	154.27	295.46
7290	Brehy	Hron	93.90	194.27	3821.38
7400	Holiša	Ipeľ (upper)	157.20	172.40	685.67
7900	Vlkyňa	Rimava	1.60	150.77	1377.41
8320	Chmelnica	Poprad	60.10	507.41	1262.41
8870	Košické Olšany	Torysa	13.00	185.70	1298.30
9500	Hanušovce nad Topľou	Topľa	47.50	160.40	1050.05

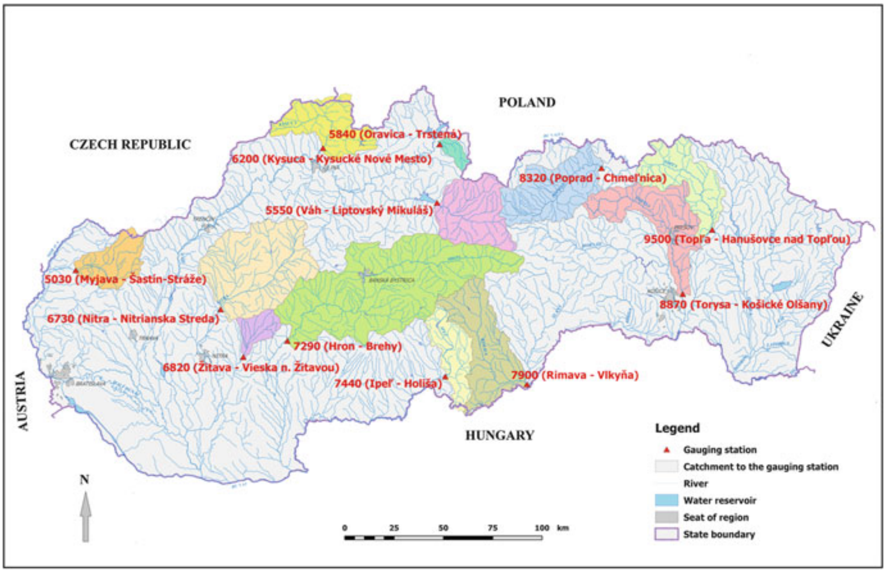


Fig. 1 Location of the evaluated river basins within Slovakia (Adapted according to [4])

The interrelationship among the time series of discharges was assessed using the Spearman rank correlation which is suitable also for data deviating from the normal frequency distribution, as expected for the discharge time series values.

After that, the drought parameters were estimated using the lfstat program (version 0.9.2) [6, 7] developed at the Institute of Applied Statistics and Computing of BOKU Vienna. The hydrological drought was evaluated using the sequent-peak algorithm (SPA) method with the fixed threshold value of the 80th percentile (Q_{80}) applied [1]. The calculation of Q_{80} was based on the time series of the reference period 1981–2010. Identification of low flow periods within the complete time series (1981–2016) enabled to select the drought period with the most massive volume for each of the years 2003, 2012 and 2015. The drought parameters consisted in (1) the annual minimum discharge AM7 ($m^3\ s^{-1}$) obtained by 7-day moving average filter, (2) maximum drought duration D (days) obtained as a number of days between the drought onset and termination, (3) maximum deficit volume V (m^3) calculated as sum of differences between the real discharge (below the threshold value) and discharge required to sustain the threshold and (4) drought intensity I ($m^3\ day^{-1}$) calculated as the ratio of the deficit volume and duration. The parameters were further processed by calculation of the return periods for each of the drought parameters [7]. The results were compared with the same parameters calculated for the reference period 1981–2010.

The three-parametric Weibull distribution was used to calculate the return period of the annual minimum values, and the generalized extreme value (GEV) distribution was used to calculate the return periods of maximum drought duration, maximum deficit volume and drought intensity. The timing of drought and its seasonality were also studied.

The Weibull cumulative distribution function can be expressed by the formula [8]:

$$F(x) = 1 - e^{-\left(\frac{x-\gamma}{\beta}\right)^{\alpha}} \tag{1}$$

where $x > 0$ and $\alpha, \beta > 0$, α location parameter, β scale parameter, γ form parameter.

The generalized extreme value (GEV) distribution, which was used for return period calculation of the maximum values (drought duration, deficit volume and intensity), can be expressed by the formula [8]:

$$F(x) = e^{-\left[1-\frac{\kappa(x-\xi)}{\alpha}\right]^{1/\kappa}} \tag{2}$$

where $\kappa \neq 0$ and ξ location parameter, α scale parameter, κ form parameter.

The conformity of the empirical distribution to the theoretical one was assessed using the L-moments method [9].

Method of clustering (Ward's method, squared Euclidean distance) was used for assessment of interrelationships among the evaluated drought parameters.

3 Results

3.1 *Primary Assessment of Discharge Time Series*

Calculation of the basic statistical parameters included the values of the central tendency, among them the arithmetic mean, median, minimum and maximum values. Parameters of variability were represented by the standard deviation and the coefficient of variation. Of particular interest here are the standardized skewness and standardized kurtosis, which can be used to determine whether the sample comes from a normal distribution. Values of these statistics outside the range of −2 to +2 indicate a significant departure from normality. Totally 12,965 complete cases were used in the calculations. The results of the discharge time series statistical evaluation are in Table 2.

The statistical evaluation showed that the average discharge values range between 2.267 $m^3 s^{-1}$ for Oravica River at Trstená gauging station and 42.007 $m^3 s^{-1}$ for Hron River at Brehy gauging station. The value of median was for all streams lower than the value of the arithmetic mean, which points to the departure of the time series data from the normal frequency distribution. The deviation was also confirmed by values of the standardized skewness and kurtosis. The extremely high positive values of the standardized skewness out of the range from −2 to 2 confirm the prevalence of the low values in all processed time series. The high values of the standardized kurtosis point to frequency distribution steeper than the normal one. The values of the coefficient of variation, as a standardized measure of the data

Table 2 Results of statistical processing of the daily discharge data ($m^3 s^{-1}$)

	Myjava	Váh (upper)	Oravica	Kysuca	Nitra	Žitava	Hron	Ipeľ (upper)	Rimava	Poprad	Torysa	Topľa
Count	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965	12,965
Average	2.656	19.245	2.267	15.716	13.694	1.364	42.007	2.494	5.797	14.858	7.476	7.394
Median	1.741	14.060	1.750	7.747	9.020	0.825	27.390	1.305	3.257	10.470	4.486	4.414
St. deviation	3.543	15.189	1.794	24.098	14.819	1.759	44.647	4.082	8.450	16.385	11.476	11.043
C. of variation	133%	79%	79%	153%	108%	129%	106%	164%	146%	110%	154%	149%
Minimum	0.208	4.200	0.002	0.989	2.121	0.060	7.870	0.037	0.251	2.240	0.891	0.787
Maximum	72.5	259.9	67.7	488.1	263.7	50.9	753.4	79.7	159.9	447.5	292.4	219.5
Stnd. skewness	332.3	133.9	297.0	265.5	244.6	346.1	186.1	282.9	281.5	325.9	442.8	340.7
Stnd. kurtosis	1898.4	377.1	3739.7	1329.9	1128.0	2847.1	627.7	1383.2	1380.1	2214.6	3457.3	1988.0

variability, were also high. The lowest coefficient of variation with the value of 79% has Váh and Oravica River discharges; in all other cases, the values of the coefficient were higher than 100%, reaching from 106% up to 164%.

The evaluation of the time series seasonality showed the different development of discharges during the hydrological year (1 November to 31 October next year) which is still used in Slovakia for hydrological data seasonality evaluation. Three types of discharge seasonality can be distinguished among the basins (Fig. 2).

The first type represented by the Myjava, Kysuca, Nitra, Žitava, upper Ipeľ and Topľa Rivers can be characterized by the maximum discharges in March. The river basins have the rain-snow combined runoff regime (for explanation see the chapter titled "key facts about water resources in Slovakia", in volume I of this book). The typical feature is the steep increase of discharges since January to March and the occurrence of the second but much smaller maxima in July. The second type, represented by the Oravica, Rimava, Hron and Torysa River discharges, has the maxima in April. It can be seen in Fig. 2 that also the March maxima are quite high except the Oravica discharges. On the other hand, the decrease of Oravica discharges after the April's peak is the smoothest one among all evaluated basins; the difference between the April and the May to July discharges is not too significant. The third type is represented by the upper Váh, and Poprad River discharges with the maxima shifted to May which is typical for temporary snow regime runoff type (for explanation see the chapter titled "key facts about water resources in Slovakia", in volume I of this book).

What the minima is concerned, the minimum values are dispersed throughout the broad time span. The autumn minima (September to November) prevail in the majority of the river basins, represented by the Kysuca, Nitra, Hron, upper Ipeľ, Rimava, Torysa and Topľa Rivers. The winter minima (January to February) occur in

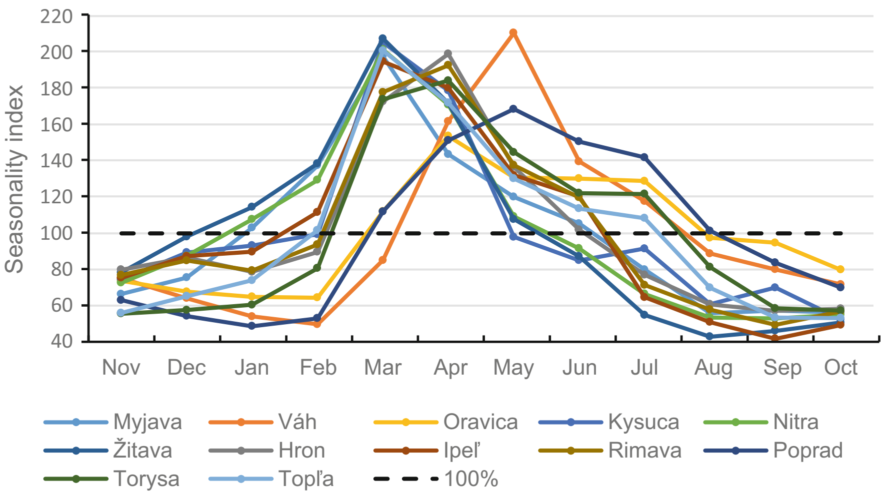


Fig. 2 Values of the seasonality index for evaluated river basins

typically high river basins, represented by the upper Váh, Oravica and Poprad Rivers, and the summer minima (August) are typical for Myjava and Žitava Rivers.

The interrelations among the discharge time series were assessed using the Spearman rank correlation, which is usable also in the case of data significantly departing from the normal frequency distribution (see Table 3). Values of the correlation coefficients are put in the first-row corresponding to each river; the *P*-values are given in the second row. *P*-values lower than 0.05 indicate the statistically significant interrelationship between two variables.

All relationships between pairs of variables are statistically significant as all *P*-values are lower than 0.05. The highest correlation coefficient of 0.928 was obtained for the relation of the Ipeľ and Rimava River discharges. These are two neighbouring basins located in the Southern Slovakia (Fig. 1) with the similar geological, geomorphological and climatic conditions. Another high correlation coefficient with the value of 0.899 was obtained for the discharge relationship of Torysa and Topľa Rivers, the two neighbouring basins located in the Eastern Slovakia (Fig. 1), also with very similar geological, geomorphological and climatic conditions. The lowest values of correlation coefficients were obtained for Oravica River; however, also there were some quite strong correlations, e.g. with the Poprad, Torysa and Topľa River discharges.

3.2 Hydrological Drought Assessment Results

The drought periods with the most significant deficit volume were selected in each of the evaluated years using the fixed threshold value of the reference period. The estimated values of the Q_{80} for each of the evaluated river basin are in Table 4.

Four examples were selected to illustrate the different drought developments in various parts of Slovakia in evaluated years. The Myjava River basin is located in Western Slovakia (see Fig. 1), the Kysuca River in Northwestern Slovakia, the Žitava River basin in the Southern Slovakia and the Torysa River basin in Eastern Slovakia. Time series of discharges separately for each of three evaluated years are in Fig. 3 for the Myjava River, in Fig. 4 for the Kysuca River, in Fig. 5 for the Žitava River and in Fig. 6 for the Torysa River.

Each figure is divided into parts *a*, *b*, *c* and *d*. The logarithmic values of discharges in the reference period 1981–2010 are in the upper (a) part of each figure. The logarithmic transformation enabled to stress the minimum values, which are of interest by the drought assessment. The threshold value, calculated as Q_{80} for the entire reference period, is drawn by the full red line. Each value below the threshold represents the discharge under drought. Discharges of three evaluated years are drawn separately in Figs. 3b, 4b, 5b, and 6b (2015); 3c, 4c, 5c and 6c (2012); and 3d, 4d, 5d and 6d (2003). In accordance with [10], the grey polygon in *b*, *c* and *d* parts of each figure represents the maximum annual low flow event below the threshold. The area of the polygon corresponds to the deficit volume, and its length (between the onset and termination day) is the event duration. Dashed lines represent

Table 3 Spearman rank correlations among daily discharges

	Myjava	Váh (upper)	Oravica	Kysuca	Nitra	Žitava	Hron	Ipeľ (upper)	Rimava	Poprad	Torysa	Topľa
Myjava												
U. Váh	0.315											
	0.000											
Oravica	0.309	0.696										
	0.000	0.000										
Kysuca	0.549	0.487	0.583									
	0.000	0.000	0.000									
Nitra	0.739	0.414	0.399	0.753								
	0.000	0.000	0.000	0.000								
Žitava	0.669	0.291	0.256	0.662	0.879							
	0.000	0.000	0.000	0.000	0.000							
Hron	0.640	0.686	0.527	0.729	0.845	0.769						
	0.000	0.000	0.000	0.000	0.000	0.000						
U. Ipeľ	0.633	0.455	0.342	0.562	0.741	0.746	0.827					
	0.000	0.000	0.000	0.000	0.000	0.000	0.000					
Rimava	0.621	0.532	0.390	0.576	0.737	0.718	0.864	0.928				
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000				
Poprad	0.339	0.879	0.753	0.536	0.415	0.287	0.651	0.467	0.535			
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000			
Torysa	0.527	0.663	0.627	0.603	0.619	0.521	0.741	0.679	0.726	0.789		
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		
Topľa	0.522	0.599	0.608	0.672	0.657	0.553	0.723	0.628	0.659	0.717	0.899	
	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

Table 4 The Q_{80} values ($m^3 s^{-1}$) used as threshold limits for drought period delineation

Basin	Myjava	Váh	Oravica	Kysuca	Nitra	Žitava	Hron	Ipeľ	Rimava	Poprad	Torysa	Topľa
Q_{80}	0.90	8.69	1.11	4.15	5.61	0.47	15.30	0.638	1.74	5.92	2.48	2.45

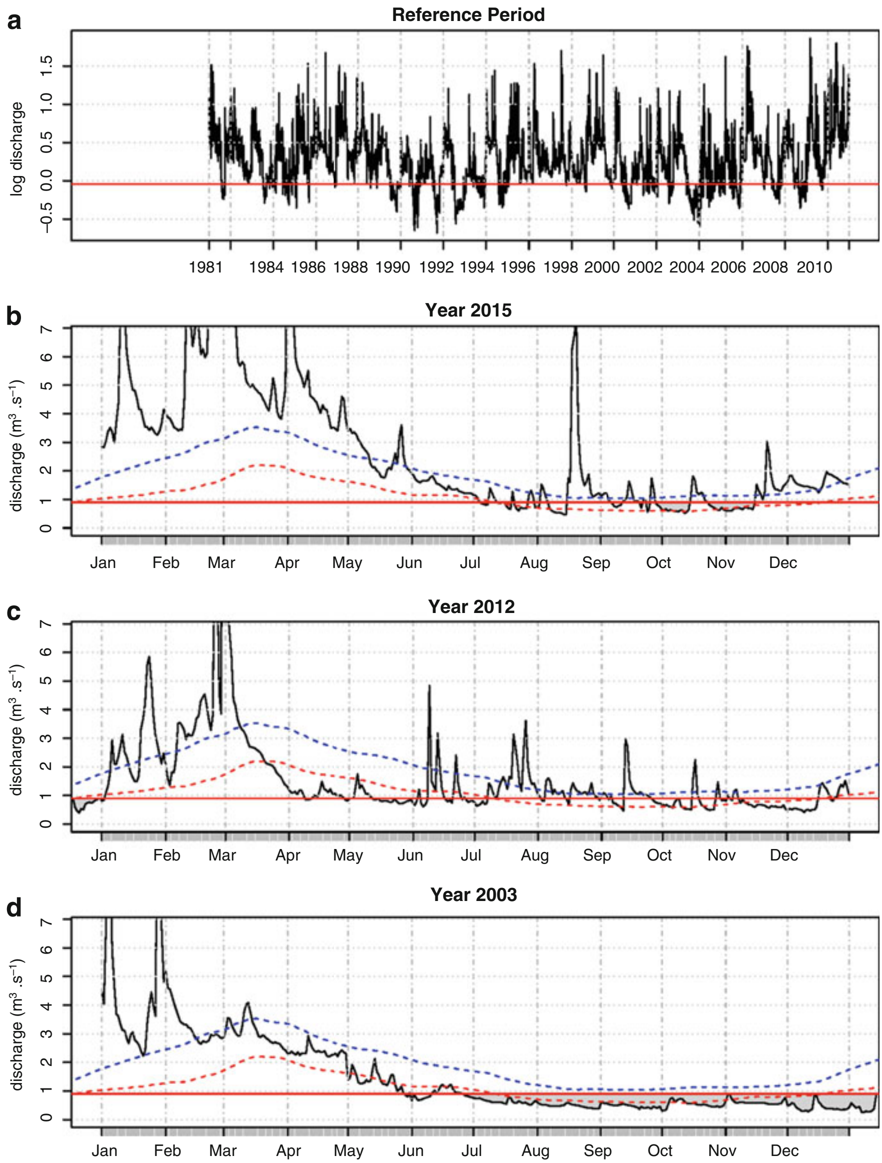


Fig. 3 Delineation of the drought periods with the most significant deficit volume for the Myjava River discharges: (**a**) discharge values in the reference period, (**b**) 2015 drought delineation, (**c**) 2012 drought delineation, (**d**) 2003 drought delineation

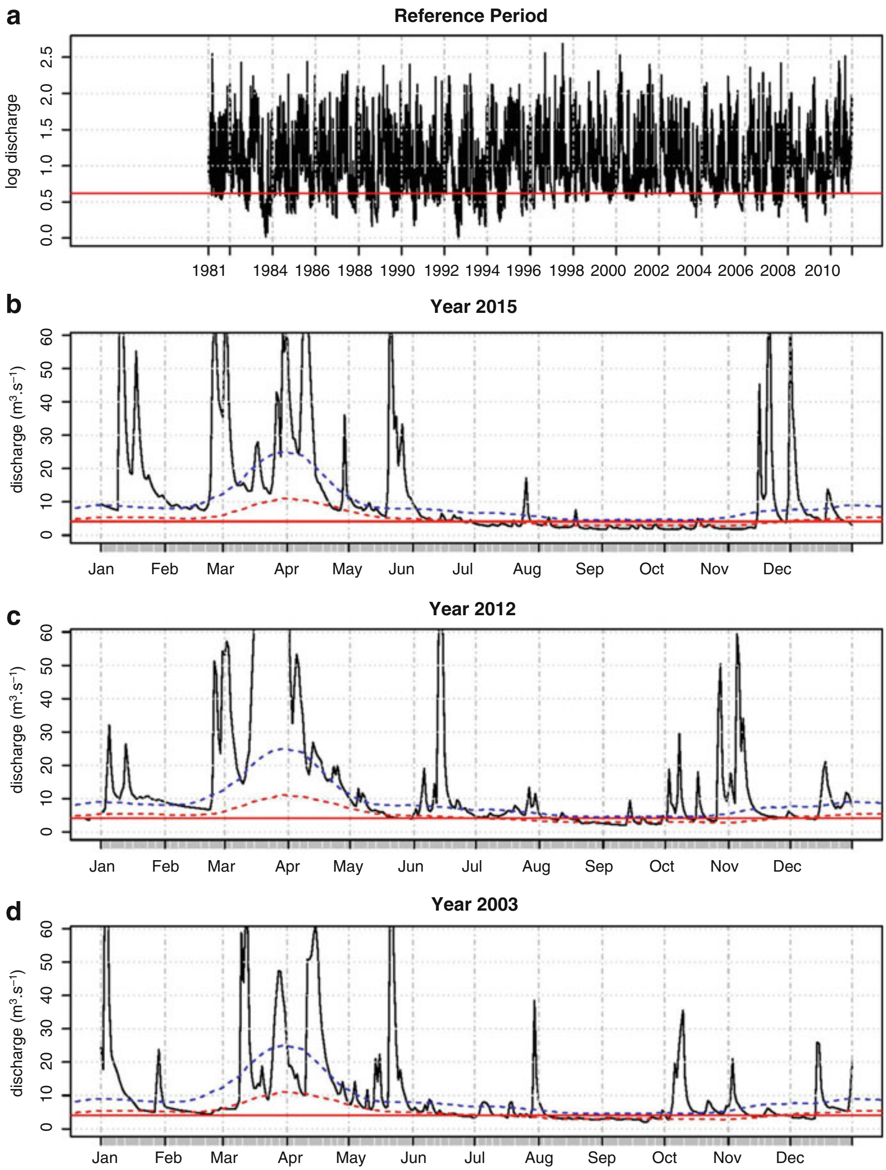


Fig. 4 Delineation of the drought periods with the most significant deficit volume for the Kysuca River discharges: (**a**) discharge values in the reference period, (**b**) 2015 drought delineation, (**c**) 2012 drought delineation, (**d**) 2003 drought delineation

varying seasonal thresholds. The blue (upper) one is the Q_{50} representing the long-term average; the red (lower) one is the Q_{80}, representing the benchmark dry seasonal conditions. Both correspond to smoothed (30-day moving average

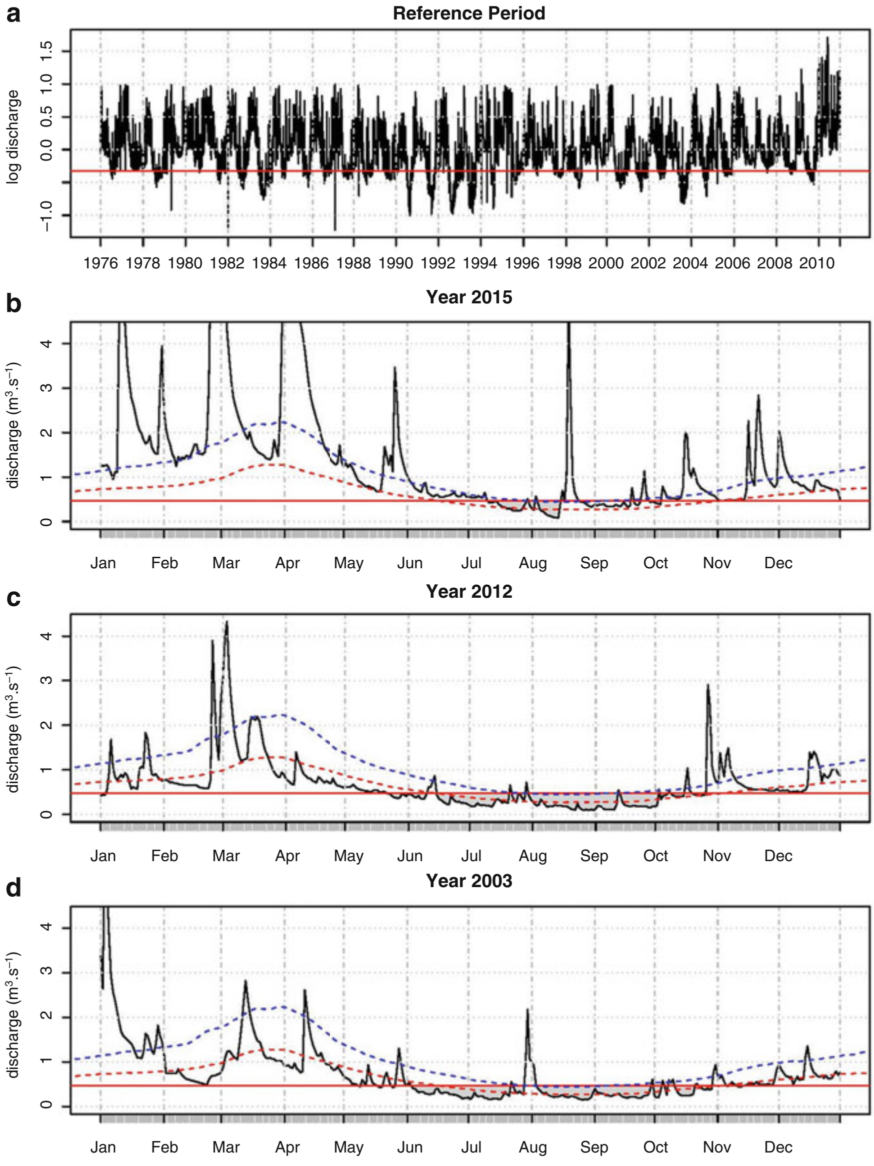


Fig. 5 Delineation of the drought periods with the most significant deficit volume for the Žitava River discharges: (**a**) discharge values in the reference period, (**b**) 2015 drought delineation, (**c**) 2012 drought delineation, (**d**) 2003 drought delineation

procedure) daily flow quantiles with an exceedance probability of 0.5 (the blue one) and 0.8 (the red one).

The results for the Myjava River discharges show that the longest low flow period occurred in 2003 (see Fig. 3d). The average discharges of the year 2003 were far

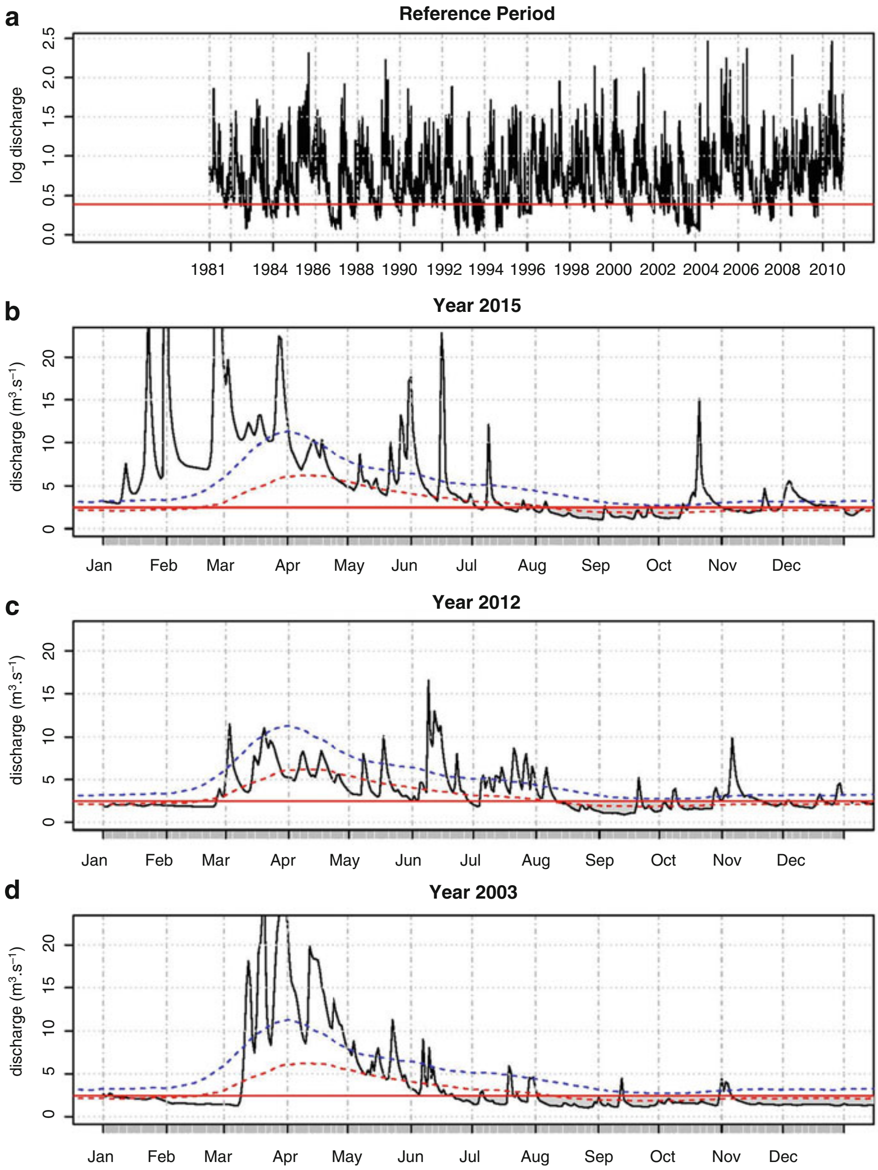


Fig. 6 Delineation of the drought periods with the most significant deficit volume for the Torysa River discharges: (**a**) discharge values in the reference period, (**b**) 2015 drought delineation, (**c**) 2012 drought delineation, (**d**) 2003 drought delineation

below the long-term average conditions except for the January–February period. Discharges of the period April–May 2012 were also low (see Fig. 3c), but the increase in discharges during the June–July period prevented the drought occurrence. The years 2012 and 2015 were almost without longer drought periods.

The results for the Kysuca River discharges (Northwestern Slovakia) differed significantly from those in the Myjava River basin. Almost no drought occurred in 2003 and 2012 (Fig. 4c, d), but in the year 2015, low flows during the June to November period caused long-term drought period occurrence (see Fig. 4b).

Another different picture of the drought period occurrence in Southern Slovakia illustrates the situation in the Žitava River basin (see Fig. 5).

The most extended drought period occurred in the year 2003 because of low discharges during the June–November period and similarly in the year 2012. The shortest drought period occurred in the Žitava River basin in 2015.

The last example is represented by the eastern Slovakian Torysa River basin drought period occurrence (see Fig. 6).

The area of Eastern Slovakia was hit by drought in all three evaluated years. The most extended drought period occurred in 2003 continuing to the year 2004; the drought periods in 2012 and 2015 were comparably long with the comparable onset and termination dates.

Drought parameters for the periods with the most massive deficit volume were further analysed for each river basin and evaluated year. The theoretical Weibull and GEV were used to calculate return periods of drought characteristics. Data calculated for the evaluated years were compared with the 1981–2010 reference period.

The return periods calculated for the minimum discharge, drought duration, deficit volume and intensity values were analysed regionally and also locally for each of the basins. The results of the regional evaluation are given in Fig. 7. Boxes refer to upper quartile, median and lower quartile of the return period; dots represent the maximum range of outliers. According to [10], return period of about 2–10 years represents mild drought conditions, 10–50 years moderate drought conditions and more than 100 years extreme drought conditions.

Drought conditions according to the minimum discharge values and the drought intensity were mild in Slovakia in all evaluated years; the lowest values of the return period were calculated for the 2015 drought, and comparable values were reached for the 2003 and 2012 droughts. On the other hand, the 2003 drought was moderately strong according to drought duration; 2012 and 2015 droughts were mild. The same is valid for the deficit volume. Again, the 2003 drought was moderate; 2012 and 2015 droughts were mild.

However, there were outliers in all evaluated parameters in almost all evaluated years. The highest return period over 100 years was calculated for minimum discharge in the Torysa River basin during the 2012 drought, representing the extreme drought conditions. The return period over 60 years reached drought duration in the Hron River basin in 2003, and the return period over 50 years was estimated for the maximum deficit volume in the Kysuca River in 2015. The estimated return periods of evaluated drought parameters reached higher values for 2003 and 2012 than those estimated for the 2015 drought. These values were also higher than the values estimated for the reference period, especially in the Myjava, Žitava, Váh and Torysa River basins. Exceptional was the situation in the Kysuca River basin, where the highest return periods were calculated for all four drought parameters for the year 2015.

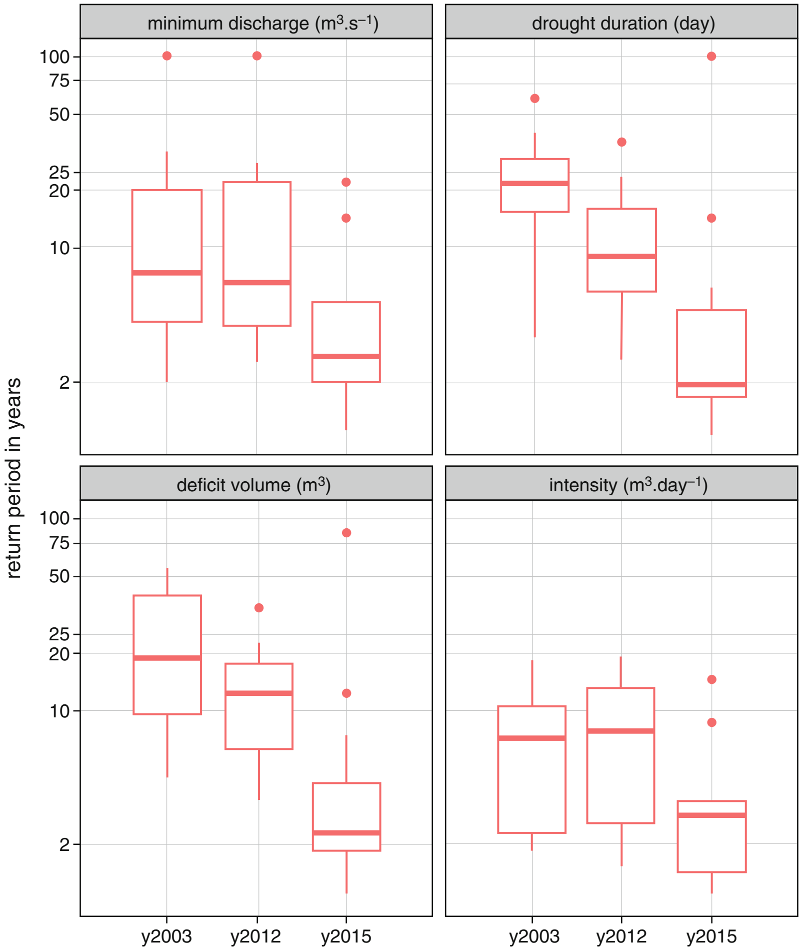


Fig. 7 Box plots of the drought parameters in all evaluated river basins in 2003, 2012 and 2015

3.2.1 Interrelations Among Drought Parameters in Evaluated River Basins

The cluster analysis was used to find interrelationships among the calculated drought parameters. Besides the other already mentioned parameters, the starting dates of the drought periods in respective years and in the reference period were also used in the cluster analysis. Clustering of the drought parameters showed that there is a close relationship between minimum values (AM7-2003, AM7-2012, AM7-2015) and drought intensities (I-2003, I-2012 and I-2015) in all evaluated years as shown in Fig. 8.

The pairwise relation was confirmed between the drought duration (D-2003, D-2012), drought starting dates (SD-2003, SD-2012) and deficit volumes

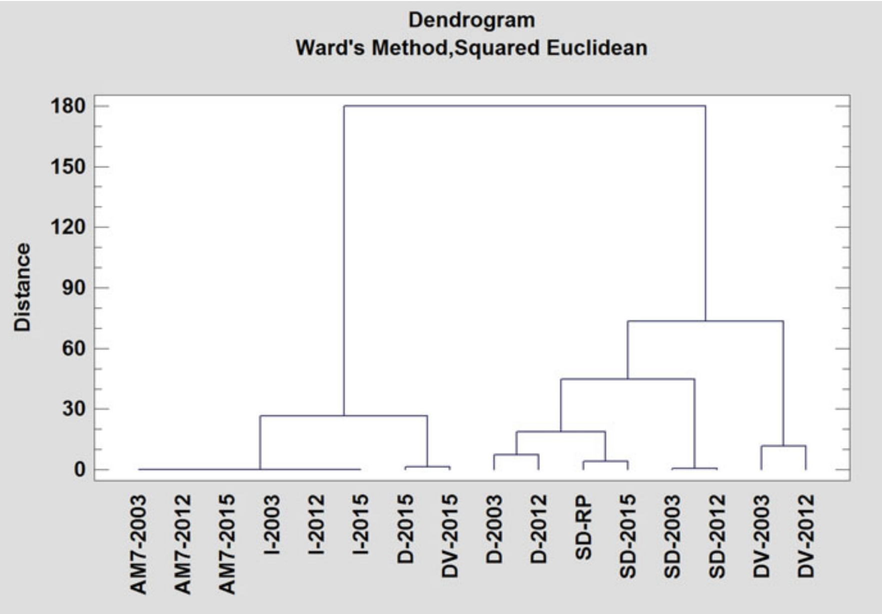


Fig. 8 Results of drought parameter clustering

(DV-2003, DV-2012) of the years 2003 and 2012. The relationship between the drought starting date in the reference period (SD-RP) and in 2015 drought (SD-2015) was also confirmed.

4 Discussion

The years 2003, 2012 and 2015 belong to the warmest years of the twenty-first century with the occurrence of meteorological and hydrological droughts on the Pan-European scale. The study of meteorological data showed that the initial climatic conditions over Europe were quite similar in all three dry years (2003, 2012 and 2015). There was a positive 500-hPa geopotential height anomaly in the upper-level atmospheric circulation over continental Europe, especially over the Central and Eastern Europe [11, 12]. As confirmed by WMO Report [13], the year 2015 was the second, the year 2012 the ninth and the year 2003 the tenth to twelfth warmest year within the observation period 1880–2016.

The evaluation of the meteorological drought on the Slovak territory [13] using the SPI and SPEI indexes showed that the manifestation of the meteorological drought was different in various parts of Slovakia. The influence of climatic conditions expressed by precipitation and potential evapotranspiration on drought parameters is notable but more pronounced since the year 2000. The more extreme values of the standardized precipitation and evapotranspiration index (SPEI) in comparison with the standardized precipitation index (SPI) were estimated for the ongoing period since the half of the 1990s of the last century. The increase of potential evapotranspiration due to the increasing air temperatures is the reason for such development. This was confirmed mainly in the Oravica, Poprad, Torysa and Topľa River basins.

Study of interrelationships between the meteorological and hydrological droughts in the Slovak territory [4] showed that there is a quite good correlation between the meteorological and hydrological drought occurrence in more than half of the evaluated river basins. The closest correlations were obtained for the Myjava, Váh, Oravica, Kysuca, Nitra, Hron, Ipeľ and Topľa basins, where the meteorological drought was followed by the hydrological one. However, the hydrological drought parameters did not follow the meteorological drought onset or intensity in Žitava, Rimava, Poprad and Torysa River basins. The hydrological drought intensity in the Žitava, Rimava and Poprad River basins in 2003 was the lowest among the evaluated years, despite the most pronounced low SPI values. The reason was in quite wet preceding years which created conditions for balancing the lack of precipitation in 2003. The intensity of hydrological drought was in better compliance with the SPEI index values in the case of the Žitava and Rimava River basins than with the SPI values.

It is worth to mention that a high variability in drought manifestation even within small distances was confirmed for the territory of Slovakia. This was shown by a detailed comparison of drought parameters done for two southern, Ipeľ and Rimava, and two eastern, Torysa and Topľa, Slovakian river basins [14]. The results showed that the Ipeľ River basin with the smallest basin area, lowest altitude and highest air temperature suffered from the 2012 drought which was in a good compliance with the meteorological drought occurrence expressed by the SPEI12 index calculated for the Boľkovce meteorological station. The situation in the adjacent Rimava River basin was different despite meteorological drought parameters very similar to those of the Ipeľ River basin. The most pronounced drought period occurred in the Rimava Basin in 2003, similarly to the eastern Slovakian basins of Torysa and Topľa. However, return periods of drought duration and deficit volume and also the deficit volume intensity estimated for the Rimava River discharges were much lower than those calculated for the Torysa and Topľa basins.

The possible reason for such development is the high variability in climatic, geomorphological and geological conditions of Slovakia, which have their influence on wetness preconditions in respective river basins.

5 Conclusions

Hydrological drought occurs quite frequently in Slovakia since the 1980s of the last century. Three drought events with the Pan-European character occurred in Slovakia already in the twenty-first century. The influence of climatic conditions expressed by precipitation and potential evapotranspiration on drought parameters is notable but more pronounced since the year 2000. The more extreme values of the standardized precipitation and evapotranspiration index (SPEI) in comparison with the standardized precipitation index (SPI) were estimated for the ongoing period since the half of the 1990s of the last century.

The evaluation of the 2003, 2012 and 2015 droughts showed that despite of generally similar weather conditions in all three evaluated years, the response of the twelve assessed river basins differed significantly. The research confirmed that the mild drought hit Slovakia according to the minimum discharge values and the drought intensity in all three evaluated years. The 2003 drought was moderately strong according to drought duration and deficit volume; 2012 and 2015 droughts were mild.

The assessment of interrelationships among evaluated drought parameters showed that the 2003 and 2012 droughts were more similar to each other than to 2015. The 2015 drought showed similarities with the average drought parameters of the reference period 1981–2010. However, there were exceptions from this development, as confirmed in the case of the Kysuca River discharges where all analysed drought parameters reached the highest return periods just in the year 2015.

The high variability in drought manifestation even within small distances was confirmed for the territory of Slovakia. Variable climatic conditions (air temperature and precipitation totals which are altitude-dependent) and geomorphological and geological conditions are the possible reasons for such development, together with the wetness preconditions in the respective river basin.

6 Recommendations

It is supposed that because of the climate change, the extreme hydrological events are going to be more pronounced and more frequent in the future also on the territory of Slovakia.

The country is quite well prepared for food protection, as it results from the existing European and also Slovak legislation, where the flood directive of the European Community [15] and the Flood Act [16] are applied.

The Ministry of Environment of the Slovak Republic worked out the document: Strategy and adaptation on unfavourable climate change impacts. At present, the revision of the document is going on. The reason was in not satisfactorily addressing the drought issue.

Another document addressing the drought issue is the Action plan on drought impact mitigation measures which was prepared at the Ministry of Environment of the Slovak Republic by the group of experts in the second half of the year 2017. Nowadays the process of its discussion is going on at the level of the applicable ministries. The action plan should be prepared for the approval by the Slovak government in the near future.

However, there is still no legislation on drought impact mitigation and protection existing within the Slovak legislative space. Therefore, after approval of the Action plan, the respective legislative measures should be prepared and approved in order to move from the crisis management, as documented by measures taken during the 2015 drought, to drought risk reduction policy. More attention should be paid to prepare the long-term prevention and mitigation measures in all involved economy sectors (water management, forestry, agriculture, social sectors and others). Development and implementation of drought management plans of Slovakia in the context of the EU Water Framework Directive are inevitable. The drought issue should be included also in the next revised version of the Water Plan of the Slovak Republic.

Acknowledgement The research was supported by the APVV-089-12 Project "Prognosis of hydrological drought occurrence in Slovakia" (principal investigator M. Fendeková). The results also contribute to the UNESCO IHP VIII program within the low flow and drought group activities.

References

1. Tallaksen LM, van Lanen HAJ (eds) (2004) Hydrological drought, processes and estimation methods for streamflow and groundwater. Elsevier, Amsterdam, The Netherlands, 579 pp
2. EEA (2010) Mapping the impacts of natural hazards and technological accidents in Europe. An overview of the last decade. EEA Technical report No. 13/2010, Copenhagen, 144 pp
3. Blaškovičová L, Podolinská J, Liová S, Fabišíková M, Rischaneková M, Danáčová Z, Paľušová Z, Borodajkevyčová M, Šipikalová H (2008) Hydrological yearbook, surface water, 2007, 1st edn. Slovak Hydrometeorological Institute, 213 pp. (in Slovak)
4. Fendeková M, Fendek M, Danáčová Z, Labudová L, Slivová V (2017) Drought manifestation in the surface and groundwater of selected Slovak catchments in the dry years 2003, 2012 and 2015. Poster at 15th Hydrogeological Congress: Groundwater and Society, Brno, 4–-7 September 2017 (in Slovak)
5. Statgraphics Centurion 17, Professional, EDU version. Statgraphics Technologies Inc., 2015, The Plains, Virginia, USA
6. Koffler D, Gauster T, Laaha G (2016) lfstat—calculation of low flow statistics for daily stream flow data. http://www.cran.r-project.org. Accessed 15 July 2017
7. Gauster T (2016) Station report Slovakia. Manuscript, Vienna, 37 pp
8. Sachs L (1984) Applied statistics. A handbook of techniques. 2nd edn. Springer, New York, 707 pp. ISBN 0-387-90976-1
9. Hosking JRM, Wallis, JR (1997) Regional frequency analysis, an approach based on L-moments. Cambridge University Press, Cambridge, UK, 244 pp. ISBN 13-978-0-521-43045-6
10. Laaha G, Gauster T, Tallaksen LM, Vidal J-P, Stahl K, Prudhomme C, Heudorfer B, Vlnas R, Ionita M, Van Lanen HAJ, Adler M-J, Caillouet L, Delus C, Fendekova M, Gailliez S, Hannaford J, Kingston D, Van Loon AF, Mediero L, Osuch M, Romanovicz R, Sauquet E, Stagge JH, Wong WK (2017) The European drought from a hydrological perspective. Hydrol Earth Syst Sci 21:3001–3024
11. Ionita M, Tallaksen LM, Kingstone DG, Stagge JH, Laaha G, Van Lanen HAJ, Scholz P, Chelcea SM, Haslinger K (2017) The European 2015 drought from a climatological perspective. Hydrol Earth Syst Sci 21(3):1397–1419
12. WMO Statement on the Status of the Global Climate (2012) World Meteorological Organization, WMO-No. 1108, Geneva, Switzerland, 33 p. ISBN 978-92-63-11108-1

13. WMO Statement on the Status of the Global Climate (2016) World Meteorological Organization, WMO-No. 1189, Geneva, Switzerland, 24 p. ISBN 978-92-63-11189-0
14. Fendeková M, Danáčová Z, Gauster T, Labudová L, Fendek M, Horvát O (2017) Analysis of hydrological drought parameters in selected catchments of the southern and eastern Slovakia in the years 2003, 2012 and 2015. Acta Hydrologica Slovaca 18(2):135–144
15. Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. Published in the Official Journal on 6 November 2007, p 27
16. Act No 7/2010 Coll. Act on protection against flood

Flood Hazard in a Mountainous Region of Slovakia

Ľ. Solín

Contents

Abstract Slovakia is a mountainous country, and the occurrence of floods in headwater areas is thus an important phenomenon. The chapter concerns the identification of regional types of flood hazards in a mountainous region resulting from the physical geographic characteristics of the upper basins. The regional type is the unit of regional taxonomy, which is not contiguous in geographical space and is referred to as the flood hazard potential or disposition of the basins to floods. A brief overview of flood events in Slovakia is provided. Then, the rest of the chapter presents the assessment of the flood hazard itself. The evaluation process consists of four steps. The first step of the regional taxonomic process is creation of a basic set of upper basins and a database of their physico-geographic attributes. The second step is identification of the physical geographic attributes that significantly influence the basic features of the drainage process

Ľ. Solín (✉)
Institute of Geography, Slovak Academy of Sciences, Bratislava, Slovakia
e-mail: solin@savba.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 147–172,
DOI 10.1007/698_2017_172,
Published online: 30 December 2017

and the spatial variability of the flood hazard. The delineation of flood hazard classes based on a combination of physical basin attributes and classification of upper basins into flood hazard classes is the third one. Testing the significance of differences between the assigned flood hazard classes in terms of the frequency of flood situations is the last fourth step.

Keywords Flood hazard, Flood situation, Regional type, Slovakia, Upper basins

1 Introduction

The period from the second half of the 1970s to the 1980s was exceptionally peaceful in terms of the occurrence of floods in the Slovak Republic (MoE SR). However, since the second half of the 1990s, we have seen more frequent occurrence of floods in Slovakia, as in other European countries, causing loss of life and considerable damage to the property of citizens and municipalities as well as to organizations in the private and public sectors [1, 2]. Preventing flood damage or minimizing its extent is, therefore, becoming a very urgent requirement. The issue of floods has become a major societal issue for government, local authorities, academic and research institutions, and water management and hydrometeorological organizations as well as non-governmental organizations.

With regard to flood issues, the paradigm of their solution is changing from a traditional engineering approach to integrated assessment and management of flood risk (c.f. [3–9]). The integrated approach is based on idea that "in evaluating disaster risk, the social production of vulnerability needs to be considered with at least the same importance that is devoted to understanding and addressing natural hazards" [10]. In the case of flood hazard, it also underlines the principle "that all types of flooding should be managed coherently, thereby including sewer flooding, pluvial flooding and groundwater flooding alongside the traditional coastal and riverine flooding" [11]. The emphasis placed only on river flooding can be considered legitimate and understandable, particularly in the middle and lower parts of rivers in lowland and basin territories. In these river sections, this type of flood hazard dominates, and flood protection structural measures are practically the only measures that can be used to reduce the extent of flooding. The situation is different, however, in the upper basins in the mountain, foothill, and hill areas. The diversity of physical attributes of upper basins not only causes various hydrological responses to precipitation but also, together with the impact of local anthropogenic factors, creates conditions for the emergence of other forms of flood hazards (e.g. sheetwash flooding) besides natural river flooding. Therefore it is necessary to assess flood hazard in headwater areas in a comprehensive way. The upper basins are of key importance in the framework of flood risk management. Increasing their retention capacity and reducing the influence of local factors that accelerate floods is the first step that is needed to reduce flood hazard in downstream areas.

Slovakia is a country where the mountains occupy 71% of the total area, and 37% of the total of 2,928 municipalities (i.e. 1,093) are located in upper basins in mountainous, foothill, or hill areas [12]. Analysis of the occurrence of flood situations in Slovakia in 1996–2006 showed that 67% of flood events occurred in municipalities located in upper basins [1]. The occurrence of floods in upper basins in the mountain, foothill, and upland areas is thus an important phenomenon in Slovakia. For this reason, it is necessary to give appropriate attention to an integrated assessment and management of flood hazard in the upper basins.

2 A Brief Overview of Flood Events in Slovakia

2.1 Historical Floods Up to the Second Half of the 1970s

The references to historical floods in Slovakia are mainly related to floods that have occurred in large streams. Basic information about the history of floods in Slovakia is provided by the website of the Ministry of Environment SR [13] or the Slovak Water Management Company [14]. Through the study of available historical documents, the occurrence of floods was documented in detail on the river Váh by [15], on the Danube by [16, 17], and on the Slana River by [18].

Probably the biggest flood on the Danube in Bratislava was the flood in 1516, marking the height of the peak level at the pillar of Vydrická Gate, and is also the oldest preserved flood mark in the territory of Slovakia [17]. The most famous flood in the eighteenth century took place at the beginning of November 1787 and was also referred to as the "Hallowmas flood". The whole of the nineteenth century was marked by ice floods, in which accumulated blocks of ice caused clogging and raised the water level. Disastrous for Bratislava was that of 5 February 1850. One of the preserved flood markings at the corner of Laurinska and Uršulinska in the historic core of the city is 182 cm above the pavement level. The flood caused tremendous damage, and six people died. From the point of view of the extent of the flooded area and the damages caused, the flood on the Danube in 1965 was extremely destructive. The prolonged high water conditions in the Danube and frequent rain from early March to the second half of July had adverse effects on the stability of the protective dykes and their subsoil, which resulted in considerable seepage. Despite the enormous efforts made, it was not possible to prevent the three breakdowns that occurred in June on the dykes along the Danube (two breaks) and the Váh River (one break). After the breakdown of the Danube dykes, 46 municipalities and three settlements were threatened, which resulted in the evacuation of 53,693 residents as well as 35,759 cattle, 394 horses, 58,041 pigs, 8,700 sheep, 654 goats, more than 83,000 poultry, and some other livestock. Flooding destroyed 3,910 houses and seriously damaged 6,180, and the water flooded 71,702 ha of agricultural land, while another 114,000 ha were waterlogged. Water damaged 250 km of roads and about 70 km of railway lines. The state insurance company registered damage amounting to 100 million euros, but the actual flood damage was probably much higher.

Historically, the biggest flood on our longest river, the Váh river (with a length of 406 km), which is preserved by archival documents, was the flood of 1813 [15]. It ravaged the entire valley of the Váh, from Žilina to Sereď. As a consequence, 243 people died, and most of the houses in 50 villages were destroyed. In the first half of the twentieth century, there were several major floods in the Váh catchment area. For example, the July 1903 flood in Orava is mentioned. Further floods on the Vah River occurred in August 1925 and 1938, in July 1943, in February 1946, and in January and June 1948. In the Váh catchment area, the largest flood since 1813 occurred in June 1958. A flood in the Liptov and Kysuca region caused extensive damage. In Liptov, 21 communes and parts of the towns of Liptovský Mikuláš and Ružomberok were flooded. The flood situation also required the evacuation of 60 families from Terchova. In the Kysuce catchment, the settlement of Skorka; the communes of Svrčinovec, Stará Bystrica, and Krásno nad Kysucou; and part of the Kysucké Nové Mesto town were flooded. The water flooded several stretches of roads, including the state roads in the Liptovský Mikuláš–Ružomberok and Turany–Sučany sections, as well as the railway line between Vrútky and the Strečno.

Past floods of the Hron catchment lack more compact records. However, some reports of floods in 1784, 1813 (the largest known flood, whose highest water status is recorded on the flood marker in Banská Bystrica), 1847, 1853, 1899 (larger than the flood in 1974), 1928, 1931, and 1960 have been preserved. The largest flood in the Hron basin in the twentieth century occurred in October 1974. A devastating flood flooded 4,650 family houses, 82 km of roads, and 30 km of railway lines, and an area of 64,000 ha was underwater. In the upper and middle parts of the Slana catchment, the course of the floods was reinforced in October 1974 by joining with flood waves in the Murán and Turiec tributaries. At the Lenártovce Slaná station, the flood culminated in a maximum discharge of 350 $m^3\ s^{-1}$, which is repeated, on average, once every 500 years.

There is no doubt that in the past, Eastern Slovakia was a frequent area of flood disasters. On the basis of preserved records, floods with an average return period of 100 years can be considered, as occurred in the Bodrog and Tisza basins in 1888. The occurrence of large floods was also frequent in this area in the twentieth century. The largest floods in the Bodrog and Tisza catchments which should be mentioned were those of 1924 and 1932. Large floods also occurred in 1967, 1974, 1979, and 1980. A major flood hit the entire catchment area of the Hornád River in 1958, and the Torysa catchment experienced flooding in 1952.

2.2 *Incidence of Floods from the Second Half of the 1990s*

Basic knowledge of the occurrence of floods, with an emphasis on the analysis of the meteorological conditions that caused the floods, is processed annually in the reports issued by the Slovak Hydrometeorological Institute (SHMÚ) and in materials prepared by the Ministry of Agriculture of the Slovak Republic (MP SR) and the Ministry of the Environment of the SR (MoE SR) for the negotiations of the Government of the SR. The incidence of flood situations in the municipalities of Slovakia in the period 1996–2014 is shown in Fig. 1.

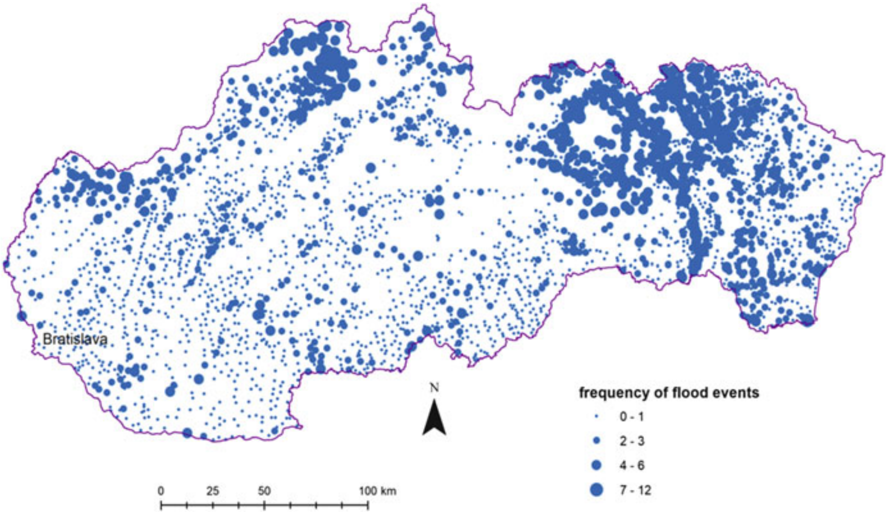


Fig. 1 The occurrence of floods in the municipalities of Slovakia in the period of 1996–2014

The analysis of the floods that occurred in 1997–1999 in small river basins in relation to their physical geographic conditions was addressed by [19, 20]. Reference [21] employed a geographical information system (GIS) to analyse the occurrence of floods on Slovak rivers in the period of 1985–2000. A detailed analysis of the occurrence of the flood events in the territory of Slovakia in the period 1996–2006 was presented by [1]. A flood event refers to a state of a river that requires the declaration of the third level of flood activity because the river has begun to overflow its channel or there is a threat that a dyke will overflow or break down. The analysis showed that during the period in question, flood events occurred in 1367 out of a total of 2,928 municipalities in Slovakia. Of these, 920 municipalities, that is, 67% of those that experienced flooding, were located in the small upper basins, 6% were located along medium-sized rivers (basin areas of 300–1,000 km^2), 20% along large rivers (basin areas over 1,000 km^2), and the remaining 7% of those affected by floods were outside the upper basins and buffer along medium and large streams (Fig. 2).

In terms of the types of flood events, they were mainly flash floods in municipalities located in upper basins (Table 1). Of the more than 800 flash floods that occurred between 1996 and 2006, the most tragic consequences were caused by the flood on the Little Svinka Creek in July 1998. During the storm, more than 100 mm of precipitation occurred in the upper part of Svinka basin in about an hour, and the subsequent flood wave with high of up to 4 m caused the loss of 50 lives and considerable material damage.

In terms of scope, extreme floods occurred in 2010, when the floods affected virtually the entire territory of Slovakia. The main cause of the floods in 2010 was the extraordinary to extreme and especially long-lasting precipitation that hit the larger areas of Slovakia repeatedly, in many cases in the same regions. The floods in 2010 affected 33,080 inhabitants, two people died, 12 were injured, and 25,224 were

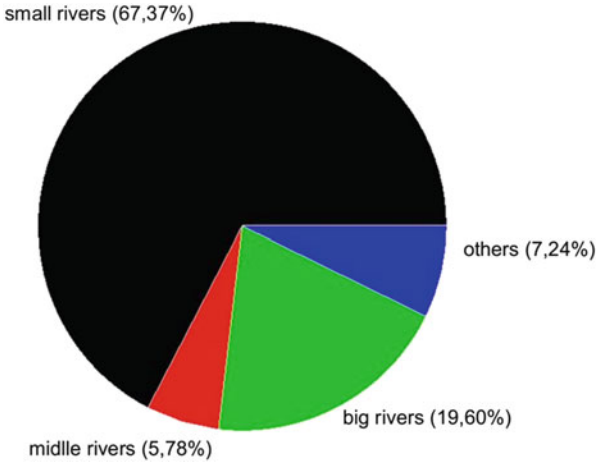


Fig. 2 The flood situations in the period of 1996–2006 in municipalities located along rivers of different sizes (reproduced from [1])

Table 1 Frequency of occurrence of flood events in 1996–2010 according to the type and size of the watercourses (reproduced from [1])

Size of river	Type of flood event R	F	L	V	H	Total
Small rivers	656	813	34	18	6	1,527
Middle rivers	89	78	5	2		174
Large rivers	275	152	24	26	21	498
Outside of river buffers	31	18		66	9	124

R, river or regional floods; *F*, flash floods; *L*, ice jam flood; *V*, internal flood; *H*, flood due to breakage of a water structure

evacuated, and the water flooded 27,521 residential buildings, of which 26,364 were family houses. An area of 97,290 ha was underwater, of which 6,680 ha was in residential areas; floods damaged 2.7 km of class I roads and 47.5 km of class II and III roads. The verified flood damage amounted to 336.9 million euros. This amount excludes flood damage in the primary agricultural, forestry, and fish farming sectors.

3 Impact of Physical Geographic Attributes of River Basin on the Spatial Variability of Flood Hazard in Headwater Areas

The primary cause of floods is precipitation or specific climatic situations. The transformation of rainfall into a runoff is, however, a complex process [22–26]. The physical geographic attributes of the basin affect three important hydrological variables (water retention areas, infiltration, and the movement of water [27]) and cause disparities in the flood hazard between upper basins. The diversity of physical geographic attributes of the upper basins (relief and soil substrate properties as well as the character of landscape cover and land use), however, means that snow melt or the same long- or short-term precipitation falling onto basins with different attributes may not always result in floods. This is also documented by the spatial variability of the occurrence of flood situations in Fig. 1. There is a higher frequency of flood events in some parts of Slovakia than in others.

General information on the basic features of the drainage process in the river basin and the resulting flood hazard is provided by a hydrogram of average daily discharges. Figure 3 shows hydrograms of three upper basins with different physical geographic attributes. The hydrogram in Fig. 3a includes a basin that is built up by a Palaeogene flysch with a predominance of clay, on which soils with very low permeability of the soil texture are created, and the forestry covers 63% of the basin. The hydrograph is characterized by sudden and steep flood waves and suggests that the dominant drainage process in the river basin is surface or direct runoff. The maximum values of normalized average daily discharges are more than ten times higher than the average annual discharge. The hydrograms in Fig. 3b, c are for river basins, the first of which is characterized by a permeable soil texture on the crystalline slate, with forestry covering 84% of the basin. In the second river, aeolian sand with a very permeable soil texture predominates, and the forest covers 47% of the river basin. The hydrograms indicate that the predominant drainage in the basins is basic runoff. In this form of runoff, there are typically shallow and longer-lasting flood waves with values of normalized average daily discharge that are only four and two times higher, respectively, than the average annual discharge.

In addition to the visual interpretation of the hydrograms, the basic features of the drainage process in the basin can be expressed in a quantitative way in the form of a base flow index (*BFI*). The value of the BFI indicates the ratio of basic runoff to total runoff. A high *BFI* suggests that the basic runoff dominates in the runoff process and that the potential for flood hazard is low. On the contrary, a low value *of BFI* indicates that the prevailing form of runoff in the catchment is a direct runoff, and the potential for flood hazard is higher. For example, the *BFI*s for the river basin shown in Fig. 3a–c are 0.26, 0.68, and 0.93, respectively. Due to the different

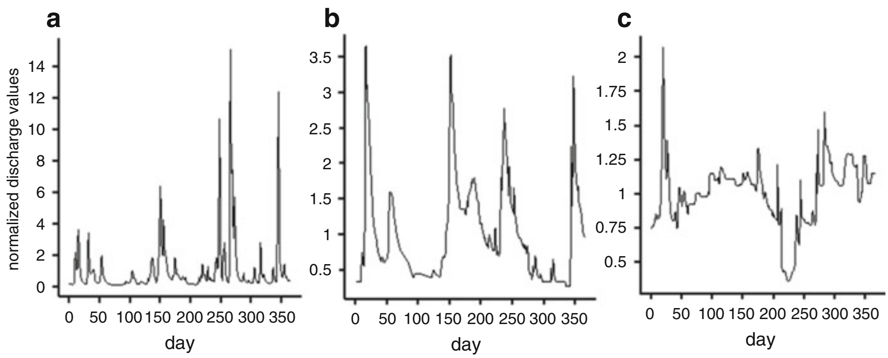


Fig. 3 Examples of different hydrological responses: (**a**) river Ladomírka, (**b**) river Rimava, (**c**) river Láb

transformations of precipitation into runoff caused by the physical geographic attributes of the river basin, we can assert that there is a greater flood hazard in the river basin in Ladomírka (Fig. 3a) than in the basins of the rivers Rimava and Láb (Fig. 3b, c).

The threat of flood occurrence resulting from the physical geographic characteristics of the basin is referred to as the flood hazard potential [28], geoecological flood hazard potential [29], or disposition of the catchment to flood [30]. The assessment of the spatial variability of the flood hazard potential in the upper basins requires:

(a) The creation of a basic set of upper basins and database of their physico-geographic attributes
(b) Identification of the physical geographic attributes that significantly influence the basic features of the drainage process and the spatial variability of the flood hazard
(c) Delineation of the flood hazard classes based on a combination of physical basin attributes and classification of the upper basins into flood hazard classes
(d) Testing of the significance of differences between the assigned flood hazard classes in terms of frequency of occurrence of flood situations

3.1 Basic Set of Upper Basins of Slovakia and a Database of Their Physical Geographic Characteristics

A digital layer of small basins had been digitalized by the Slovak Environmental Agency (SAŽP) in the years 1997–1998 from the map of water management in scale of 1:50,000. However, water divides of basins had to be adjusted by [31] to take the function of the basic spatial units for the needs of regional taxonomy. The digital layer contains almost 4,587 autochthonous small upper river basins with areas ranging from 0.04 to 150 km^2. In view of the fact that the response from the river basin, whose area occupies more than 5 km^2, is hydrologically significant [32], the original set of upper river basins was reduced to 1,678 basins with an area in the range of 5–150 km^2. The upper limit of the size of the area of the basin reflects the diversity of the relief of the territory of Slovakia.

A database of physico-geographical characteristics of upper basins containing a large set of attributes representing precipitation, relief, geology, soil, and land cover was created by [33]. The input digital layers for the determination of river basin attributes were a digital relief model [34], soil map [35], a map of the CORINE Land Cover [36], hydrogeological map [37], and a map of average annual precipitation [38]. Graphical visualization of the basic physical geographic attributes of the upper basins is presented in Figs. 4, 5, 6, and 7.

Differentiation of soils from the point of view of permeability is the result of two basic physical soil properties, texture and structure, which determine the size, shape, and geometric arrangement of soil pores. Permeability is the ability of the soil to allow the

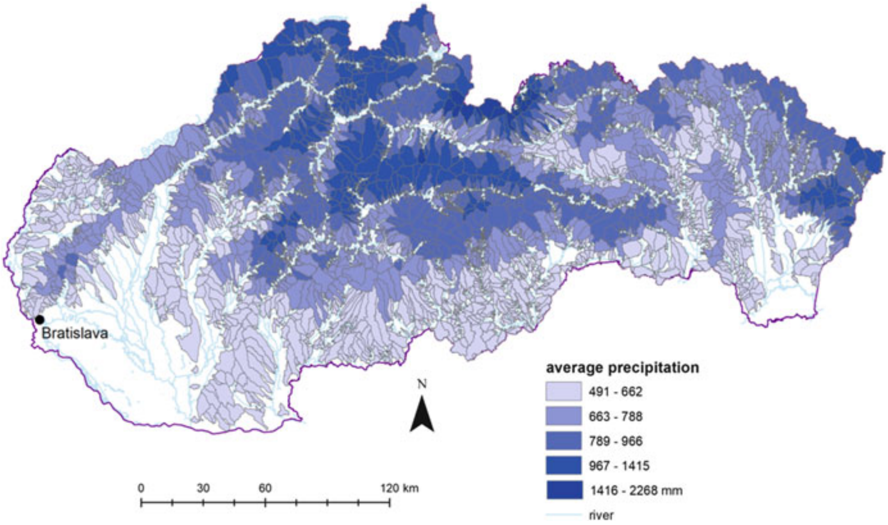


Fig. 4 Average annual precipitation (1976–1995) of the upper basins (reproduced from [33])

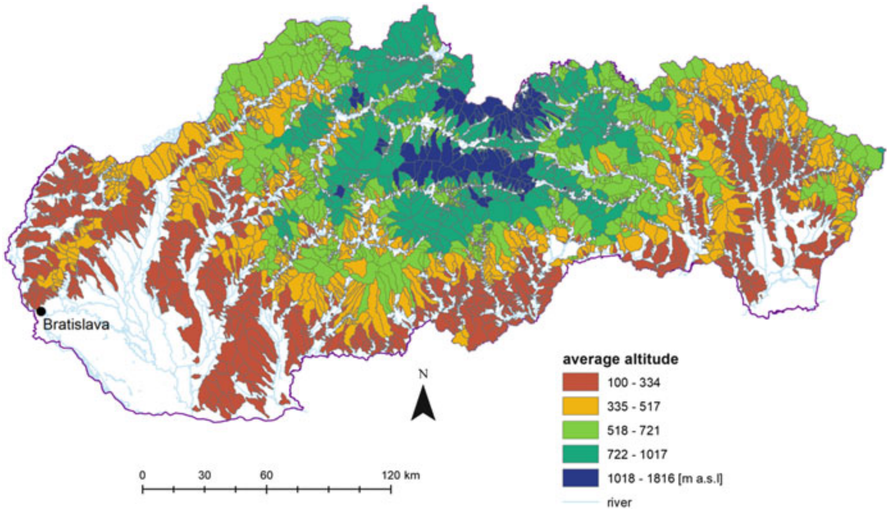


Fig. 5 Average altitude of upper basins (reproduced from [33])

passage of precipitation water from the surface of the soil into deeper soil horizons. With regard to the soil texture of non-capillary pores, there is a decline from coarse-grained categories to fine-grained categories [39]. As a result, the permeability decreases from coarse-grained categories to fine-grained categories (Table 2).

Based on the relationship between the rock and soil texture determined by [40, 41], as shown in Table 3 and on the hydrogeological map of Slovakia at a scale of 1:500,000, a

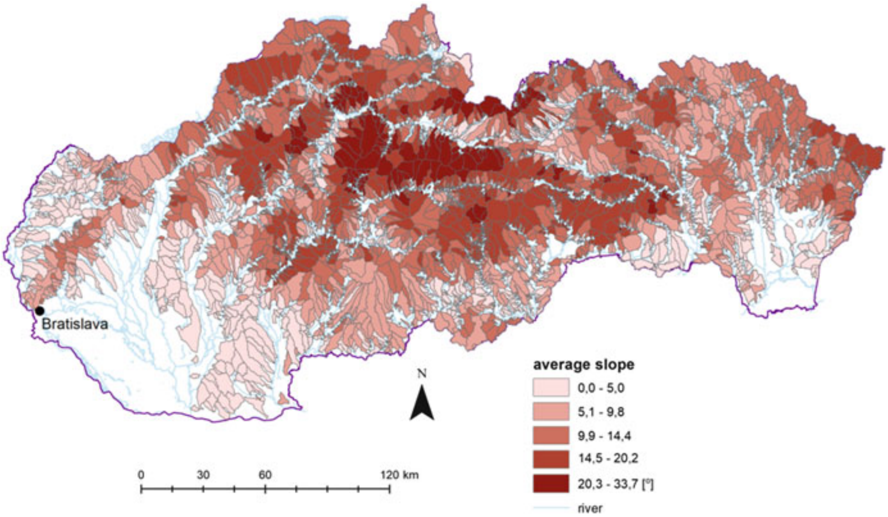


Fig. 6 Average slope of upper basins (reproduced from [33])

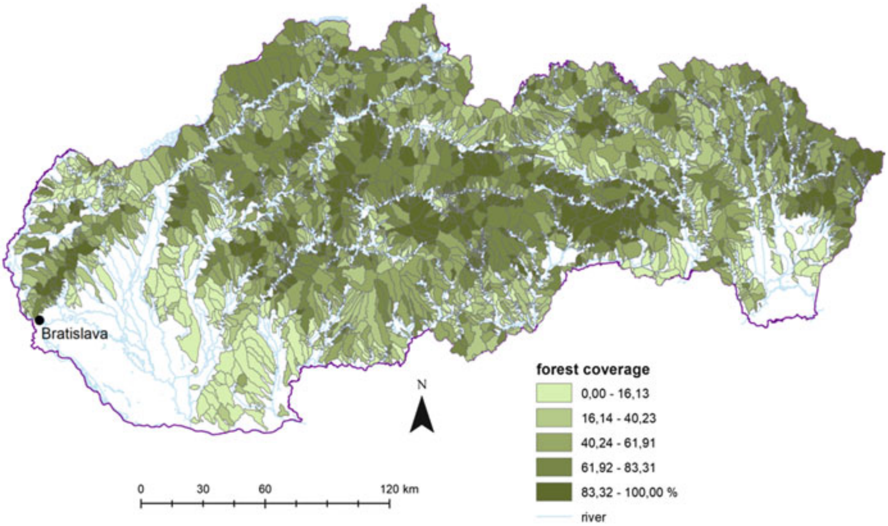


Fig. 7 Percentage of forest in upper basins (reproduced from [33])

map of the spatial distribution of the soil texture categories was compiled. By overlaying this thematic layer with that of the small basins of the SR, the percentages of the individual soil texture categories in each basin were assessed. The index of soil texture permeability of the basin (*ISTP*) was set afterwards by:

Table 2 Permeability of soil texture categories

Soil texture category	Share of particles smaller than 0.01 mm	Category of permeability	Ordinal value of permeability
Sandy	0–10%	Absolutely permeable	7
Loam-sandy	10–20	Very well permeable	6
Sand-loamy	20–30	Well permeable	5
Loamy	30–45	Permeable	4
Clay-loamy	45–60	Poorly permeable	3
Very clayey	60–75	Very poorly permeable	2
Clay	>75	Not permeable	1

Table 3 Relationship between soil texture and rock

Soil texture	Rock
Sandy	Sand deposits
Loam-sandy	Quartzite, granite, granodiorite
Sand-loamy	Melaphyre, granodiorite, gneiss, porphyroid, flysch-sandstone
Loamy	Andesite rocks, porphyroid, gneiss, amphibolite, loess, dolomite
Clay-loamy	Andesite rocks, phyllites, loess, limestone, flysch-clayey shale
Clayey	Marlite, marly shale, marly limestone
Clay	Neogenic formations of clay and marl

$$ISTP = \frac{\sum P_{pj} \cdot I_{pj}}{100} \quad (1)$$

where *ISTP* is the permeability index of the basin, P_{pj} is the percentage of soil texture category of the total basin area, and I_{pj} is the corresponding permeability value. The values of *ISTP* were then grouped into interval classes of soil texture permeability (Table 4). The classification of the upper basins in terms of *ISTP* is visualized in Fig. 8.

In the case of the soil structure of the soil horizons, it is assumed that the permeability decreases from unstructured aggregates and structural aggregates that are evenly developed in three directions towards structural aggregates that are vertically and horizontally elongated (Table 5). Each soil unit is characterized by a certain grouping of soil horizons, and in the assessment of the soil unit permeability as a whole, the "bottleneck" principle was applied [42]. This means that the permeability corresponding to the least permeable soil horizon was attributed to the soil unit (Table 6, numbers in bold in the last column).

By overlaying the map soil units with the layer of small basins in Slovakia, the percentage of each type of soil unit in the basin was expressed. Subsequently, an

Table 4 The classes of soil texture permeability index

Permeability index *ISTP*	Class of soil texture permeability
1.00–1.50	1 – Not permeable
1.51–2.50	2 – Very poorly permeable
2.51–3.50	3 – Poorly permeable
3.51–4.50	4 – Permeable
4.51–5.50	5 – Well permeable
5.51–6.50	6 – Very well permeable
6.51–7.00	7 – Absolutely permeable

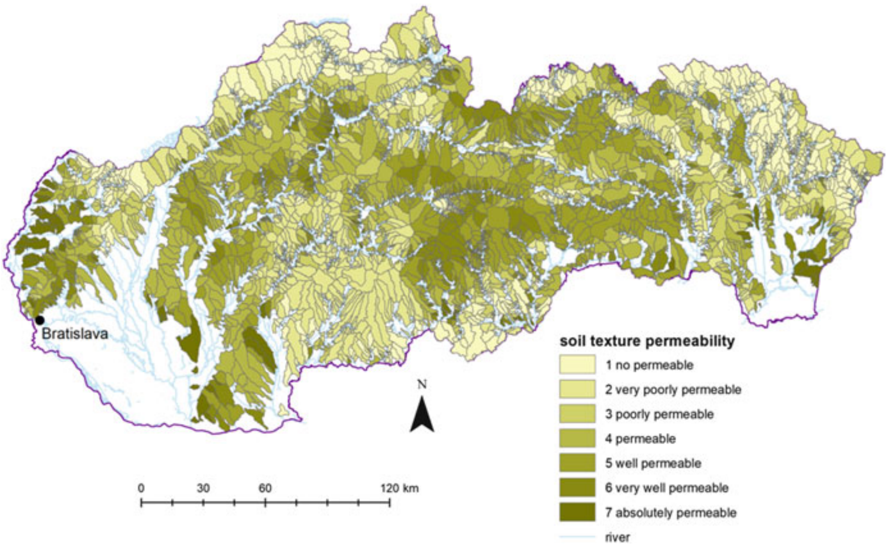


Fig. 8 Classes of soil texture permeability of upper basins

index soil structure permeability (*ISSP*) was assessed for each basin by using Eq. (1), where classes of soil structure permeability were used instead of soil texture permeability classes. The distribution of upper basins into classes in terms of soil structure permeability is presented in Fig. 9.

3.2 Analysis of the Influence of Basin Attributes on Spatial Variability of the Flood Hazard

The analysis of the impact of the physical geographic attributes on flood hazard includes the investigation of the dependence between classes of physical geographic attributes of the basins on the one hand and *BFI* values and frequency of flood events on the other hand [28]. In the case of *BFI*, the analysis was carried out

Table 5 Permeability of soil horizons

Soil horizon	Soil structure	Class of soil structure permeability
Layer of loose sandy material	Structureless – loose	7 – Absolutely permeable
Weathered substrate	Structureless – stone	6 – Very well permeable
Humus	Granular	5 – Well permeable
Metamorphic	Polyhedron	4 – Permeable
Illuvial	Prismatic, columnar	3 – Poorly permeable
Eluvial	Platy	2 – Very poorly permeable
Gley	Structureless – dense	1 – Not permeable

Table 6 Classification of permeability of soil units

Soil unit	Soil horizons	Soil structure	Class of soil structure permeability
Leptosols	Shallow humus	Granular: fine to medium	**6**
	Weathered rock		
Arenosols	Loose sand	Structureless loose	**7**
Rendzic leptosol and calcaric cambisols	Humus	Granular: fine to medium	5
	Metamorphic	Granular: fine to medium	**4**
	Weathered rock		
Chernozems	Humus	Fine granular	**5**
	Loose loess		
Haplic luvisols	Humus	Granular: fine to medium	5
	Illuvial	Polyhedron to prismatic	**3**
	Loose substratum		
Albic luvisols	Humus	Granular: fine to medium	5
	Eluvial	Platy	**2**
	Illuvial	Prismatic	3
	Loose substratum		
Cambisols and andosols	Humus	Granular: fine to medium	5
	Metamorphic	Polyhedron	**3**
	Weathered rock		
Podzols	Humus	Medium granular	5
	Eluvial	Structureless loose	6
	Illuvial	Polyhedron	**3**
	Weathered rock		
Planosols and stagnosols	Humus	Granular: fine to medium	5
	Gley	Structureless dense	**1**
	Loess loams deposit		
Fluvisols	Alluvial deposits	Structureless	**5**
Mollic fluvisols and mollic gleysols	Humus	Fine granular	4
	Gley	Prismatic to platy	**2**
	Loose deposit		

in the basins by hydrometeorological observation. A sample of 126 small gauged catchments was selected, and the *BFI* values were set by applying the IHACRES precipitation/runoff model [43]. The relationship between the *BFI* and the basin attributes was analysed by the box plot method. In the case of frequency of flood events, their relationship to the basin's attributes was studied within the whole set of

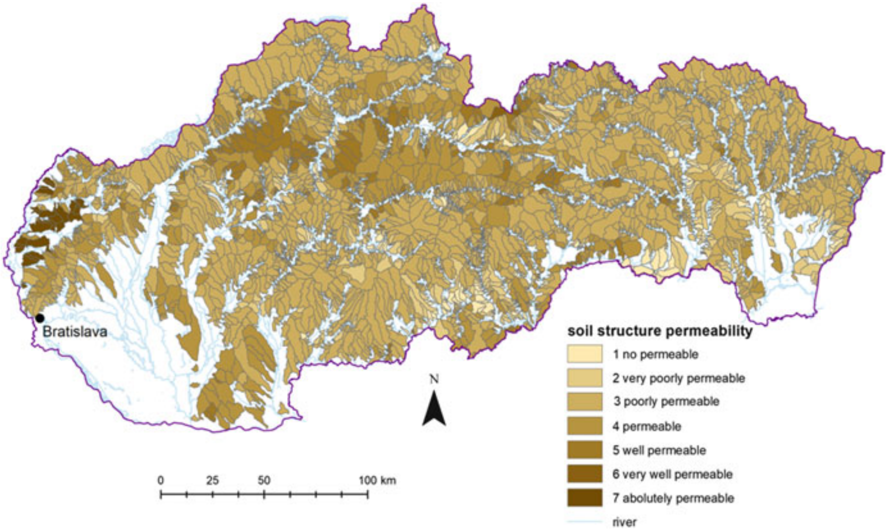


Fig. 9 Classes of soil structure permeability of upper basins

1,678 upper basins, and the significance of their differences was tested by the ANOVA method.

With regard to the altitude, slope, and forestry, the upper basins are divided into the following four physical geographic classes:

- Classes of average altitude of the basin: A, 101–385 m a.s.l.; B, 385–652 m a.s.l.; C, 652–976 m a.s.l.; D, 976–1,816 m a.s.l.
- Classes of average slope of the basin: A, 0–6°; B, 6–12°; C, 12–18°; D, 18–33°
- Classes of basin forestry: A, 0–24%; B, 24–5%; C, 51–76%; D, 76–100%

The intervals of each class are defined by the breakpoints corresponding to the division into four classes when processing the classification of upper basins in the GIS.

In terms of the soil texture permeability, the upper basins have been grouped into seven classes (see Table 4; class 1, not permeable soil texture; class 7, absolutely permeable soil texture). In relation to soil structure, instead of the seven original classes, three classes of permeability of the soil structure were used. The first one (class 1) is poorly permeable and consists of basins with a prevalence of soil types for which prismatic and columnar structure with vertically elongated soil aggregates is typical. The second (class 2) is permeable and contains the upper basins with a prevalence of soil types typified by the cubiform and polyhedral structures with distinctly developed edges in three directions. The third (class 3) is very well permeable and consists of an upper basin with a prevalence of soil types, for which a granular structure with spherical soil aggregates is typical.

The results of the relationship between *BFI* values and the classes of physical geographic attributes of the upper basins are presented in Fig. 10. The graphs show that only the permeability of the soil texture has a significant effect on the differentiation of *BFI* values of the basins (Fig. 10a); that is, with increases in the soil texture permeability of the basin, the proportion of the base runoff in the total runoff increases. In the case of other physical geographic attributes, box plots point only to insignificant dependencies. In relation to the soil structure, the average *BFI* value in the class of basins with the lowest permeability of the soil structure (class 1) is somewhat lower than the *BFI* value in the remaining two classes of basins with higher permeability (Fig.10b). Similarly, in the case of the average slope of the basin, the *BFI* is in the class of basins with a slope of up to 6%, which is slightly higher than that in the other classes with higher slope (Fig. 10d). In relation to the forestation and altitude of the basins, the differences between *BFI* values are very insignificant and do not indicate any trend (Figs. 10c, e).

With regard to the second indicator of the flood hazard, that is, the frequency of flood events, the results are given in Tables 7, 8, 9, and 10.

The comparison of the arithmetic average of the frequency of flood events vs the soil texture permeability classes of basins shows that in basin classes with low permeability (classes 1 and 3), the frequency of flood events is higher than that in basin classes with permeable soil texture (classes 4–7). Surprisingly, however, the lowest value of the average frequency of flood events is obtained in the case of class 2, with a low-permeability soil texture.

In terms of forestry, in classes B, C, and D, but not class A, the value of the arithmetic average of the occurrence of the flood events decreases as the basin forestation increases. Differences between arithmetic averages are quite clear. The impact of forestry is even more pronounced if it is judged within individual classes of soil texture permeability (Fig. 11). Within each of the soil texture permeability classes, the arithmetic mean of the frequency of flood events is higher in the upper basin group in which forestry fails to predominate than in the basin group with predominant forestry. The graph also shows that the impact of forestry on the occurrence of flood situations becomes weaker as the permeability of the river basin texture decreases.

Regarding the relief attributes of the river basins, the data do not indicate the assumption that the increase of the average slope of the river basin or altitude will increase the frequency of the flood events; rather, the data point to the opposite trend.

The above analysis suggests that the basin attributes that have a significant influence on the frequency of the flood events are mainly the permeability of the soil texture and the forest cover of the basins.

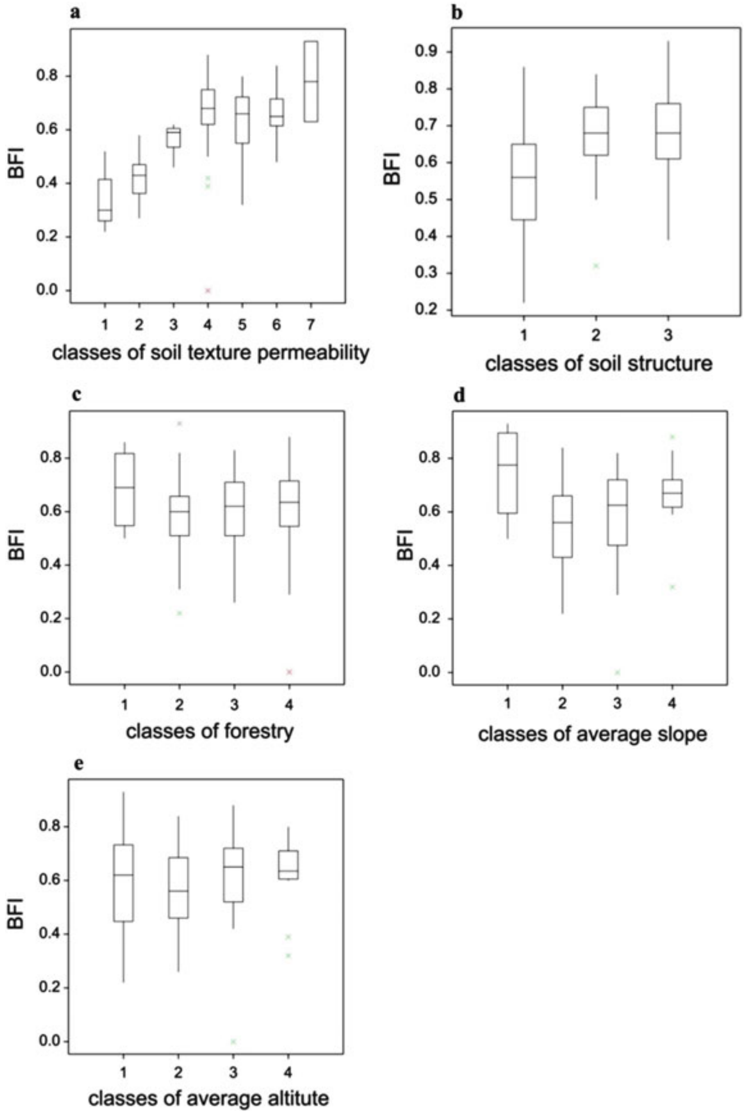


Fig. 10 *BFI* vs physical geographic basin attributes. (**a**) Classes of soil texture permeability: 1, not permeable; 2, very poorly permeable; 3, poorly permeable; 4, permeable; 5, well permeable; 6, very well permeable; 7, absolutely permeable. (**b**) Classes of soil structure permeability: 1, poorly permeable; 2, permeable; 3, well permeable. (**c**) Classes of percentage coverage by forest: A, 0–24%; B, 24–51%; C, 51–76%; D, 76–100%. (**d**) Classes of average slope: A, 0–6°; B, 6–12°; C, 12–18°; D, 18–33°. (**e**) Classes of altitude: A, 101–385 m a.s.l.; B, 385–652 m a.s.l.; C, 652–976 m a.s.l.; D, 976–1,816 m a.s.l.

Table 7 Permeability of soil texture of basins vs frequency of flood situations

Class of soil texture permeability	Number of basins	Arithmetic mean of flood frequency events
1	269	0.88
2	317	0.45
3	313	0.70
4	341	0.49
5	339	0.40
6	137	0.32
7	62	0.40

Table 8 Forestry of basins vs frequency of flood situations

Forestry class (%)	Number of basins	Arithmetic mean of flood frequency events
A: 0–24	314	0.44
B: 24–51	420	0.86
C: 51–76	517	0.62
D: 76–100	427	0.18

Table 9 Average slope of basins vs frequency of flood situations

Slope class [°]	Number of basins	Arithmetic mean of flood frequency events
A: 0–6	417	0.42
B: 6–12	589	0.68
C: 12–18	487	0.57
D: 18–33	185	0.26

Table 10 Average altitude of basins vs frequency of flood situations

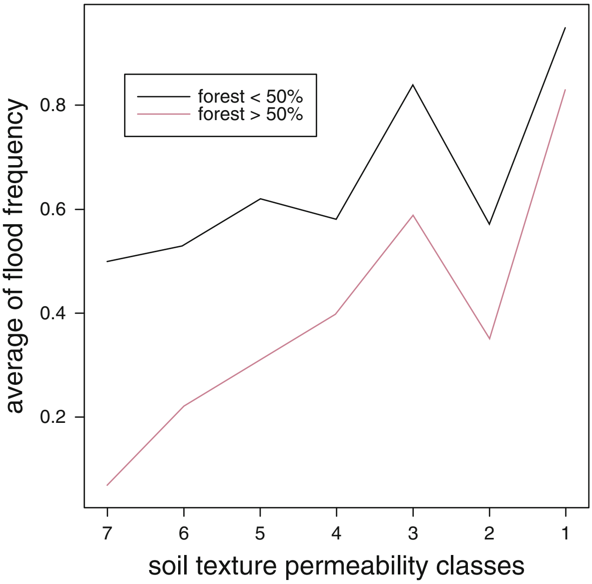
Altitude class [m a.s.l.]	Number of basins	Arithmetic mean of flood frequency events
A: 101–385	633	0.43
B: 385–652	558	0.67
C: 652–976	380	0.62
D: 976–1,816	107	0.16

4 Identification of Regional Types of Flood Hazards in Headwater Areas

4.1 Assignment of Physical Geographic Classes

The aim of the regional typification process is to group the upper basins on the basis of physical geographic attributes that significantly influence the flood hazard into classes that will have the character of regional types. The regional type is a unit that

Fig. 11 Frequency of flood events within the soil texture permeability classes with different classes of basin forestry



is not spatially contiguous in the geographical space and is the basic output of spatial analysis based on the regional taxonomic concept [44, 45]. The classes identified according to this concept acquire the character of regional classes only if they meet either the internal homogeneity or the external heterogeneity criterion in relation to the set of attributes.

An application of a regional taxonomic concept in hydrogeography or hydrology has some specificity, however. Classes are allocated based on the physical geographic attributes of the basins, but the regional status is assessed in relation to the hydrological attributes instead of physical geographical ones [46]. Physical geographic classes of flood hazards thus acquire regional status if, in terms of frequency of flood events, they meet the requirement of significant heterogeneity between classes while preserving some similarity of frequency within the physical geographic class. The regional types of flood hazards identified on the basis of the combination of physical geographic attributes of the basins then obtain an explanatory function in relation to the frequency of flood events.

Several methods can be used to group basins into classes, such as cluster analysis [47], discrimination analysis [48], artificial neural networks or fuzzy logic [49, 50], and methods based on the application of logical principles [51, 52]. Given the small number of physical geographic attributes that are relevant for explanations of the spatial variability of the flood events in the upper basins, it is effective to identify the classes of flood hazards by the logical division method. The general classification scheme of logical partitioning is displayed by Table 11. According to [51], consistency of logical division is achieved when the following rules are complied with:

Table 11 Hierarchical classification scheme of logical division

<table>
<tr><td colspan="8">I</td><td colspan="8">I</td><td>Classes of hierarchical level I</td></tr>
<tr><td colspan="4">II</td><td colspan="4">II</td><td colspan="4">II</td><td colspan="4">II</td><td>Classes of hierarchical level II</td></tr>
<tr><td colspan="2">III</td><td colspan="2">III</td><td colspan="2">III</td><td colspan="2">III</td><td colspan="2">III</td><td colspan="2">III</td><td colspan="2">III</td><td colspan="2">III</td><td>Classes of hierarchical level III</td></tr>
<tr><td colspan="16">↓</td><td>↓</td></tr>
<tr><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>n</td><td>Classes of hierarchical level n</td></tr>
</table>

- The division is exhaustive; that is, all individuals (spatial units) are included in classes.
- Classes within the hierarchical level are mutually exclusive.
- At each hierarchical level, only division according to one attribute is applied.
- An attribute at a higher hierarchical level is more significant than one at a lower hierarchical level in terms of the classification goal.

As shown by the results of the analysis of the relationship between frequency of flood events and basin characteristics, it is sufficient for the physical geographic classification scheme to contain only two hierarchical levels. At the first hierarchical level, the division of the basins into groups is done on the basis of the permeability of the soil texture, and the basins were allocated into seven classes. At the second hierarchical level, the classification attribute is forestry, and the basins were grouped into four classes. However, the data in Tables 7 and 8 suggest that in both cases, a certain reduction in the original number of classes is necessary to meet the requirement of heterogeneity among classes in terms of frequency of flood events.

It seems to be optimal for the classification scheme at the hierarchical level I to contain only two classes of soil texture permeability (*CSTP*) instead of the original seven classes. The first class (*CSTP A*) is formed by merging the original poorly permeable classes 1–3 into one class. The well permeable classes 4–7 are merged into the second (*CSTP B*). In the case of forestation, two classes of forestry were used instead of the four original classes at hierarchical level II. The first class includes river basins in which less than 50% ($L < 50\%$) of the total catchment area is forested, while the second class contains catchments with more than 50% forestation ($L \geq 50\%$). By combining two classes of soil texture permeability and two forestry classes, four physical geographic classes of flood hazard (*CFH*) were created (Table 12).

CFH A represents basins with low soil texture permeability (*CSTP A*) and less than 50% forest ($L < 50\%$).

CFH B represents basins with low soil texture permeability (*CSTP A*) and above 50% forest cover ($L \geq 50\%$).

CFH C represents basins with good soil texture permeability (*CSTP B*) and below 50% forest cover ($L < 50\%$).

CFH D represents basins with good soil texture permeability (*CSTP B*) and above 50% forest cover ($L \geq 50\%$).

The frequency of flood events in the flood hazard classes *A, B, C*, and *D* is shown in Table 13. Cell values reflect the joint effect of classes of permeability of soil

Table 12 Classification scheme of flood hazard classes

CSTP A		*CSTP B*	
$L < 50\%$	$L \geq 50\%$	$L < 50\%$	$L \geq 50\%$
CFH A	*CFH B*	*CFH C*	*CFH D*

Table 13 Joint and separate effect of reduced classes of permeability of soil texture and forestry on the frequency of flood events

	CSTP A	*CSTP B*	Row averages
$L \geq 50\%$	0.58/*CFH B*	0.31/*CFH D*	0.44
$L < 50\%$	0.77/*CFH A*	0.58/*CFH C*	0.68
Column averages	0.66	0.42	*0.54*

texture and forestry on the arithmetic mean of the frequency of flood events. The values indicate that the highest mean frequency of the flood events is found in *CFH A* and the lowest in *CFH D*. *CFH B* and *CFH C* have the same values of arithmetic averages and correspond to the middle level of frequency of the flood events. They show mutual balancing of the impacts of both attributes. Increased forestry mitigates the increasing frequency of flood events due to the low permeability of the soil texture, and conversely, increased deforestation of the basin increases the level of flood frequency of the river basin with good soil texture permeability.

The values in the last row and column labelled “row averages” and “column averages” represent the impacts of forestry and soil texture permeability on the frequency of flood events separately. The column averages indicate a higher frequency of flood events in the less permeable basins (*CSTP A*) than in the more permeable ones (*CSTP B*). Also, row averages in relation to forestry indicate a higher frequency of flood events in the basins with $L < 50\%$ than in the basins with $L \geq 50\%$.

It follows from the above that there is no difference in frequency of flood events between *CFH B* and *CFH C*. Therefore, it is sufficient to classify the upper basins into three flood hazard classes: *CFH I* is identical to CFH A, *CFH II* is *CFH B* and *CFH C*, and *CFH III* is the same as *CFH D* (Table 14).

4.2 Testing the Significance of Flood Frequency Differences Between Flood Hazard Classes

The data in Table 14 indicate some differences among *CFH I, II,* and *III* in the arithmetic means of the frequency of flood events, but it is necessary to verify whether these differences are statistically significant. Only if this is the case will the classes become regional types of flood hazards. The testing of the significance of differences between arithmetic means was carried out by the analysis of variance (ANOVA) method [53].

First, the zero hypothesis (H_0) that the expected mean values of frequency of flood events (μ_r) of the flood hazard classes are equal was tested.

Table 14 Arithmetic averages of frequency of flood situations in modified flood hazard classes

	CFH I	*CFH II*	*CFH III*
Arithmetic mean of frequency of flood events	0.77	0.57	0.31
Number of basins	346	812	520

$$H_0 : \mu_1 = \mu_2 = \cdots \mu_{\mathrm{r}} \tag{2}$$

The test criterion is the value of the F^* ratio. The zero hypothesis of the equality of mean values μ_{r} is rejected if it is true that

$$F^* > F(1 - \alpha; r - 1; n_T - r) \tag{3}$$

where $(r - 1, n_T - r)$ are the degrees of freedom of the nominator and denominator in the F ratio (n_T, number of basins; r, number of factor) and $F(1 - \alpha; r - 1; n_T - r)$ is the $(1 - \alpha)$ 100th percentile of the F distribution. The significance level α has a probability value of 0.01. The rejection of the zero hypothesis means that there is some dependence between the identified flood hazard classes and the frequency of flood events.

If the zero hypothesis that the expected mean values are equal is rejected, the analysis proceeds to the second step, pairwise comparison by testing the zero hypothesis:

$$H_0 : \mu_1 - \mu_2 = 0, \cdots, \mu_i - \mu_j = 0 \tag{4}$$

That is that the difference between the expected mean values of the flood events of the two physical geographic classes of flood hazards is zero. Testing was performed using the LSD method (Fisher's protected least significant difference) [54]. The criterion for testing whether the difference is statistically significant is:

$$\frac{\bar{x}_i - \bar{x}_j}{s\left(\widehat{D}\right)\sqrt{2/n}} > t_{\alpha/\nu} \tag{5}$$

where $\bar{x}_i - \bar{x}_j$ is the difference in the arithmetic average of the flood situations of the two comparative flood hazard classes, $s\left(\widehat{D}\right)$ is the standard deviation of the differences, $t_{\alpha/\nu}$ is the quantile of the t distribution for ν degrees of freedom, and n is the number of basins.

The zero hypothesis is rejected if the expression on the left side of the inequality (5) is greater than the quantile of the t distribution. The rejection of the zero hypothesis means that there are statistically significant differences between the physical geographic classes of the flood hazard in terms of the average values of frequency of the flood events. The flood hazard classes acquire regional status if all differences are statistically significant. The results of the variance analysis and the pairwise comparison are presented in Tables 15 and 16.

An F value with a probability of less than 0.001 means that the hypothesis that the expected mean values of the frequency of the flood events are equal can be rejected. Also, the pairwise comparison showed that all the differences between the arithmetic averages of the flood events of flood hazard classes are statistically

Table 15 Results of ANOVA

Source of variation	Degrees of freedom	Sum of squares	Mean square	*F* value	*F* probability
Between flood hazard classes	2	46.9316	23.4658	23.48	< 0.001
Error	1,675	1674.2776	0.9996		
Total	1,677	1721.2092			

Table 16 Results of pairwise comparison

Mean vs mean	*T*	Significant
CFH III vs *CFH II*	−4.808	Yes
CFH III vs *CFH I*	−6.614	Yes
CFH II vs *CFH II*	−2.951	Yes

significant. The three identified classes of flood hazard, therefore, have the character of regional types and, in terms of the number of classes, are the optimal distribution. The classification of small river basins of Slovakia into three regional types of flood hazards is shown in Fig. 12.

5 Summary and Conclusions

The primary cause of the floods is heavy rainfall or rapid melting of snow, but their appearance is also significantly influenced by the physical geographic attributes of the upper basins. As a result, the incidence of flood situations in Slovakia is clearly spatially differentiated. The disposition of the basin attributes to the most frequent flood events (river flooding and sheetwash flooding) is referred to as the flood hazard potential. Its evaluation results in identifying the regional variability of the flood hazard. The regional taxonomic process is based on identifying the physical geographic attributes of the upper basins that have a significant impact on the flood hazard, on creating physical geographic classes based on their combination, and testing the significance of differences in the frequency of flood events between them.

In assessing the flood hazard potential of the upper basins in the mountainous region of Slovakia, it has been shown that, in particular, the soil texture permeability and the forest cover are the basin attributes that have the greatest influence on the spatial variability of flood hazard. Based on their combination, several physical geographic classes were created. Physical geographic classes acquire the character of regional types of flood hazards if they meet the heterogeneity condition in terms of frequency of flood situations, that is, if that the differences in the frequency of flood events between physical geographic classes are statistically significant. This requirement is met if three classes of flood hazards are created on the basis of the combination of classes of soil texture permeability and forestry of the basin.

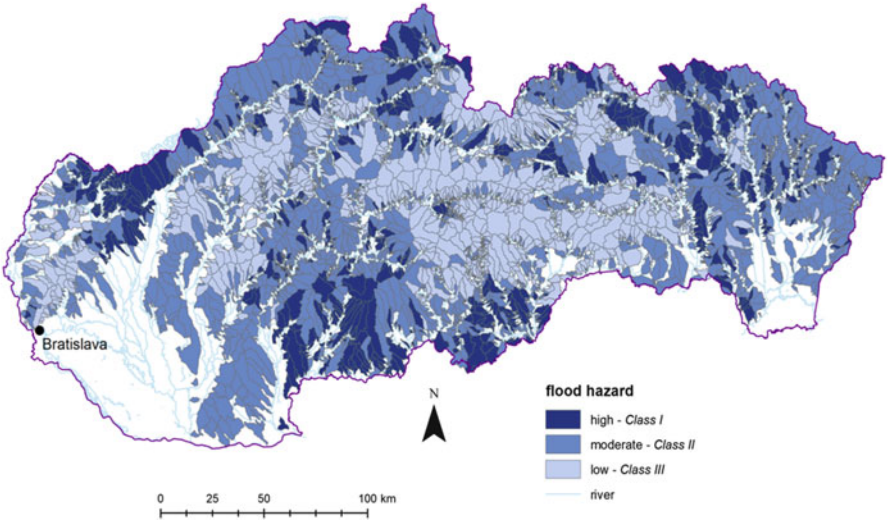


Fig. 12 Classification of small river basins into regional types of flood hazards

Identifying the regional variability of the flood hazard is one of the elements of flood risk assessment and provides exhaustive information on the spatial differentiation of the flood hazard in the upper basins. This enables the state administration and self-government authorities responsible for flood protection to spatially differentiate the application of mainly nonstructural measures to reduce the level of flood hazard.

6 Recommendations

In the present study, the assessment of the flood hazard in the upper basins is based on the physical geographic attributions of the catchment area, i.e. the systematic factors that form the basic features of the hydrological response of the basin. However, the impact on the occurrence of the flood events also has a number of local or incidental factors, e.g. pollution of river channel by solid waste, storing different materials on the bank of the river, deposition of sediment on the beds of watercourses, and overgrown and unkempt river channel. These factors slow down the flow of water, clogging the channel under the bridges by solid waste, increase level of water, and cause flooding. Important local factors also include the inappropriate use of land in the river basin and land devastation after logging forest, which accelerates the formation of overland flow and sheetwash flooding. An attention to local factors has not been given in this work. That is the challenge for further detailed research into flood hazard assessment in the near future.

The fact that local factors have a significant impact on the flood hazard in the upper basins increases the importance of activities aimed at raising public awareness of the flood hazard and increasing individual responsibility for reduction of the flood hazard. Effective management of this role is primarily a challenge for regional and local government and self-government authorities, as well as for non-governmental organizations. However, it is also required to increase the watercourse managers' awareness of the need to maintain the flow capacity and cleanliness of watercourses and zones near watercourses.

Acknowledgement This chapter was written under Project No. 2/0038/15 Flood Risk Assessment and Integrated Management on the Regional Level funded by the VEGA Grant Agency of the Ministry of Education of the Slovak Republic.

References

1. Solín Ľ (2008) Analýza výskytu povodňových situácii na Slovensku v období rokov 1996–2006. J Hydrol Hydromech 56:95–115
2. Rosenthal U, Hart P (eds) (1998) Flood response and crisis management in western Europe. A comparative analysis. Springer, Heidelberg, Berlin
3. Brown JD, Damery SL (2002) Managing flood risk in the UK: towards an integration of social and technical perspectives. Trans Inst Br Geogr 27:412–426
4. Fleming G (2002) How can we learn to live with rivers? The findings of the Institution of Civil Engineers Presidential Commission on flood-risk management. Philos Trans R Soc 360:1527–1530
5. Plate E (2002) Flood risk and flood management. J Hydrol 267:2–11
6. The Associated Programme on Flood Management (APFM) (2004) Integrated flood management. Technical Document No. 1. WMO and GWP, Geneva
7. Werrity A (2006) Sustainable flood management: oxymoron or new paradigm? Area 38:16–23
8. Liao KH (2014) From flood control to flood adaptation: a case study on the lower Green River Valley and City of Kent in King County, Washington. Nat Hazards 71:723–750. https://doi.org/10.1007/s11069-013-0923-4
9. Fritsch O (2016) Integrated and adaptive water resources management: exploring public participation in the UK. Reg Environ Change. https://doi.org/10.1007/s10113-016-0973-8
10. Wisner B, Blaikie P, Cannon T, Davis I (2004) At risk: natural hazards, people's vulnerability, and disasters.2nd edn. Routledge, London
11. Johnson CL, Priest SJ (2008) Flood risk management in England: a changing landscape of risk responsibility? Int J Water Resour Dev (4):513–525. https://doi.org/10.1080/07900620801923146
12. Solín Ľ, Martinčáková M (2007) Niekoľko poznámok k metodológii tvorby povodňových máp Slovenska. Geografický časopis 59:131–158
13. https://www.minzp.sk/files/sekcia-vod/priloha_2-doplnenie_k_castiam_analyzy.pdf
14. https://www.svp.sk/sk/uvodna-stranka/povodne/historicke-povodne/
15. Horváthová B (2003) Povodeň to nie je len veľká voda. Veda SAV, Bratislava
16. Pišút P (2011) Dunajská povodeň v roku 1787 a Bratislava. Geografický časopis 63:87–109
17. Pekárová P, Miklánek P, Melo M, Halmová D, Pekár J, Bačová Mitková V (2014) Floods marks along the Danube River between Passau and Bratislava. VEDA SAV, Bratislava
18. Melo M, Bernáthová D (2013) Historické povodne v povodí Slanej od konca 18. Do začiatku 20. Storočia. Acta Hydrologica Slovaca 14(2):291–298
19. Grešková A (2001) Identifikácia rizikových oblastí a rizikových faktorov vzniku povodní v malých povodiach. Geografický časopis 53(3):247–268

20. Grešková A (2002) Relevantné faktory vzniku a podmienky formovania sa povodňových prietokov v povodí Krupinice v roku 1999. Geographia Slovaca 18:39–47
21. Trizna M, Zvolenský M (2001) Povodňové situácie na slovenských tokoch v rokoch 1985–2000. Geografie XII, Masarykova univerzita 347–351
22. Horton RE (1933) The role of infiltration in the hydrological cycle. Trans Am Geophys Union 14:446–460
23. Hewlett JD, Hibbert AR (1967) Factors affecting the response if small watersheds to precipitation in humid areas. In: Sopper WE, Lull HW (eds) International symposium on Forest hydrology. Pergamon, Oxford, pp 275–290
24. Betson RP (1964) What is watershed runoff? J Geophys Res 69:1541–1551
25. Dunne T, Black RD (1970) Partial area contribution to storm runoff in a small New England watershed. Water Resour Res 6:1296–1311
26. Waeyman DR (1970) Throughflow on hillslopes and its relation to the stream hydrograph. Bull Int Assoc Sci Hydrol 15:25–33
27. Smith K, Ward R (1998) Floods. Physical processes and human impacts. Wiley, Chichester
28. Solín Ľ (2011) Regionálna variabilita povodňovej hrozby malých povodí na Slovensku. Geografický časopis 63:29–52
29. Minár J, Trizna M, Barka I, Bonk R (2005) Povodňový potenciál na území Slovenska. Geografika, Bratislava
30. Weingartner R, Barben M, Spreafico M (2003) Floods in mountains areas – an overview based on examples from Switzerland. J Hydrol 282:10–24
31. Solín Ľ, Grešková A (1999) Malé povodia Slovenska – základné priestorové jednotky pre jeho regionálne členenie. Geografický časopis 51:78–96
32. HMÚ (1965) Hydrologické pomery ČSSR I. Hydrometeorologický ústav, Praha
33. Solín Ľ, Cebecauer T, Grešková A, Šúri M (2000) Small basins of Slovakia and their physical characteristics. Institute of Geography of SAS, Slovak Committee for Hydrology, Bratislava
34. Hofierka J, Šúri M, Cebecauer T (1998) Rastrové digitálne modely reliéfu a ich aplikácie. Acta Facultatis Studiorum Humanitatis et Naturae Universitatis Prešoviensis, Prírodné vedy 30, Folia. Geographica 2:208–217
35. Šály, R, Šurina B (2000) Pôdy Slovenska – mapa 1:500 000. VÚPOP, Bratislava
36. Feranec J, Oťaheľ J, Pravda J (1996) Krajinná pokrývka Slovenska – identifikovaná metódou CORINE Land Cover. Geographia Slovaca 11, Geografický ústav SAV, Bratislava
37. Porubský A (1980) Hydrogeológia. In: Mazúr E (ed) Atlas SSR Geografický ústav SAV, Slovenský úrad geodézie a kartografie, Bratislava
38. Faško P (1999) Mapa izohyet priemerných ročných úhrnov zrážok 1931–1980 v mierke 1:750,000. SHMÚ, Bratislava
39. Bedrna Z, Fulajtar E, Zrubec F, Juráni B (1989) Pôdne režimy. Veda SAV, Bratislava
40. Šály R (1962) Lesné pôdy Slovenska. Veda SAV, Bratislava
41. Šály R (1986) Svahoviny a pôdy Západných Karpát. Veda SAV, Bratislava
42. Solín Ľ (2004) Susceptibility of basins to floods-regional typification of small basins of Slovakia from the point of view of soil permeability. In: Conference proceedings. XXII conference of Danubian countries on the hydrological forecasting and hydrological bases of water management. ČHMÚ, Brno, CD-ROM
43. Littlewood IG, Down K, Parker JR, Post DA (1997) IHACRES v1.0. Wallingford (Centre for Ecology and Hydrology), Canberra Integrated Catchment Assessment and Management Centre, Australian National University
44. Fischer MM (1987) Some fundamental problems in homogeneous and functional regional taxonomy. Bremer Beiträge zur Geographie und Raumplanung 11:264282
45. Bezák A (1996) Regional taxonomy: a review of problems and methods. Acta Facultatis Rerum Naturalium Universitatis Comenanae, Geographica 28:43–59
46. Solín Ľ (2006) Identification of homogeneous regional classes for flood frequency analysis in the light of regional taxonomy. Hydrol Sci J 50(6):1105–1118
47. Anderberg MR (1972) Cluster analysis for applications. NTIS, New Mexico

48. Lachenbruch PA (1975) Discriminant analysis. Hafner, London
49. Hall MJ, Minns AV (1999) The classification of hydrologically homogeneous regions. Hydrol Sci J 45:693–704
50. Jingyi Z, Hall MJ (2004) Regional flood frequency analysis for the Gan-Ming river basin in China. J Hydrol 296:98–117
51. Grigg D (1965) The logic of regional systems. Ann Assoc Am Geogr 55:465–491
52. Armand DL (1975) Nauka o landšafte. Mysľ, Moskva
53. Neter J, Wasserman W, Kutner RM (1985) Applied linear statistical models. Irwin, Inc., Homewood, IL
54. Hsu JC (1996) Multiple comparison. Chapman, Boca Raton

Flood Risk of Municipalities in Upper Basins of Slovakia

Ľ. Solín and M. Sládeková Madajová

Contents

Abstract The aim is to present a comprehensive, integrated flood risk assessment for municipalities located in the upper basins. An integrated approach perceives the flood risk as the combination of flood hazard and vulnerability. The flood hazard is expressed as the potential of the basin to flood due to basin attributes. The vulnerability is understood as inherent characteristics of municipalities that create the potential of municipalities for the susceptibility of houses to damage and of people to suffer physical and mental harm and the ability of people to cope with negative consequences of floods. A spatial multicriteria decision analysis was applied to express the flood risk relatively by an ordinal scale. Municipalities were classified into the five classes of flood risk by an aggregation of sub-indices reflecting flood hazard and vulnerability. An integrated approach addresses the assessment and management of the flood risk in a more complex way and eliminates the negative effects of more traditional engineering approaches.

Ľ. Solín (✉) and M. Sládeková Madajová
Institute of Geography, Slovak Academy of Sciences, Bratislava, Slovakia
e-mail: solin@savba.sk; geogmada@savba.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 173–194,
DOI 10.1007/698_2017_173,
Published online: 9 December 2017

Keywords Flood hazard, Flood risk, Integrated assessment, Multicriteria analysis, Upper basins, Vulnerability

1 Introduction

Moving from a passive traditional, technically oriented flood control strategy to flood adaptation is a strategy based on an integrated assessment and management of flood risk. In this strategy flood risk is no longer just about the natural disaster itself but also the assessment of the expected loses (e.g. property damage, persons injured, lives or economic activity disrupted) due to a particular flood hazard and vulnerability of society [1–3].

Although this change in the flood risk paradigm has been in place since the 1970s [4], moving from a traditional flood protection strategy to an integrated assessment and management of the flood risk has been slowly taken up in Slovakia. Certain expectations for changing the approach to tackling floods have been generated by "Directive No. 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks" [5]. This directive was implemented into the legal system of the Slovak Republic by Act No. 7/2010 [6] and its amendment, Act No. 71/2015 [7]. However, the drawing up of flood hazard and flood risk assessment maps, as well as flood risk management plans, was considered a formal matter [8]. The proposed flood risk management plans continue to be based solely on the reduction of the flood hazard through technical measures. There was an attempt to change flood risk management which began with the *Programme of Landscape Revitalisation and Integrated Basin Management* [9] approved by the Slovak Government in October 2010, but after the March 2012 elections, the project was cancelled by the new government. The project also aimed to activate and create conditions in the long term, for the effective functioning of a comprehensive and integrated system of measures to ensure flood prevention. In the end, however, it focused mainly on the ability of the landscape to retain flood waters through the implementation of water-retention and revitalization measures on small watercourses.

The current state of flood protection in Slovakia is primarily the result of the strong tradition of constructing technical water management structures and flood protection through the regulation of watercourses. The construction of protective dams, water reservoirs and polders are considered a priori to be the core of flood risk management. There is little or no attention paid to measures reducing the vulnerability, or these are only considered as an add-on without fundamental significance. However, the systematic implementation of vulnerability reduction measures has become important not only because of the changing paradigm of flood risk management but also because of the ongoing threat of climate change and changes in landscape cover within the catchment area. These changes may contribute to the effects from extreme climatic and hydrological phenomena, where existing flood protection infrastructure may not have the capacity to protect communities at risk. Conversely, the failure of which can cause further disaster. Absolute flood protection through technical constructions does not exist, and society must be prepared to deal with natural catastrophic phenomena. One of the ways to achieve this is to evaluate flood risk in a more comprehensive way than traditional assessment. The aim of the chapter is to move to the integrated assessment of flood risks of municipalities located in small basins by the combination of results achieved in relation to the assessment of the flood hazard and vulnerability.

2 Conceptual and Methodological Framework for Integrated Flood Risk Assessment and Management

2.1 Conceptual Framework

The basic feature of an integrated approach to flood risk assessment and management is its complex nature. The engineering approach understands the concept of risks in relation to the threat of flooding only (flood risk = flood hazard). Flood hazard can be expressed in the form of probability or in the form of potential, i.e. the disposition of the basin to the flood, which is determined by basin attributes [10–12]. Integrated approach perceives the risk as the combination of flood hazard and the negative consequences that a flood event may cause (flood risk = flood hazard × negative consequences). The negative effects of a flood (besides the flood hazard attributes) "depend on the vulnerability of objects of the social, economic and environmental systems to floods in a given area" [13–15]. Integrated flood risk management consists of a combination of the three sub-strategies [16]: (a) flood reduction strategies, (b) vulnerability reduction strategies and (c) mitigation strategies.

The main cause of the paradigm shift in preventive flood protection can be found in changing the value system of the society that emphasizes sustainable development [17]. While the occurrence of floods and the damage they cause are constantly increasing, the exclusive application of the engineering approaches to mitigate floods is considered unsustainable. In the longer term, limiting the technical approach to flood protection and linking an integrated flood risk assessment and management strategy are considered to be more effective [16, 18]. The emphasis is placed on reducing the level of flood risk to an acceptable level, by various measures. These are, on the one hand, aimed at reducing the flood hazard potential and property vulnerability to damage. On the other hand, the same attention is paid to increasing the capacity of the population to withstand floods, by learning to cope with the negative impacts of floods and taking individual responsibility to alleviate the damage caused by the floods.

In the context of natural disasters, vulnerability research in the 1970s has ventured into the social sciences, which began to take a closer look at the consequences of natural disasters. Due to its diverse nature, the concept of vulnerability was subsequently elaborated in several disciplines (social, environmental and geographical). Apart from the context of natural hazards and sustainable development, the vulnerability can also be studied regarding climate change, technological hazard or, for example, terrorism

[19]. As a result, several conceptual frameworks for study and assessment of vulnerability have been developed. An overview of current views on vulnerability research offers, for example, [20–23]. Thywissen [21] has prepared a summary of the definition of the term and Birkmann [20] presented a certain systematization of views on vulnerability.

Various vulnerability concepts differ from each other regarding components and domains [19]. The vulnerability is multidimensional (social, economic, environmental and institutional) and has multiple structures. From it as a research subject, the so-called *socially based vulnerability* and *place-based vulnerability* can be distinguished [24, 25]. The first is aimed at assessing the vulnerability of individuals or social groups (family, community, nation) [26–28]. Also the vulnerability of economic subjects (so-called *economic vulnerability*), natural environment and natural resources (*environmental vulnerability*) or institutional authorities that shape disaster reduction policy (*institutional vulnerability*) can be analysed. The second deals with the vulnerability of a place (e.g. rasters, polygons, regions, administrative units and so on) [19, 29–34]. The level of vulnerability associated with a place is composed of the social, physical and built environment characteristics that make the place susceptible to damage and influence the ability to recover after floods [30].

Depending on whether or not the influence of the natural hazard is taken into account when assessing the vulnerability of objects, two approaches to the vulnerability assessment are distinguished. The first analyses the vulnerability about the concrete attribute of the hazard – this is *the hazard-dependent vulnerability*; the second is *hazard-independent approach* [25], and it does not account for the level of exposure to the natural hazard. In this case, vulnerability is seen as a potential of the social, economic and environmental system for:

- Susceptibility to suffer damage, physical and psychological harm (susceptibility potential to damage).
- Resistance to floods at the time of their occurrence (coping capacity or resistance potential) and to deal with the negative consequences of the floods after their end (adaptive capacity or resilience potential).

Meanwhile, the concept of susceptibility represents the passive (negative) component of vulnerability. Vulnerability increases with increased susceptibility. On the other hand, the concepts of resistance and resilience are active (positive) components of vulnerability, and with increasing resistance and/or resilience, the vulnerability of systems decreases.

In addition to vulnerability, an important aspect that affects the negative impacts of floods is awareness of flood risk, resulting from an individual and institutional responsibility for flood protection. Several European studies [35–37] point out that the level of individual responsibility for natural disasters is low. At the very least in Slovakia, the engineering approach to flood protection and the financially demanding of building technical structures, which creates the idea that protection against flooding is mainly the responsibility of the government, contribute to this.

As reported by [38], several studies indicate that responsibility for behaviour is related to the perceptions that people hold (e.g. [39–41]). It is argued that individuals may differ in their perceptions of social responsibility, based on their unique set of factors. However, there are contrasting findings on the influence of these factors. Past personal experiences of flooding [42–44], age [41, 45], gender [46, 47] or ethnicity [48–51] are recognized by many researchers as factors that can significantly influence the awareness of risk, response and preparedness.

It is important to realize that there is no absolute flood protection and, as Liao [52] points out, rather than preventing floods, we must learn to live with them. Structural measures (flood defence) should be complemented by other measures (flood protection through adaptation), especially those that increase individual and institutional responsibility in flood protection. Pitt [53] highlights the need for community groups (householders, small business) to work together with the government in resilience-enhancing actions (via local resilience forums). These initiatives can help to clarify what individuals are expected to do by themselves and how the government can support them.

2.2 Methodological Framework

There are two groups of methods for setting the level of flood risk [54]. The first group consists of methods expressing flood risk in an absolute way, for example, by expected damage value in euros, while the second group includes the method expressing the flood risk relatively by an ordinal scale.

The assessment of flood risk in an absolute way combines the expected losses from all levels of hazard severity also taking into account their probability [55, 56]. This means that flood risk is represented by the area under the damage-probability curve (see Fig. 1).

The size of this area expresses the overall average annual damage. Summation sets the expected monetary value of overall average annual damage ($E[X]$) on the discrete scale:

$$E[X] = \sum_{i=1}^{l} p_i x_i \tag{1}$$

where p_i is flood event probability and x_i is the amount of damage caused by flood event expressed, for instance, in €.

The average annual damage is the basic quantitative characteristic of flood risk to the economic system. It is the indispensable source for the assessment of the financial effectiveness of particular flood defence measures via the cost-benefit analysis. Despite some progress achieved in the methods of financial estimation of social and environmental systems [57, 58], there are some problems connected with the financial expression of social and environmental consequences [59, 60]. This is the reason why instead of expressing flood risk in an absolute way, it is expressed relatively – on the ordinal scale, namely, the dimensionless values of the hazard and

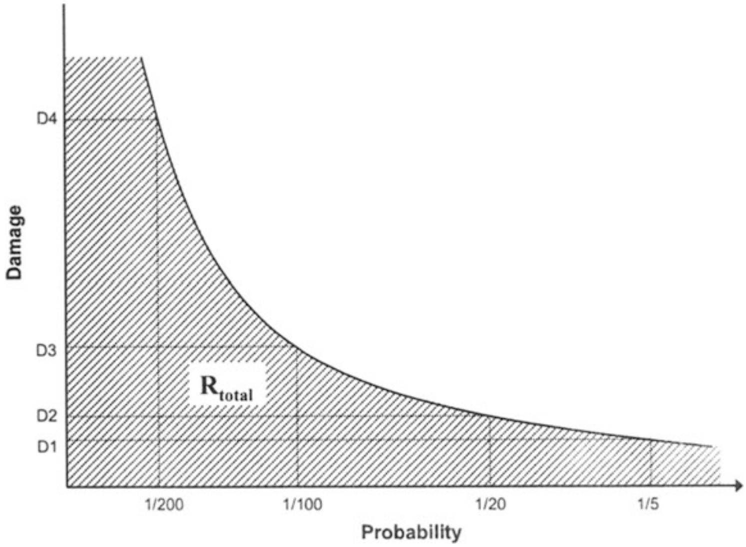


Fig. 1 Damage-probability curve (reproduced from [56])

vulnerability are aggregated and then ranked into classes expressing high, moderate or low level of risk. This process is the core of the spatial multicriteria decision analysis (MCDA).

The spatial MCDA is a relatively new and rapidly advancing method that continues to develop with GIS systems [61, 62]. The MCDA aims to establish the overall order of alternatives from the most preferred to the least preferred one. Regarding the nature of the decision-making space (discrete and continuous), there are two types of the MCDA: multiattribute decision-making (MADM) and multiobjective decision-making (MODM). The MADM solves a problem by choosing the best alternatives from the set of given alternatives. MODM searches for the optimal alternatives for the objective function. In the case of assessing the flood risk of a given set of spatial units (alternatives), which means an assessment of different areas regarding their flood risk status and finding the best strategies and measures to reduce flood risk to an appropriate level, the MADM approach is preferred [32, 63]. The process of flood risk assessment by the MADM approach consists of several steps [61]:

1. Definition of the problem
2. Evaluation criteria
3. Alternatives
4. Evaluation of criteria/decision matrix
5. Standardization of criteria and their weighting criteria
6. Decision-making rules
7. Sensitivity analysis/uncertainty
8. Result/evaluation/selection/recommendation

The first step in any decision or evaluation is naturally defining the problem. In relation to the flood risk assessment, the problem is the lack of information on the size and spatial differentiation of risk [32]. The choice of evaluation criteria affects the result of the analysis to a large extent; therefore, it is one of the most sensitive parts of the analysis. The set of criteria should be complete on the one hand (so that it affects all aspects of the problem about which we decide or that we evaluate) but also minimal and non-redundant (so that the evaluation/decision process is as short and simple as possible). Individual alternatives must be then evaluated in relation to each criterion. Standardization is the transformation of original variables expressed by various physical units to dimensionless units by mathematical operations, while the relationships, intervals and spans of values are preserved. Standardization of variables is carried out by several methods such as the linear transformation or by the value/utility function. Weighting expresses the size of effects of the individual variables on the overall level of flood risk. This is a crucial and very delicate step of MCDA because even a slight change of overall weights can later transform into a relatively important change of the analysis outcome. Establishment of weights can be carried out by several methods: ranking, rating, pairwise comparison, swing weight approach, group decisions and also as one of the steps from the analytic hierarchy process (AHP). Aggregation of weighed values of individual variables constitutes the core of the MADM. Clustering algorithms are various. They can be based on comparatively simple decision-making rules (dominance strategy and disjunctive approach) or other more sophisticated ones (different additive models, analytic hierarchy process – AHP, ideal point method and others). For the detailed description of individual algorithms, see [61, 63].

An important aspect of flood risk assessment and management is the spatial level of its research [14, 56, 64]. Typically, three levels of research are identified, namely, national (macro), regional (meso) and local (micro). With a changing spatial level, the level of detail of the input data necessary for the assessment of the flood hazard and vulnerability and also the spatial and substantive aspect of the assessment change. At the national level, the flood risk of the basic territorial units as a whole is evaluated. At the regional level, the flood risk of areal units representing the economic, social and environmental system of basic territorial units is evaluated. At the local level, the flood risk of individual buildings and the groups of objects are evaluated respectively.

3 Integrated Assessment of Flood Risk of Municipalities in Headwater Areas

The assessment of the flood risk of municipalities in the upper basins represents national level research with the objective to identify the spatial variability of flood risk. There are 1,876 municipalities (64%) of the total number of 2,928 municipalities in Slovakia, located in the upper basins. The integrated assessment of their flood risk, which is based on the idea that flood risk is the product of flood hazard and vulnerability, has been elaborated in work [65]. The flood risk assessment is based on the potential basis, and MADM was applied to quantify flood risk on an ordinal scale. The following model represents this approach:

$$IIFR = FHI + ITV \quad (2)$$

where *IIFR* is integrated index of flood risk, *FHI* is flood hazard index and *ITV* is an index of total vulnerability.

The *FHI* and *ITV* index values express a score of aggregation of standardized values of proxy variables, representing flood hazard and vulnerability of municipalities. Variables were standardized using the maximum score approach according to Malczewski [62]. The transformation equation is

$$x_{ij}^{'} = \frac{x_{ij}}{x_j^{\max}} \quad (3)$$

where x'_{ij} is the standardized value of the variable, x_{ij} is original value of the variable score and $x_j^{\max}$ is the maximum value of the variable. The subscript index *i* applies to the municipality and *j* to the variable.

3.1 Flood Hazard Assessment

The assessment of flood hazard of municipalities in the upper basins is derived from the flood hazard of the catchment areas which the municipalities are located in. In our chapter titles “Flood hazard in a Mountainous Region of Slovakia” in this volume it was proven that the optimal grouping of headwater basins is into three regional flood hazard classes (low, medium, high). Ranking values have been assigned to each class to express the level of flood hazard: low flood hazard (ranking value = 1), medium flood hazard (ranking value = 2) and high flood hazard (ranking value = 3). The flood hazard index (*FHI*) is expressed as a flood hazard score of standardized ranking values (x_{ij}) for the flood hazard classes. They have a value of 0.33, 0.66 and 1.00, respectively. By overlaying the layer of flood hazard classes of basins with the layer of centroids representing 1,876 individual municipalities in GIS, the level of flood hazard for each municipality has been established. It corresponds to *FHI* of the basin in which it was located. Graphical visualization of flood hazard is based on the boundary of the municipality (Fig. 2).

3.2 Assessment of Vulnerability

Vulnerability assessment of municipalities in the framework of potential is carried out regardless of the flood hazard attributes; it is hazard independent. Because it is

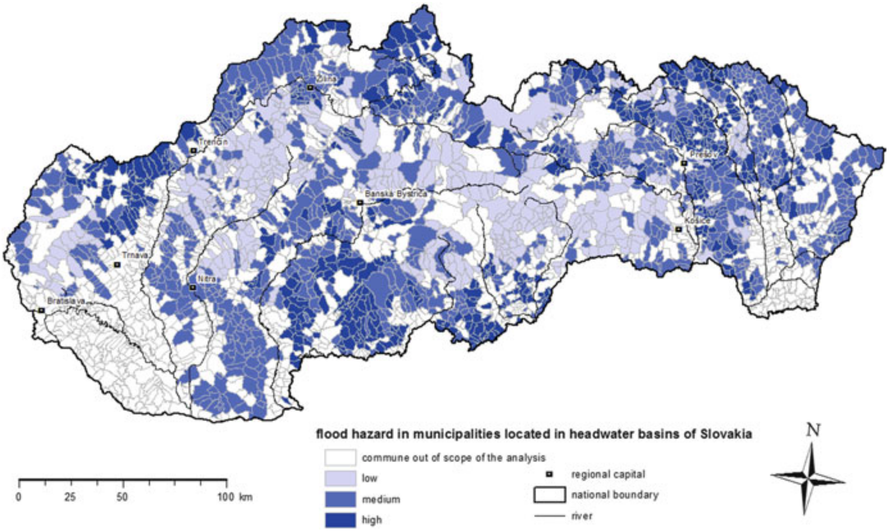


Fig. 2 Flood hazard of municipalities located in headwater basins (Courtesy of WIT Press from [65])

not possible to measure vulnerability directly [66], it can be only declared by means of indicators or proxy variables. These variables express the internal predisposition or potential of municipalities for susceptibility of the houses to damage, susceptibility of people to suffer physical and mental harm and ability of people to cope with negative consequences of floods. One way to quantify the level of these different aspects of vulnerability is to express it through sub-indices as: Index of Susceptibility to Damage (*ISD*), Index of Susceptibility to Physical and Mental Harm (*ISPMH*) and Index of Resilience (*IR*). They are determined as a score (U) on the basis of proxy variables:

$$U_{ij} = \sum_j w_j u_{ij} \tag{4}$$

where U_{ij} score of the vulnerability aspect j of municipality i, u_{ij} is the standardized score of the variable corresponding to the vulnerability aspect j of municipality i and w_j is a weighting that represents the effect of a variable on the vulnerability aspect j.

By aggregating scores of partial sub-indices of vulnerability together, we get an index of total vulnerability (*ITV*) of the municipality to flood hazard:

$$ITV = ISD + ISPMH + IR \tag{5}$$

The 2001 census data and data about flood insurance events provided by the Allianz-Slovak Insurance Company for the period 2002–2011 were used in the assessment of the vulnerability. The ability to cope with the negative consequences of floods and the capabilities of communities to restore their original state were expressed through the level of insurance against the risk of flooding [65].

3.2.1 Assessment of Susceptibility of the Asset to Damage and Social System to Suffer Physical and Mental Harm

The issue of susceptibility of houses to damage and people to suffer physical and mental harm is expressed by the proxy variables, in relation to which some rules and justifiable criteria of vulnerability have been applied. Rules generally describe the anticipated impact of proxy variables on some aspects of vulnerability. Criteria are selected values of proxy variable attributes by which the vulnerability is assessed. With the rising value of a given criterion, the vulnerability of households in municipalities may increase (i.e. negative influence of proxy variables on vulnerability). Proxy variables for different aspects of vulnerability and their criteria are summarized in Table 1.

The susceptibility of houses to damage is expressed by two variables: material used for their construction and the period of their building. In the 2001 Slovakia census, according to the material used in the construction of the load-bearing walls, houses were classified into four groups: (1) stone and brick houses, (2) wooden houses, (3) unfired brick houses and (4) other and unspecified materials. In relation to this proxy variable, the following rule was applied: houses with external walls built of unfired bricks and other unspecified materials are more prone to damage than houses built of stone, brick and wood. In keeping with this rule, the percentage of houses built from unfired bricks and unspecified materials (*UBUM*) in municipalities was determined as criteria for assessing the susceptibility of houses to damage.

Regarding the period during which the houses were built, it seems useful to distinguish three construction periods: (1) before 1945, (2) 1946–1980 and (3) after 1980. These groups are characterized by distinct typological differences between the houses from the point of view of the height of the ground floor above the ground and waterproofing of the houses [19]. Although the architecture of rural houses built

Table 1 Proxy variables of vulnerability

Vulnerability aspect	Proxy variable	Criterion of vulnerability
Susceptibility to damage	Material of bearing walls	*Percentage of earthen houses, other and unspecified materials*
	Date of construction	*Percentage of houses before 1945*
Susceptibility to mental and physical harm	Age structure	*Percentage of people over the age of 65*
	Ethnicity	*Percentage of Romany ethnicity*
	Family completeness	*Percentage of incomplete families*
	Category of family house	*Percentage of houses of the 3rd and 4th category*

in Slovakia before 1945 typically exhibits certain regional differences, the houses possess one common characteristic, i.e. the ground floor is near to the ground (1–2 steps above ground level), and the level of waterproofing is comparatively low, given the materials that were available at the time. The building of family houses on a square plan with dimensions of about 10 × 10 m, with a ground floor about 1.5 m above the terrain, is typical for the period 1946–1980, for the whole of Slovakia. The increased elevation of the ground floor provided comparative safety against flooding. However, these houses are at risk of the flooding of their cellars where, as a rule, their central heating boilers are situated. By the beginning of 1990, the construction of bungalows with floor situated just above ground level had become common. Although this lower floor increased the level of risk, advances in the materials and technology of construction meant that the level of waterproofing in these houses is significantly better than in those built before 1945. Considering the year of construction, the following rule was applied to family houses: construction solutions in older family houses create greater potential for damage to property compared to a construction solution for houses built in more recent years. Percentage of family houses built before 1945 (*Hb45*) in the municipality is then used as a criterion which represents susceptibility to damage by flood.

In assessing the suffering of physical and mental harm to people in municipalities, four proxy variables have been used: age structure of the population, ethnicity, completeness of family and category of family house. As far as the age structure of the population is concerned, generally a rule is applied to seniors over 65 who may not be physically and mentally vital enough to adequately protect themselves and their property from the negative effects of floods. So, criterion percentage of seniors over 65 (*So65*) in the municipality was set to assess a vulnerability. Incomplete households, because of a missing family member (e.g. husband or wife), are exposed to much greater stress in protecting themselves and their property from the negative effects of floods. The percentage of incomplete families (*IF*) in the municipality was then set as another criterion.

Reference [29] stated that race and ethnicity impose language and cultural barriers that affect access to post-disaster funding and residential locations in high hazard areas. From this point of view, Romany ethnicity is important in the case of Slovakia. Many people of Romany ethnicity live in segregated colonies. Their increased vulnerability is connected with the construction of colonies near water streams, the poor quality of their dwellings (huts and shacks) and overcrowding. Pursuing the annual statements concerning dwellings on a low sociocultural level from the end of 2000, 620 Romany colonies were registered in cadastral territories of municipalities in Slovakia [67]. The fact is that ethnicity is a delicate variable and any generalization of attitude to ethnicity may result in prejudice and discrimination. On the other hand, the most tragic consequences of flooding in Slovakia are connected precisely with the Romany community. During the flooding in July 1998, the Romany colony located in the basin of Malá Svinka had 50 causalities. The so far imposed evacuations also concerned mostly the Romany people in their colonies. So, the percentage of Romany ethnicity (*RE*) of the total population of the municipality is considered a significant criterion of vulnerability.

Poverty is a significant factor that affects damage and mental harm as well as the ability to cope with the negative consequences of floods. However, no information about income or savings of households is available. The financial situation of the population is, as a rule, estimated using indices of financial deprivation, which contain various variables [68]. In this work, a categorization of the family houses was used to express financial status. Houses in the 1st category contained central heating and complete or partial basic accessories. Houses in the 2nd category had no central heating but did have a complete set of basic accessories. Houses in the 3rd category had no central heating but did have a partial set of basic accessories, while those in the 4th category had neither central heating nor basic accessories. It was presumed that houses classified in the 3rd and 4th categories indicated much smaller financial resources than houses in the 1st and 2nd categories. Following this rule, the percentage of 3rd and 4th category houses (*CH34*) of the total number of houses in municipality were set as another criterion for vulnerability.

Using Eq. (4) a combination of two criteria of susceptibility of houses to damage (percentage of *UBUM* and percentage *Hb45*) forms the sub-index Susceptibility to Damage (*ISD*). In the same way, a combination of the four criteria expressing physical and mental harm to people in communes (percentage *So65*, percentage *IF*, percentage *RE*, percentage *CH34*) forms the sub-index of Susceptibility to Physical and Mental Harm (*ISPMH*). By aggregating partial sub-indices *ISD* and *ISPMH* together, we obtain a summarized index of commune vulnerability in terms of susceptibility to damage and physical and mental harm (*SISDH*):

$$SISDH = ISD + ISPMH \tag{6}$$

Spatial variability of communes from the point of view of *SISDH* is presented in Fig. 3.

3.2.2 Assessment of Ability to Cope with Negative Flood Consequences

In addition to reducing the extent of flooding and vulnerability of society, the mitigation of negative impacts of floods becomes no less important with an up-to-date strategy within the integrated flood risk assessment and management [69, 70]. This essential part involves the participation of the state and the insurance companies in providing compensation for the damages caused by floods, but it also focuses on increasing individual responsibility and awareness for flood hazards.

The legislative system of the Slovak Republic (SR) does not impose on the state the statutory obligation to participate in damages caused by floods to individuals and legal persons. In Slovakia, under Section 43 of Act No. 7/2010 on floods [6], the State is required to reimburse only the costs incurred in carrying out flood security and rescue work during the level 2 and level 3 flood emergency. However, in the case of large flood damage, the Government of SR may decide to provide a one-off

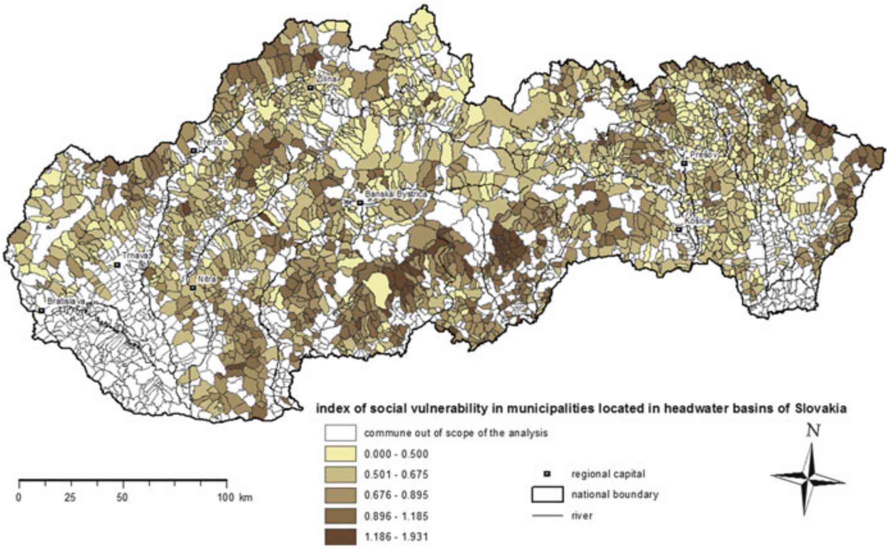


Fig. 3 Vulnerability index *SISDH* of municipalities located in headwater basins (Courtesy of WIT Press from [65])

contribution to the damage. This is usually a partial reimbursement made through the state budget reserve (mainly reserve from the Prime Minister).

Further options for covering the consequences of floods in Slovakia are other non-state sources. Since state and other external assistance is limited and insufficient, the issue of individual responsibility for flood preparedness is an important aspect. Active participation of individuals in the mitigation strategy of flood damage is possible through commercial insurance, for example. Insurance plays an important role in the ability of households to cope with the negative consequences of the floods [71].

However, reliable data on the use of commercial flood risk insurance is relatively difficult to obtain. At present, 14 insurance companies are operating in SR, which also provide insurance for damage caused by floods in the area of non-life insurance (as of 31 March 2016) [72]). Three of them have the largest market share: Allianz-Slovak Insurance Company has 35%, Kooperativa 27%, and Generali 10%. The flood risk insurance level by individual municipalities during the years 2002–2011 was provided from data on the number of policy holders and insurance claims by the Allianz-Slovak Insurance Company.

An analysis of empirical data about flood risk insurance during the years 2002–2011 by individual municipalities has been done by [73]. The trend analysis of the flood risk insurance shows a relatively large decrease in the number of insurance policies in the monitored period. The significant decline in the interest of the population in flood risk insurance is not a local phenomenon, but it is of an all-Slovak nature. At the end of 2011, only 54.4% of the insurance contracts were active compared to 2002. The mean level of insured properties against flooding in municipalities situated in headwater basins decreased from 60% in 2002 to 33% in 2011. Apparently, these values have to be interpreted with some reservations, as it is only data of one (although the largest) insurance company in the insurance market. However, it can be assumed that a similar trend exists in other insurance companies. Based on these facts and the position of Allianz in the insurance market, we estimate that the total flood risk insurance rate in Slovakia may be approximately around 50%.

The loss of policyholders may be due to some factors which influence the decision to continue an insurance policy, e.g. the acceptability of premiums, certain population awareness about flood hazard as well as the population's financial situation. However, as the analysis provided by [71, 73] showed, the level of flood hazard has no significant impact on the decision to insure against damage caused by floods. On the other hand, there is a trend between the number of flood insurance policies in municipalities and the vulnerability of municipalities (Fig. 4). Box plots show a distinct decrease in the number of policyholders with the increase in the vulnerability class of municipalities expressed by *SISDH*.

The ratio of the number of insured residential buildings in individual municipalities to the total number of residential buildings (single-family houses and flats) forms the insurance rate. The standardized values of insurance rate in 2011 by the method of maximum value are the Index of Resilience (*IR*). The spatial variability of the municipalities in upper basins in terms of *IR* is shown in Fig. 5.

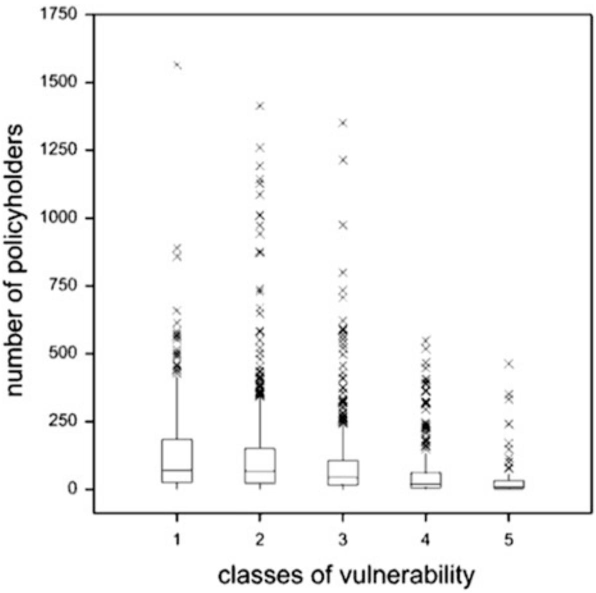


Fig. 4 The relationship between the vulnerability classes and the number of policyholders in municipalities located in the headwater basins (Courtesy of Wiley from [73])

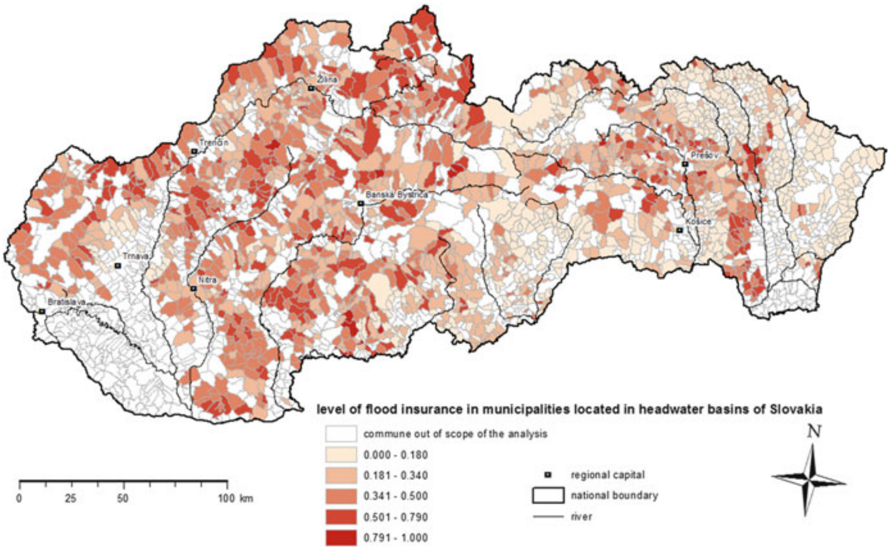


Fig. 5 Index of resilience *IR* of municipalities located in headwater basins (Courtesy of WIT Press from [65])

3.3 Flood Risk Assessment

The level of overall flood risk is expressed by the index *IIFR* calculated in Eq. (2). This index is the aggregate of the values of the sub-indices reflecting flood hazard and vulnerability, i.e.

$$IIFR = FHI + SISDH + IR \tag{7}$$

The result of the integrated approach to the preliminary flood risk assessment of municipalities in upper basins is shown in Fig. 6. Municipalities located in upper basins were, according to the flood-risk index, classified into five ranks [65]: very high, high, medium, low and very low levels of flood risk.

Flood-risk assessment on an integrated approach represents a rationale for the application of a spatially differentiated approach in flood-risk management. For each class, it is possible to design the optimal strategy and measures to reduce flood risk. The integrated approach deals with the assessment of flood risk in an exhaustive manner (i.e. all municipalities in upper basins are subject to assessment). This creates a rational basis for increasing public awareness of flood risk and strengthening individual responsibility for the mitigation of the negative impacts of floods and involves all corresponding stakeholders in the decision-making process on reducing flood risk.

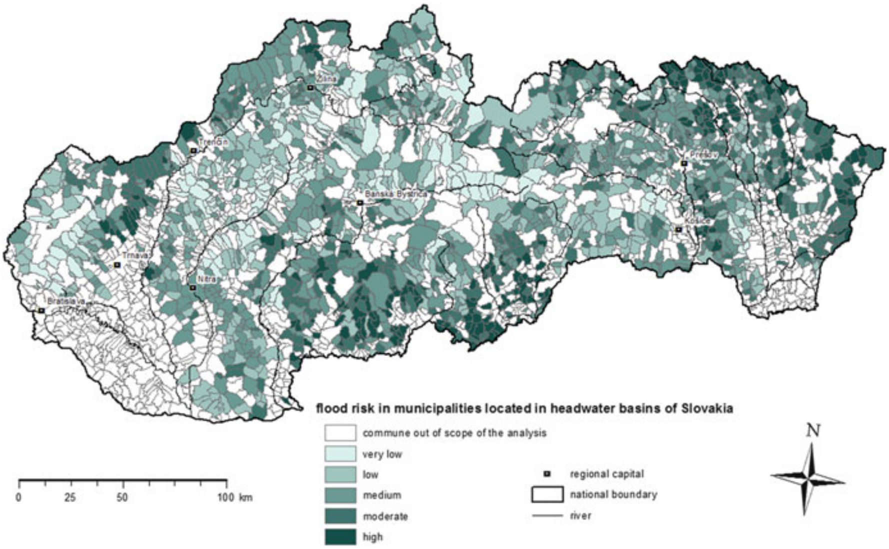


Fig. 6 The level of flood risk in municipalities located in headwater basins (Courtesy of WIT Press from [65])

4 Summary and Conclusions

The results of evaluation of flood risk in this chapter present an integrated approach to flood risk assessment through both flood hazard and vulnerability assessment. The flood hazard in headwater basins is understood as a potential – i.e. the disposition of the basin to suffer from flood – which is influenced by attributes of the headwater basins and manifests itself as the frequency of all types of flood events in municipalities. In the basins with less permeable soils, flood events are more frequent than in basins in which permeable soils prevail. The vulnerability of municipalities was characterized by the following proxy variables: the materials the houses were built from and the period in which they were built, the age structure of the population, ethnicity, family structure and the category of the house. The ability for recovery after floods was expressed by flood insurance rates in these municipalities. The result of the preliminary flood risk assessment, achieved on the basis of a combination of the aforementioned factors, is the classification of 1,876 municipalities in small river basins into five ordinal classes of flood risk. For each class, it is possible to design the optimal strategy of flood risk management.

Unlike the engineering approach, an integrated approach addresses the issue of the flood risk in a more complex way, which greatly eliminates the accompanying negative phenomena of the engineering approach to flood risk issue. In the case of flood hazard assessment, it underlines the principle that all types of flooding should be assessed and managed coherently [74]. Therefore it is not sufficient to consider only river flooding in upper basins, and a comprehensive assessment of flood hazard is required. The concept of vulnerability is a key factor in the assessment and management of flood risk. The systematic implementation of vulnerability strategy aimed at reducing individual as well as institutional vulnerability and to increase the ability to cope with the negative consequences of floods is becoming important.

To reduce vulnerability, public participation is also necessary. As [75] points out, one of the basic pillars of the strategy of actively involving individuals in the process of mitigating the consequences of floods is the availability and affordability of flood cover on the one hand and education on the other. The issue of the availability of flood hazard information is also important given the decreasing rate of flood risk insurance. Individuals should be able to find as much information as possible about the potential risk to increase their preparedness. For instance, it is important to know that flood losses are not necessarily only caused by river flooding and strictly bound to objects in the floodplain zones. Knowledge about hazard exposure would undoubtedly contribute to the increasing public awareness of flood risk and also help to defuse the problems associated with the cost of insurance [76].

5 Recommendations

The framework of integrated flood risk assessment was taken into account in particular the impact of the factors involved in spatial (regional) variability of flood risk. An important aspect of the flood risk is also its temporal variability caused by climate change and changes in land use/land cover. Although we have not addressed this aspect of integrated flood risk assessment and management, we realize its importance. This is a challenge for our future research.

In terms of efficiency of a strategy to mitigate the negative impacts of floods, the Government should introduce a systematic, legislative solution that would accurately specify the role and tools of the state, local authorities and private insurers. In the case of state help, the amount of financial aid to people for the restoration of damaged property should be balanced in order not to discourage people from active participation and individual responsibility for flood defence. On the other hand, a rapid recovery from a natural hazard should be an enabler. The insurance companies have to logically adapt their strategy to the decreasing number of policyholders and increasing frequency of flood events.

Flood risk management as well as the calculation of the correct price coefficients that would reflect the risk of flood insurance should not be based only on probabilistic flood hazard models. They should also take into account regional specificities and other factors that condition flood situations and affect the amount of damage caused by the flood [70].

Acknowledgement This article was written under Project No. 2/0038/15 Flood Risk Assessment and Integrated Management on the Regional Level funded by the VEGA Grant Agency of the Ministry of Education of the Slovak Republic.

References

1. United Nations (UN) (1992) Internationally agreed glossary of basic terms related to disaster management risk. UN Department of Humanitarian Affairs, Geneva
2. United Nations (UN), Secretariat of the International Strategy for Disaster Reduction (ISDR) (2004) Living with risk: a global review of disaster reduction initiatives. http://www.unisdr.org/lwr. Accessed 9 Feb 2014
3. United Nations Development Program (UNDP) (2004) Reducing disaster risk: a challenge for development, a global report. http://www.undp.org/content/undp/en/home/librarypage/crisis-prevention-and-recovery/reducing-disaster-risk--a-challenge-for-development.html. Accessed 9 Feb 2014
4. Schneiderbauer S, Ehrlich D (2004) Risk, hazard and people's vulnerability to natural hazards: a review of definitions, concepts and data. Office for Official Publication of the European Communities, European Commission – Joint Research Centre (EC-JRC), Brussel
5. EU Floods Directive (2007) Directive 2007/60/EC of the European Parliament and of the Council on the assessment and management of flood risks. Off J Eur Union L288/27. http://ec.europa.eu/environment/water/flood_risk/index.htm. Accessed 8 Nov 2014
6. Act on Flood Protection No. 7 (2010) Slovakia. www.zbierka.sk/sk/predpisy/7-2010-z-z.p-33387.pdf. Accessed 10 Dec 2015 (in Slovak)
7. Act on Flood Protection No. 71 (2015) Slovakia. www.zbierka.sk/sk/predpisy/71-2015-z-z.p-36077.pdf. Accessed 10 Dec 2015 (in Slovak)
8. Solín Ľ (2014) Niekoľko poznámok k predbežnému hodnoteniu povodňového rizika na Slovensku a k vytvoreným mapám povodňového ohrozenia a rizika (Several comments on the preliminary flood risk assessment in Slovakia and on the flood hazard and flood risk maps). Životné prostredie 48(4):236–239
9. Government of the Slovak Republic (2010) Programme of Landscape Revitalisation and Integrated Management of River Basins in the Slovak Republic. Resolution of the Government No. 744. http://archiv.vlada.gov.sk/krajina/data/files/7183.pdf. Accessed 12 May 2011
10. Weingartner R, Barben M, Spreafico M (2003) Floods in mountains areas – an overview based on examples from Switzerland. J Hydrol 282:10–24
11. Minár J, Trizna M, Barka I, Bonk R (2005) Povodňový potenciál na území Slovenska (Flood potential on the territory of Slovakia). Geografika, Bratislava
12. Solín Ľ (2011) Regionálna variabilita povodňovej hrozby malých povodí na Slovensku (Regional variability of flood threat in small basins of Slovakia). Geogr Čas 63:29–52
13. Wisner B, Blaikie P, Cannon T, Davis I (2004) At risk: natural hazards, people's vulnerability, and disasters.2nd edn. Routledge, London
14. Messner F, Meyer V (2005) Flood damage, vulnerability and risk perception – challenges for flood damage research, discussion papers. Department of Economics, UFZ (Umweltforschungszentrum), Leipzig–Halle. https://www.ufz.de/export/data/2/26222_Disk_Papiere_2005_13.pdf. Accessed 12 Aug 2013
15. Fuchs S (2009) Susceptibility versus resilience to mountain hazards in Austria – paradigms of vulnerability revisited. Nat Hazard Earth Syst Sci 9:337–352
16. The Associated Programme on Flood Management (APFM) (2004) Integrated flood management, Technical Document No. 1. WMO and GWP (World Meteorological Organization and Global Water Partnership), Geneva. http://cap-net.org/sites/cap-net.org/files/Flood%20concept%20paper%20eng.pdf. Accessed 5 Nov 2011
17. Brown JD, Damery SL (2002) Managing flood risk in the UK: towards an integration of social and technical perspectives. Trans Inst Br Geogr 27:412–426
18. The Associated Programme on Flood Management (APFM) (2006) Social aspects and stakeholder involvement in integrated flood management, Technical Document No. 4. WMO and GWP (World Meteorological Organization and Global Water Partnership), Geneva. http://www.adpc.net/v2007/Resource/downloads/socialaspect13oct_2.pdf. Accessed 5 Nov 2011

19. Solín Ľ (2012) Spatial variability in the flood vulnerability of urban areas in the headwater basins of Slovakia. J Flood Risk Manage 5:303–320
20. Birkmann J (2006) Measuring vulnerability to promote disaster-resilient societies: conceptual frameworks and definitions. In: Birkmann J (ed) Measuring vulnerability to natural hazards, United Nations. University Press, New York, pp 9–54
21. Thywissen K (2006) Components of risk: a comparative glossary. United Nations University – Institute for Environment and Human Security (UNU-EHS), Bonn
22. Füssel HM (2007) Vulnerability: a general applicable conceptual framework for climate change research. Glob Environ Chang 17:155–167
23. Hufschmidt G (2011) A comparative analysis of several vulnerability concepts. Nat Hazards 58:621–643
24. Blaikie P, Cannon T, Davis I, Wisner B (1994) At risk: natural hazards, people's vulnerability and disasters. Routledge, London
25. Adger N, Brooks N, Bentham G, Agnew M, Eriksen S (2004) New indicators of vulnerability and adaptive capacity, Technical Report 7. Tyndall Centre for Climate Change Research, Norwich
26. Morrow H (1999) Identifying and mapping community vulnerability. Disasters 23:1–18
27. Green C (2004) The evaluation of vulnerability to flooding. Disaster Prev Manage (4):323–329
28. Penning-Rowsell E, Floyd P, Ramsbottom D, Surendran S (2005) Estimating injury and loss of life in floods: a deterministic framework. Nat Hazards 36:43–64
29. Cutter SL, Boruff BJ, Shirley WL (2003) Social vulnerability to environmental hazards. Soc Sci Q 84:242–261
30. Cutter SL, Barnes L, Berry M, Burton CH, Evans E, Tate E, Webb J (2008) A place-based model for understanding community resilience to natural disasters. Glob Environ Chang 18:598–606
31. Borden AK, Schmidtlein MC, Emrich CHT, Piegorsch WW, Cutter SL (2007) Vulnerability of U.S. cities to environmental hazards. J Homel Secur Emerg Manag 4(2):1–21
32. Meyer V, Haase D, Scheuer S (2007) GIS-based multicriteria analysis as decision support in flood risk management, discussion papers 6. UFZ (Umweltforschungszentrum), Leipzig-Halle
33. Simpson DM, Human RJ (2008) Large-scale vulnerability assessments for natural hazards. Nat Hazards 47:143–155
34. Damm M, Fekete A, Bogardi JJ (2010) Intersectoral vulnerability indices as tools of framing risk mitigation measures and spatial planning. In: 2nd international interdisciplinary conference on predictions for hydrology, ecology, and water resources management: changes and hazards caused by Direct Human Interventions and Climate Change, Prague, 20–23 Sept 2010
35. Krasovskaia I (2005) Perception of flood hazard in countries of the North Sea region of Europe. Norwegian Water Resources and Energy Directorate, Oslo
36. Kievik M, Gutteling JM (2011) Yes, we can: motivate Dutch citizens to engage in self-protective behaviour with regard to flood risks. Nat Hazards 59:1475–1490
37. Joseph R, Lamond J, Proverbs DG (2015) Homeowners' perceptions of property-level flood risk adaptations (PLFRA) measures: the case of the summer 2007 flood event in England. Int J Saf Secur Eng 5(3):251–265
38. Soetanto R, Mullins A, Achour N (2017) The perceptions of social responsibility for community resilience to flooding: the impact of past experience, age, gender and ethnicity. Nat Hazards 86:1105–1126
39. Cheah ET, Jamali D, Johnson JEV, Sung MC (2011) Drivers of corporate social responsibility attitudes: the demography of socially responsible investors. Br J Manag 22:305–323
40. Panwar R, Han X, Hansen E (2010) A demographic examination of societal views regarding corporate social responsibility in the US forest products industry. Forest Pol Econ 12:121–128
41. Wells VK, Ponting C, Peattie K (2011) Behaviour and climate change: consumer perceptions of responsibility. J Mark Manag 27(7–8):808–833
42. Valentine G (2001) Social geographies: space and society. Prentice Hall, Harlow
43. Delanty G (2003) Community. Routledge, London

44. Tapsell SM, Penning-Rowsell EC, Tunstall SM, Wilson TL (2002) Vulnerability to flooding: health and social dimensions. Philos Trans R Soc. https://doi.org/10.1098/rsta.2002.1013
45. Hakes JK, Viscusi WK (2004) Dead reckoning: demographic determinants of the accuracy of mortality risk perception. Risk Anal 24(3):651–663
46. Bartlett S (2008) Climate change and urban children: impacts and implications for adaptation in low and middle income countries, Human Settlements Discussion Paper Series – Climate Change and Cities 2. International Institute for Environment and Development (IIED), London
47. Harvatt J, Petts J, Chilvers J (2011) Understanding householder responses to natural hazards: flooding and sea-level rise comparisons. J Risk Res 14(1):63–83
48. Ellis RJ, Thompson F (1997) Seeing green: cultural biases and environmental preferences. In: Ellis RJ, Thompson M (eds) Culture matters: essays in honour of Aaron Wildavsky. Westview Press, Boulder
49. Steg L, Sievers I (2000) Cultural theory and individual perceptions of environmental risks. Environ Behav 32(2):248–267
50. Kahan DM, Braman D, Gastil J, Slovic P, Mertz CK (2007) Culture and identity-protective cognition: explaining the white-male effect in risk perception. J Empir Leg Stud 4:465–505
51. Larson L, Whiting J, Green G (2011) Exploring the influence of outdoor recreation participation on proenvironmental behaviour in a demographically diverse population. Local Environ 16(1):67–86
52. Liao KH (2014) From flood control to flood adaptation: a case study on the lower Green River Valley and City of Kent in King County, Washington. Nat Hazards 71:723–750. https://doi.org/10.1007/s11069-013-0923-4
53. Pitt M (2008) The Pitt review – learning lessons from the 2007 floods. Cabinet Office, London
54. Solín Ľ, Skubinčan P (2013) Flood risk assessment and management: review of concepts, definitions and methods. Geografický Časopis 65(1):23–44
55. Coburn AW, Spence RJS, Pomonis A (1994) Training manual: vulnerability and risk assessment, 2nd edn. UNDP Disaster Management Training Programme. http://www.provetionconsortium.org/files/undp/VulnerabilityAndRiskAssessmenmrGuide.pdf. Accessed 13 Dec 2010
56. Flood Site (2006) Guidelines for socio-economic flood damage evaluation. FLOOD site project report number T9-06-01, Wallington. http://www.floodsite.net/html/partner_area/project_docs/T9_06_01_Flood_damage_guidelines_D9_1_v1_0_p01.pdf. Accessed 13 Dec 2010
57. Parikh JK, Parikh KS (1998) Valuing environment in developing countries: a challenge. In: Uno K, Bartelmus P (eds) Environmental accounting in theory and practice. Kluwert Academic Publishers, Dodrecht, pp 321–335
58. Bouma JJ, Francois D, Troch P (2005) Risk assessment and water management. Environ Model Softw 20:141–151
59. Cochrane H (2004) Economic loss: myth and measurement. Disaster Prev Manag 13:290–296
60. Rose A (2004) Defining and measuring economic resilience to disasters. Disaster Prev Manag 13:307–314
61. Malczewski J (1999) GIS and multicriteria decision analysis. Wiley, New York
62. Malczewski J (2006) GIS-based multicriteria decision analysis: a survey of literature. Int J Geogr Inf Sci 20:703–726
63. Meyer V, Scheuer S, Haase D (2009) A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany. Nat Hazards 48:17–39
64. Apel H, Aronica GT, Kreibich H, Thieken AH (2009) Flood risk analyses – how detailed do we need to be? Nat Hazards 49:79–98
65. Solín Ľ, Skubinčan P, Madajová M (2014) A preliminary flood-risk assessment of municipalities located in headwater basins of Slovakia based on the integrated approach. In: Brebbia CA (ed) Risk analysis IX, WIT transactions on information and communication technologies. WIT Press, Southampton, UK, pp 61–72
66. Tate E (2012) Social vulnerability indices: a comparative assessment using uncertainty and sensitivity analysis. Nat Hazards 63:325–347

67. Mušinka A, Škobla D, Hurrle J, Mtlovičová K, Kling J (2014) Atlas rómských komunít na Slovensku 2013 (Atlas of Roma Communities in Slovakia 2013). UNDP, Bratislava
68. Michálek A (2005) Koncentrácia a atribúty chudoby v Slovenskej republike na lokálnej úrovni (concentration and attributes of poverty in the Slovak Republic at the local level). Geografický Časopis 57(1):3–22
69. Thieken AH, Petrow T, Kreiblich H, Merz B (2006) Insurability and mitigation of flood losses in private households in Germany. Risk Anal 26(2):383–395
70. Holub M, Fuchs S (2009) Mitigating mountain hazards in Austria: legislation, risk transfer, and awareness building. Nat Hazards Earth Syst Sci 9:523–537
71. Madajová M, Solín Ľ, Michálek A (2015) Vývoj a priestorová variabilita poistenia obyvateľstva proti riziku povodne na Slovensku v období 2002–2011 (The Development and Spatial Variability of Flood Risk Insurance in Slovakia in the Period 2002–2011). Ekonomický Časopis 63 (2):167–187
72. Slovak Insurance Association (2016) Poistné produkty na slovenskom poistnom trhu (Insurance products on the Slovak insurance market). https://www.slaspo.sk/tmp/asset_cache/link/0000056636/Poistne%20produkty%20na%20SK%20poistnom%20trhu%20k%203103%202016%20pracovny%20mat.pdf. Accessed 13 June 2016
73. Solín Ľ, Madajová M, Skubinčan P (2015) Mitigating flood consequences: analysis of private flood insurance in Slovakia. J Flood Risk Manag. https://doi.org/10.1111/jfr3.12191
74. Johnson CL, Priest SJ (2008) Flood risk management in England: a changing landscape of risk responsibility? Int J Water Resour Dev (4):513–525. https://doi.org/10.1080/07900620801923146
75. Carter RA (2012) Flood risk, insurance and emergency management in Australia. J Emerg Manag 27(2):20–25
76. Solín Ľ, Sládeková Madajová M, Michaleje L (2017) Flood hazards in the headwaters area: lessons learned from a survey of households in the upper Myjava basin, Slovakia. Water Pol. https://doi.org/10.2166/wp.2017.008

Mountain Watersheds, Torrents, and Torrent Control in Slovakia

M. Jakubis and M. Jakubisová

Contents

Abstract The Slovak Republic with an area of 49,035.81 km^2 is in most of its territory a mountain landscape and has watercourses with a total length of 61,147 km. From this length, approximately 24,000 km (39.25%) have the character of torrents. The chapter deals with the issues of mountain watersheds, torrent control, and torrents which are in Slovakia in the length of 19,408 km managed by forestry organizations. The chapter provides basic information about Slovakia's mountain watersheds and torrents and about the methods to the determination of watercourse type (river, brook, and torrent) through technical standards or calculation. The chapter includes the history of torrent control and torrent flash floods in mountain

M. Jakubis (✉)
Department of Forest Harvesting, Logistics and Ameliorations, Faculty of Forestry, Technical University in Zvolen, Zvolen, Slovakia
e-mail: jakubis@tuzvo.sk

M. Jakubisová
The Arboretum Borová hora, Technical University in Zvolen, Zvolen, Slovakia
e-mail: jakubisova@tuzvo.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 195–222,
DOI 10.1007/698_2017_146,
Published online: 30 December 2017

watersheds of Slovakia. Also, it deals with lessons from the history of flash floods. The chapter analyzes the discharge capacity of natural torrent beds in various geomorphologic units of Slovakia. A part of this chapter deals with forests in mountain watersheds and their impact on runoff formation and water balance of individual forest altitudinal vegetation zones of Slovakia. In a separate part, an example of water balance in mountain watersheds of the highest mountain of Slovakia (the High Tatras) is explained. Finally, we present the calculation procedure to the determination of T-yearly discharges in forestry practice in Slovakia.

Keywords Flash floods, Forests, Runoff, Small catchments, Watercourses

1 Introduction

Water sources in mountain areas create conditions for the existence of the various living organisms. Man living in mountain areas has been in direct connection with the torrents since the beginning of his existence. From a certain degree of intelligence, perception, and logical thinking, we assess them from two fundamental points of view, namely, from their negative and positive impacts on society. On the one hand, the torrents bring and represent great benefits for a man and, on the other, great damages and danger. Most of the water sources in Slovakia and in the world is located in protected natural areas. These protected areas have great importance for the conservation of sustainable water resources. Water resources create appropriate living conditions to preserve the biological diversity of animal and plant species. Together with riparian stands and areas, these create very valuable bio-centers and bio-corridors, which are significant interaction elements in the landscape. The torrents are of the utmost importance because they create appropriate living conditions for some specific species of animals and plants. They bring for man great benefits as a source of drinking water, water for industrial purposes, food, irrigation, energy, raw materials, etc. They have a microclimatic function, act as a valuable aesthetic and landscaping element, and have a significant health-recreational significance. On the other hand, man perceives the torrents as a great potential danger, because under certain conditions they can cause diverse and often very extensive damages in the country, as well as losses of human lives. In the case of neglected torrent and torrent watershed management, they can cause very dangerous flash floods and erosion processes, flooding and damaging of adjacent landscapes and structures, destabilization or complete devastation of associated ecosystems, etc. In order to prevent such disasters, there arose a very purposeful, systematic activity – torrent control. Historical records in connection with mountain watercourses indicate that first flood control constructions have been built by the ancient Greeks and the Romans [1].

Humanity has always been concerned about the causes and consequences of floods. The main causes of the floods in Alpine countries were extreme natural conditions of mountain and alpine areas in where torrents and their watersheds are naturally occurring and deforestation or damage of forest ecosystems in mountain watersheds. Considering to expanding population and infrastructure density in the foothills, more and more people were threatened. Historical data about the beginnings of torrent control in Europe vary. In Central Europe the first local torrent control constructions have been known from the thirteenth and fourteenth century from the territory of today's Austria [1]. In the years 1650–1662, the first continuous torrent control in the South Tirol was built [2]. Author [3] states that on a wider scale, torrent control began in the French Alps after the catastrophic floods in 1856. In 1860 the law on reforestation of mountain soil was created and in 1864 the law about the grassing of mountain soils in France. In Switzerland they began torrent control activities after disastrous floods in 1868. In today's Austria and Czech Republic, they began the systematic activities of torrent control after the creation of law No. 117/1884 on measures for harmless runoff of mountain waters. The organized regulation of endangered areas began on an official basis and had to cover the area of what is Austria today, Northern Italy (Südtirol), Slovenia, Northern Croatia (Dalmatien), the Czech Republic, Slovakia, and Southern Poland (Schlesien, Galizien). Later, the systematic torrent control activities gradually expanded to other European and world countries.

2 Torrents in Slovakia

The Slovak Republic with an area of 49,035.81 km^2 is in most of its territory a mountain landscape (Table 1) and has watercourses extending a length of 61,147 km. Of that length, approximately 24,000 km (39.25%) have the character of torrents (see Figs. 1 and 2).

Within the framework of state forestry organizations, these enterprises manage 19,408 km of small watercourses (31.74% of total watercourses length in the SR), which are predominantly torrents.

The length of managed small watercourses on forest land is 13,818.5 km (71.2%), outside of forest land 4,328.0 km (22.3%), and in the village intravilan 1,261.5 km (6.5%). Other torrents (approximately 5,000 km) are managed by the Slovak Water Management Enterprise. The torrents are characterized by extreme

Table 1 Elevation ranges of Slovakia's surface and their area and percentage of total area [4]

Height zones	Height level (m asl)	Area (km^2)	Representation of area (%)
Lowlands	98–300	20,172	40.89
Low highlands	300–800	22,652	45.92
Middle highlands	800–1,500	6,139	12.44
High highlands	1,500–2,654.4	368	0.75

Fig. 1 Tichý potok torrent in the Western Tatras (photo M. Jakubis)

changes in discharges even in relatively short periods of time and significant creation, transport, and deposition of sediments (with the erosive activity). The torrents are located in the highest situated – alpine and mountain – regions of Slovakia. The watersheds and torrents in these areas are very important as a very significant source of quality fresh water. In the Slovak Republic, all of the torrents are situated in large-scale protected areas (national parks, protected landscape areas). Therefore, torrent control and torrent watershed management are extremely demanding. These activities require experienced experts who are able to integrate landscape protection requirements for floods and erosion and valid legislation in the protection of landscape, nature, and water management. The area of 9 national parks in Slovakia is 317,540.5726 ha (6.48% area of the SR), the area of their protective zones is 262,591.3307 ha (5.36% area of the SR), and the area of 14 protected landscape areas in the SR is 522,581.5090 ha (10.66% area of the SR). This means that the total area of large-scale protected areas is 1,102,713 ha (22.49% area of the SR).

Fig. 2 Natural bed of Studený potok torrent in the High Tatras with damaged riparian stands after wind calamity in 2004 (photo M. Jakubis)

3 Determination of Watercourse Type in Slovakia

In Slovakia, the types of watercourses are most often divided into the following categories: the rivers, brooks, and torrents. Two different technical standards (STN) are used in the integrated watershed management of these watercourses: STN 75 2102 Rivers and brooks regulations [5] and STN 48 2506 Forestry amelioration – torrent and gully control [6]. Deciding on the type of watercourse is very important in terms of integrated watershed and watercourse management.

The difference between the river and the brook is given by the following characteristics in Table 2.

The difference between the brook and the torrent is assessed by visual assessment in terrain with a focus on real erosion processes and discharge characteristics, especially discharge fluctuation and their duration. In disputed cases (brook or torrent), it is possible to use the informative equation to the calculation of watershed torrentivity coefficient (C_{wt}):

$$C_{wt} = \frac{D \cdot \mathrm{LD} \cdot H_m \cdot P \cdot E \cdot (S_w + 1)^{0.5}}{L \cdot (S_c + 1)^{0.5}} \tag{1}$$

where C_{wt} is the watershed torrentivity coefficient (–), D density of hydrographical network in the watershed (km km^{-2}), LD length of divide (km), H_m middle height difference of the watershed (km), P coefficient expressing the soil permeability in the watershed which reached the values 0.3–1.0, E coefficient of recent erosion (0.1–1.0), S_w watershed area (km^2), L length of the mainstream from spring to closed discharge profile of the watershed (km), S_c area of the anti-erosive vegetation cover in the watershed (km^2), which is the forest and permanent grassland area in the watershed.

On the basis of the previous research carried out in 145 catchments in 9 geomorphological units of the Slovak Republic, we have created (Table 3) the following scale of the watershed torrentivity coefficient (C_{wt}):

Based on the research in 145 mountain watersheds with an area S_w from 0.25 to 50.38 km^2 (Fig. 3) and discharges Q_1 from 0.20 to 12.0 m^3 s^{-1} and Q_{100} from 1.0 to

Table 2 Characteristics to determine the watercourse type in Slovakia

River	Brook
W_A[a] $\geq$ 100 km^2	$W_A <$ 100 km^2
Q_{100}[b] $\geq$ 50 m^3 s^{-1}	$Q_{100} <$ 50 m^3 s^{-1}
Q_{90d}[c] $\geq$ 0.6 m^3 s^{-1}	$Q_{90d} <$ 0.6 m^3 s^{-1}
Q_{30d}[d] $\geq$ 0.15 m^3 s^{-1}	$Q_{30d} <$ 0.15 m^3 s^{-1}
Streaming: mostly river	Streaming: river, in shorter section torrential

[a]Watershed area (km^2)
[b]100 – yearly discharge (m^3 s^{-1})
[c]90 – daily discharge (m^3 s^{-1})
[d]30 – daily discharge (m^3 s^{-1})

Table 3 Scale of stream evaluation by watershed torrentivity coefficient C_{wt}

Rate	Name (stream tape)	C_{wt}
0	Brook	<0.10
I	Very slightly torrent	0.10–0.15
II	Slightly torrent	0.16–0.25
III	Middle strongly torrent	0.26–0.40
IV	Strongly torrent	0.41–0.70
V	Very strongly torrent	0.71–1.00
VI	Exceptional strongly torrent	1.01–2.00
VII	Extreme strongly torrent	>2.00

Fig. 3 Tichý potok torrent in the Western Tatras, watershed area of 50.38 km^2, discharge $Q_{100} = 140.0$ $m^3\ s^{-1}$, watershed torrentivity coefficient $C_{wt} = 0.81$ (photo M. Jakubis)

145.0 $m^3\ s^{-1}$ in 9 geomorphological units of the SR, we found that the values of the watershed torrentivity coefficient C_{wt} reflect the real type of the investigated streams. Calculated C_{wt} values ranged, for example, for the torrents in geomorphological unit of Poľana (480–1,458 m asl), from 0.10 to 0.66; of Veľká Fatra (485–1,592 m asl) from 0.18 to 1.69; of Malá Fatra (460–1,709 m asl) from 0.16 to 1.62; of Štiavnické vrchy (230–1,009 m asl) from 0.11 to 0.41; of Kremnické vrchy (270–1,317 m asl) from 0.12 to 0.45; of the Western Tatras (690–2,248 m asl) from 0.24 to 1.82; of the High Tatras (905–2,645.8 m asl) from 0.25 to 2.81; of Nízke Tatry (395–2,043 m asl) from 0.22 to 1.79; of Veporské vrchy (490–1,438.8 m asl) from 0.11 to 0.44; and of Javorie (310–1043.7 m asl) from 0.10 to 0.33.

4 History of Torrent Control in Small Mountain Watersheds of Slovakia

Historical records show that flash floods, torrents, and avalanche disasters have struck mountainous and sub-mountainous villages and landscape on the territory of contemporary Slovak Republic since time immemorial. Heavy deforestation was carried out during the thirteenth and fourteenth centuries (from the negative influence of colonization, settlement, mining, metallurgy, wood-gathering, etc.) in the regions of the present Central Slovakia.

Torrent control originated in the eighteenth and nineteenth centuries and is inscribed in the historical chronicles of various villages and towns. Some traditional measures to control torrents were adopted: such as stone barrages, stone crib dams, temporary ditch plank fences, longitudinal reinforcements of shores with stems, and even afforestation aimed at soil conservation in the mountain watersheds of torrents. Although these measures were quite effective, flash flood disasters in mountainous watersheds were frequent and destructive for both humans and landscape. One of the reasons for these flash flood disasters was the deforestation of the mountainous watersheds in the previous centuries [7].

The area of contemporary Slovak Republic was, until 1918, a part of the Austro-Hungarian monarchy; it then became part of an independent Czechoslovakia. The first notes about torrent control on the territory that is now the Slovak Republic originated in the eighteenth and nineteenth centuries, in the historical chronicles of submontane villages and towns. The first law No. 117/1884 on measures for harmless runoff of mountain waters came into force in 1884, and the first department of what is now called Torrent and Avalanche Control was imperial and royal Forest-Technical Department for Torrent Control.[1] At the beginning of World War I (1914), this Department had 15 subsidiaries covering the area of the monarchy. Modern torrent control activities in Slovakia began in 1923. In that year, a specialized office for torrent control was established in Turčiansky Svätý Martin (now Martin) in Central Slovakia, led by Prof. Dr. Ing. Leo Skatula (1889–1974). That institution operated throughout the whole Slovak Republic. The first systematic torrent control – Jelenec – was situated in Hornojelenecká Valley in Veľká Fatra in Central Slovakia. During the fifteenth and sixteenth centuries, deforestation in Hornojelenecká Valley was severe, leading to fatal flash floods and avalanche disasters in this area. The first historical record about an avalanche in Hornojelenecká Valley was in 1751; it caused the deaths of ten people. During the sixteenth century, professional commissions had been formed (in 1535 and 1563), but while they recognized the importance of the forest of Hornojelenecká Valley, no significant protection effort materialized. This was one of the primary reasons for the large-scale floods and avalanches in later years. In the twentieth

[1]Wildbach – und Lawinenverbauung (Department) was k. k. (kaiserlich-königlich) forsttechnische Abtheilung für Wildbachverbauungen.

century, there were two major disasters (in 1924 and 1925) that led to the loss of lives and destruction of resources. The first catastrophe was on February 6, 1924. A huge avalanche had a height of 35 m of the front face and about 2,400.000 m^3 of cubage. The next catastrophe was on May 30, 1925, when a gigantic flash flood destroyed this entire valley (houses, roads, equipment, etc.). In the upper part of the Jelenec torrent basin (watershed area of 9.58 km^2, forestation of the watershed 70%), 75 mm of precipitation falls in less than 3 h (the maximum daily rainfall by then was 66.5 mm). This resulted in a flash flood that ravaged the whole Hornojelenecká Valley which was completely devastated. A flash flood in a few tens of minutes flooded all houses and other buildings in the settlements of Horný Jelenec, Valentová, and Rybô. Many houses in the valley were damaged by coarse sediments which flood brought from the upper parts of the watershed. These two catastrophes were the cardinal reason for the beginning of Jelenec torrent control on the territory of today's Slovak Republic. The first systematic torrent control in Slovakia – Jelenec in Hornojelenecka Valley – was built in 1926–1927; this torrent had many peculiarities: longitudinal reinforcement of the torrent bed with wood (pine and fir), stone paving on the slopes of the bed, and the first stone arched correction and sediment storage dam, passages for fish, and others (Figs. 4 and 5). Longitudinal reinforcement of the torrent bed was built only in settlements in the valley; a naturally stabilized torrent bed outside the settlements was left in its natural state. Over the course of more than 90 years since its inception, the torrent

Fig. 4 The weir built in natural rock of oldest torrent control in Hornojelenecká Valley from 1926 to 1927 and the torrent Jelenec in Slovakia (photo M. Jakubis)

Fig. 5 Longitudinal reinforcement by pavement stone, the stone weir, and system of wooden sills in the oldest torrent control – Jelenec in Hornojelenecká Valley from 1926 to 1927 (photo M. Jakubis)

control in Slovakia went through periods of expansion and recession, too. Currently, from the total length of watercourses managed by state forestry organizations (19,408 km), 590 km (3.04%) of them is controlled; it is 2.46% from the total torrent length in the Slovak Republic. From this length of controlled torrents, 131 km (22.2%) is reinforced by longitudinal vegetation reinforcement, 415 km (70.3%) by no vegetation reinforcement, and 44 km (7.5%) by combined longitudinal reinforcement.

5 History of Torrent Flash Floods in Slovakia

The first more precisely documented flash flood in the territory of today's Slovak Republic was the mentioned flood in Hornojelenecká Valley (geomorphologic unit Veľká Fatra) on May 30, 1925. Another documented torrential flood occurred in the watersheds of torrents Račková (35.8 km^2), Tichý potok (54.6 km^2), Kôprovský potok (30.5 km^2), and Belá (85.1 km^2) in the Váh river basin. On August 11, 1929, on the southern slopes of the Western Tatras, 83 mm of precipitation fell in 3 h [8, 9]. The floodplains were affected by a catastrophic flash flood that devastated the area along the sides of the watercourse Belá and caused major flood damages in the municipalities of Pribylina, Liptovská Kokava, Vavrišovo, Dovalovo, Liptovský Peter, and Liptovský Hrádok. In the territory under the confluence of the Tichý potok and Kôprový potok (Belá), the width of the channel reached more than 40–50 m (normally it is about 8–10 m). This flood was an incentive to build a second significant torrent control Račková on the territory of today's Slovak Republic in 1938–1940 (Figs. 6 and 7).

Fig. 6 Highest torrent dam of Slovakia built (1938) in Račková Valley in the Western Tatras (photo M. Jakubis)

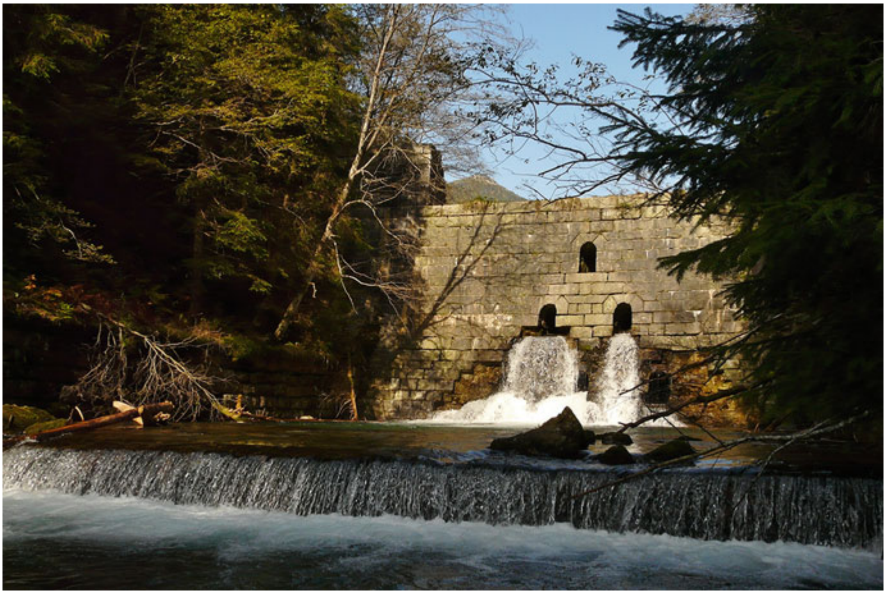


Fig. 7 The old torrent control objects need repairs, Račková in Western Tatras (Photo M. Jakubisová)

In mountain torrent catchments in Slovakia, other devastating flash floods occurred in the past. In the area of Zverovka (1,037 m asl) on the northwest slopes of the Western Tatras (Roháče) in a geomorphological unit of Tatras on July 16, 1934, 220 mm of precipitation fell within 1 day. These precipitations cause extensive local flash floods in the catchments of the torrents Látaná, Roháčský potok, and Studený potok. In the catchment area of the Kôprovský potok, Račková, and Jalovský potok (in the Váh river main basin) on the southern slopes of the Western Tatras, a major flood occurred on June 29, 1958. The flood was caused by precipitation, which in some localities reached over 100 mm in 24 h. On July 25, 1965, a great flash flood occurred near the village of Budča (district Zvolen, Central Slovakia) in the Sietno Valley (altitude 290–525 m asl) in a geomorphological unit of Kremnické vrchy (the Hron river basin). Within 2 to 3 h of rain, 110 mm of precipitation fell. The subsequent flood destroyed more than 3 km of a reinforced valley forest road including five bridges, and at that time the main and important road in the direction of Banská Bystrica – Zvolen – Bratislava, was destroyed which led to the foot of the valley. On July 20, 1998, in the Bachureň geomorphological unit (Hornád river basin), in the eastern Slovakia, catastrophic floods caused intense rainfall in the basin of Malá Svinka (the altitude of the basin 328–1,081 m asl) which caused 60 victims in human lives. During intense rainfall in the watershed (whose geological base forms a flysch), fell within 1.5 to 2 hours from 60 to 100 mm of precipitation; in some locations up to 130 mm. The torrent level has risen from a height of 0.40–0.50 m to 5–6 m and extended from 2–3 m wide to 40–50 m. As a result of extreme precipitation, a peak flow rate was generated over several decades $Q_{\mathrm{culm}} = 190\ \mathrm{m}^3\ \mathrm{s}^{-1}$ ($Q_{100} = 76\ \mathrm{m}^3\ \mathrm{s}^{-1}$ and average long-term flow $Q_{\mathrm{a}} = 0.30\ \mathrm{m}^3\ \mathrm{s}^{-1}$). Significant impacts on flooding have also had collisions that occurred in the period immediately prior to this event. The enormous impact on the number of victims of this flood had a very inappropriate location of dwellings in the immediate vicinity of the Malá Svinka stream, which absolutely did not take into account the potential danger of floods. Intensive torrential rainfall caused a major flood in the district of Krupina (Central Slovakia) in a geomorphological unit of Krupinská planina and Štiavnické vrchy on July 13, 1999. The town of Krupina is located in a valley surrounded by eastern and western slopes. The main watercourse is the river Krupina (Ipeľ river basin) with two torrents from the east (Kňazov potok and Jakubov jarok) and two torrents from the western side (Vajsov potok and Kltipoch) which flow directly into the town's inner city. The storm cloud was located directly above the city, and the floods arose not only on the river Krupinica but on all four tributaries. River Krupinica's level in the city rose from 0.70 to 5.30 m during two and a half hours. The intensity of the hourly precipitation ranged from 50 to 70 mm [10], and the intensity of precipitation during the 2–3 h had reached from 81 to 120 mm [11]. Previous precipitation in the area of town Krupina and its environs from July 8 to July 12, 1999 (5 days before the abovementioned precipitation event), reached a total of 38.9 mm [9] and from July 7 to July 12, 1999 (6 days prior to this event), to 86.2 mm. In the town of Krupina, a discharge $Q = 170\ \mathrm{m}^3\ \mathrm{s}^{-1}$ was achieved which is considered to discharge Q_{1000} ($Q_{100} = 100\ \mathrm{m}^3\ \mathrm{s}^{-1}$, mean long-term discharge $Q_{\mathrm{a}} = 1.22\ \mathrm{m}^3\ \mathrm{s}^{-1}$). On July 17, 2001, a daily sum of precipitation of 142 mm was recorded in Veporské vrchy and Poľana geomorphological units in the area of villages Hronec (492 m asl) and Osrblie (600 m asl) in the Osrblianka and Hronec river basin in Central Slovakia (the Hron river basin). The precipitation triggered a local flood with major damage to citizens' property and infrastructure, especially in the municipality of Hronec. On July 31, 2002, in the Hutná torrent basin in village Ľubietová in the northern part of the geomorphologic unit of Poľana, 80–100 mm of precipitation fell in 90 min (1.00–2.30 p.m.), causing a discharge $Q = 64\ \mathrm{m}^3\ \mathrm{s}^{-1}$ ($Q_{100} = 50.0\ \mathrm{m}^3\ \mathrm{s}^{-1}$) and a flash flood with disastrous consequences. On June 7, 2011, a catastrophic flash flood with a discharge $Q = 44.5\ \mathrm{m}^3\ \mathrm{s}^{-1}$ ($Q_{100} = 23\ \mathrm{m}^3\ \mathrm{s}^{-1}$) in the Gidra torrent basin (32.9 km^2) was created on the eastern slopes of the geomorphological unit of Malé Karpaty, which was a major flood damage, especially in the village of Pila. During this day, precipitation from 51 to 104 mm fell on the southeastern slopes of the Malé Karpaty geomorphological unit (Western Slovakia). On July 21, 2014, a great flash flood occurred in Vrátna Valley in a geomorphological unit of Malá Fatra. This flash flood was caused by rainfall with intensity of 60 mm for 1.5 hours in the highest part of the watershed (area 6.01 km^2). Subsequent discharge $Q = 36\ \mathrm{m}^3.\mathrm{s}^{-1}$ was equal to 100 – yearly discharge. On July 31, 2016, a flash flood occurred in a geomorphological unit of Kremnické vrchy after torrential precipitation with intensity 70–75 mm h^{-1} (110–125 mm 24 h^{-1}) with subsequent extensive damage to the adjacent infrastructure in the vicinity of the village Kremnické Bane.

6 Lessons from the History of Flash Floods in Mountain Watersheds of Slovakia

Based on the analysis of the 33 flash floods that occurred in the small mountain watersheds of the SR [12, 13] in the period 1925–2016, we found that:

- The main causes of flash floods were torrent rains with intensity 80–-91 mm 0.5 h^{-1}, 65–100 mm h^{-1}, 81–130 mm 2 h^{-1}, 75–130 mm 3 h^{-1}, 130–228.5 mm 4 h^{-1}, and 100–231.9 mm 24 h^{-1}.
- From 33 analyzed flash floods, 3 occurred in May (9.1%), 9 in June (27.3%), 18 in July (54.5%), and 3 in August (9.1%).
- The high forest cover of the watershed (94 or 97.8%) cannot prevent the flash flood [watersheds of torrent Hronček and Osrblianka in geomorphological unit of Poľana (2001), watershed Gidra in geomorphological unit of Malé Karpaty (2011), etc.].

The causes of the increased flood damages were mainly:

- Neglected maintenance of watercourse beds
- Construction in the immediate vicinity of watercourses
- Storage of different materials near the streams
- Neglected tending of riparian vegetation
- Storage of wood near watercourses
- Negligence and irresponsibility of inhabitants and self-government of municipalities (municipal waste in watercourse beds)
- Improperly designed and build construction (pipes, benches, bridges)
- Absent, neglected maintenance or wanting drainage, accelerated runoff, and erosion on unpaved forest roads

7 Discharge Capacity and Bankfull Discharge of Natural Torrent Beds of Slovakia in Relation to T-Yearly Discharges

This question is important from the point of view of the frequency of bankfull discharges and potential flood situations in terms of their recurrence interval. Based on the research in 594 experimental flow profiles on 80 mountain torrents with watershed areas S_w from 0.25 to 50.38 km^2 and discharges Q_1 from 0.20 to

12.0 $m^3 s^{-1}$ and Q_{100} from 1.0 to 145.0 $m^3 s^{-1}$ in 3 geomorphological units of the SR, we found that values of the discharge capacity (bankfull discharge) of natural (unpaved, uncontrolled) torrent beds correspond to certain T-yearly discharges. For the torrents in a geomorphological unit of Poĺana (480–1,458 m asl) with watershed areas from 0.384 km^2 to 48.40 km^2, the recurrence interval of bankfull discharge is from Q_1 to $Q_{7.35}$ (with an average $Q_{2.63}$). It means that the recurrence interval for bankfull discharge is from 1 year to 7.35 years. In geomorphological unit of Kremnické vrchy (270–1,317 m asl) with watershed areas 3.79–21.13 km^2, the interval is from Q_1 to Q_{10} (with an average $Q_{2.33}$). In the Western Tatras (690–2,248 m asl) with watershed areas from 1.20 to 50.38 km^2 in the geomorphological unit of Tatras, the interval is from Q_1 to $Q_{17.2}$ (with an average $Q_{4.21}$). In the High Tatras (905–2,645.8 m asl) in the geomorphological unit of Tatras with watershed areas from 0.25 to 19.34 km^2, the recurrence interval varies from 1–13.17 years (Q_1 to $Q_{13.17}$) with an average $Q_{5.09}$ [14–17].

8 Forest and Runoff in Mountain Watersheds

Since the establishment of forestry activities in torrent control in the Slovak Republic, they are carried out by forest owners, who understand these activities as complex (integrated) management of small mountain catchments. In this management, the water management function of forest ecosystems plays a very important role. Author [18] states that in torrential watersheds, the conservation improvement and establishment of forest tree cover are important for their highly beneficial effect on infiltration and water concentration time, as well as on surface runoff and flood flow control. Wherever possible, any suitable watershed land should be reforested in preference to any other forms of land use.

The forest ecosystem has important functions in relation to runoff and subsequent discharge [19]:

– Retention (water retention) – how and where to retain rainfall water on the surface of forest vegetation, in the humus layer, etc.
– Accumulation (accumulation of water) – as and where in forest land (accumulation function)
– Retardation of surface runoff (slowing down of surface runoff which is delaying the time of runoff) and its turn into a subsurface runoff

In connection with runoff formation, the mountain watersheds are very important:

– Total forest quality (hydric efficiency); existence, absence, and quality of the humus layer; interceptor capacity of the forest ecosystem; and its ability of transpiration and evaporation (i.e., evapotranspiration)
– Saturation of the catchment through the previous precipitation
– Geomorphological characteristics of the terrain (slope, roughness)
– Soil characteristics (permeability)

– Hydrogeological characteristics of the basin (rock permeability)
– Meteorological conditions, etc.

It is generally known that forests affect the process of runoff formation and their development. In connection with the runoff, the forest ecosystems have particular significance in mountain watersheds, but their influence on the runoff formation may be very different under existing conditions. Composite authors [20] reported that in Slovakia the area of forest plots has been continually increasing and reached 2014,731 ha in 2015 (it is 41.4% of the territory of Slovakia, which is 49,035.81 km^2). In the same period, the area of forest cropland, or forest stands, respectively, has similarly shown an upward trend and reached 1,942,567 ha (it is 39.6% of the territory of Slovakia). Forest cover which is calculated as a percentage of the area of forest holdings to the total area of Slovakia reached almost 41.4% in 2015. The authors also report that in addition to forest on forest land, there is in Slovakia a certain percentage of agricultural and other lands covered with stands of forest tree species [20]. The area covered by this type of forest vegetation represented almost 275,000 ha. Thus the Slovakia's forest cover as the proportion of forest on both forest and non-forest land (2,217,567 ha), compared to the total area of Slovakia, stands at 45.2%. In general, each forest ecosystem has a certain hydrological significance. The hydrological efficiency of forest ecosystems is limited (bounded) and depends on many influential factors. One of the most important among them is the current state of saturation of the forest ecosystem (including forest land) by previous precipitation. After the forest ecosystem has fully saturated with previous rainfall, the forest is no longer able to withstand further precipitation. Within interceptions, the forest ecosystem may retain several millimeters of precipitation during one crash event in tree crowns (according to the quality of forest stands). Interceptions are significant, for example, in annual hydrological balances [21, 22]. In this case, the interceptions represent up to several tenths of the total annual rainfall depending on the quality of the forest vegetation, the wood species, etc. This value is 19–46% of the average annual rainfall sum [23]. During one collision, interceptions in the forest ecosystem can be a maximum of 6–9 mm [24]. The forest ecosystem can hold up to 300–350 l (0.3–0.35 m^3) of water per square meter under appropriate conditions in the soil. Another important component of the hydrological balance within the forest ecosystem is transpiration – productive evaporation – drainage of forest water through root systems of forest trees with subsequent growth processes and biomass production. The rainfall sums that the forest ecosystem is able to contain within a single rainfall or 24 h can be very different and depend on many influential factors. Authors [21] report that the hydrological function of the forest, understood as its interceptor capacity, the infiltration capacity of the forest soil and the rock environment, and the ability of the forest to slow out the outflow from a small river basin, can only positively affect precipitation and drainage processes for precipitations not exceeding 20–24 mm in 24 h. The importance of hydrological function of the forest ecosystem grows within the longer term – seasonal or annual hydrological balances. Author [20] states that the actual retention capacity of forest stands is relatively large (30–70 mm), but not so much as to prevent the occurrence of floods, in the event of extreme precipitation or at the time of saturation of forests by previous precipitation. Authors [25] report the retention capacity of forest ecosystems 30–40 mm, after extreme precipitation up to 68 mm. Author [26] indicates the value of rainfall retained by the forest of 50 mm. Author [27] states that the saturation capacity of forest woods by precipitation represents a value of 10 mm. The capacity of shrubs and herbaceous vegetation and the layer of fallen leaves and tree needles is from 5 to 20 mm, and the retention capacity of the soil (for most extended forest land in Slovakia) is from 30 to 40 mm, so the total retention capacity of forest stands can be estimated at about 40–70 mm. However, this value is valid for 100% forest coverage of the landscape and for 1.0 crop density (100% crown canopy, respectively). It follows that even the high forest cover of the watershed cannot prevent the occurrence of floods in the event of extreme torrential rainfall (sometimes in combination with the precipitation of the catchment through previous precipitation), as evidenced by several examples from recent years and also from the territory of Slovakia.

Surface flowing water rate in the concentrated runoff is in the range of about 0.1–3.0 m s^{-1}, in humus layer it is 0.01–0.1 m s^{-1}, and in the forest soil (subsurface runoff), it is 0.000001–0.00001 m s^{-1} [28]. In this context, measures to reduce the risk of floods in forest ecosystems should, in particular, be aimed at avoiding a concentrated runoff, conversion of surface runoff to the subsurface, to protect the humus layer and avoiding damage to forest soil.

Slovak forest falls into three categories (Table 4). Composite authors [20] report that all forests regardless of their category provide a whole host of different services and benefits (over 90% of all forest are so-called poly-functional forests). Most forests fall into production category. Their primary function is the production of high-grade timber without compromising other important ecological and social functions through integrated forest management.

Forests with primarily an ecological nature to their services and benefits are protection forests. The management of the protected forests is primarily focused on various benefits of their ecological functions (soil, water, and infrastructure protection) and to ensure sustainable fulfillment of their ecological services. Social and cultural functions are most important in forests, which due to their specific societal group of benefits have been given the status of special-purpose forests. These forests are under special management with enhancement of one or more functions, for example, water purification, nature conservation, education, research, etc. [20].

From the point of view of water balance of forest stands in mountain watersheds of Slovakia, it is important to divide them into "forest altitudinal vegetation zones."

Table 4 Forest categories in the SR

Category	Area (ha)	Area (%)
Production forests	1,397,000	71.93
Protection forests	334,500	17.23
Special-purpose forests	210,700	10.84

Table 5 Forest altitudinal vegetation zones in Slovakia and their informative average water balance

Zone	A^a (ha)	A^a (%)	E^b (m asl)	P^c (mm)	∅P[d] (mm)	T^e (°C)	∅T[f] (°C)	∅ETR[g] (mm)	∅ETR[h] (%)	∅R[i] (mm)	∅R[i] (%)	α^j
1. Oak	138,907	7.2	≤300	≤600	550	≥8.5	9.0	550	100	0	0	0
2. Beech-oak	265,377	13.7	200–500	600–700	650	6.0–8.5	7.25	442	68	208	32	0.32
3. Oak-beech	460,282	23.7	300–700	700–800	750	5.5–7.5	6.5	487	65	263	35	0.35
4. Beech	404,519	20.8	400–800	800–900	850	5.0–7.0	6.0	510	60	340	40	0.40
5. Fir-beech	428,333	21.9	500–1,000	900–1,050	975	4.5–6.5	5.5	342	55	439	45	0.45
6. Spruce-beech-Fir	183,461	9.5	900–1,300	1,000–1,300	1,150	3.5–5.0	4.25	518	45	632	55	0.55
7. Spruce	40,398	2.1	1,250–1,550	1,100–1,600	1,350	2.0–4.0	3	705	30	945	70	0.70
8. Dwarf pine	21,290	1.1	≥1,500	≥1,500	1,600	≤2.5	2	320	20	1,280	80	0.80

[a] Area (ha, %)
[b] Elevation (m asl)
[c] Precipitation (mm)
[d] Average precipitation (mm)
[e] Temperature (°C)
[f] Average temperature (°C)
[g] Average evapotranspiration (mm)
[h] Average evapotranspiration (%)
[i] Average runoff (mm, %)
[j] Runoff coefficient

Fig. 8 The damaged riparian stands of Kôprový potok (torrent of Western Tatras) after wind calamity on November 19, 2004, need urgent tending (photo M. Jakubisová)

Fig. 9 Map of Slovakia and location of the High Tatras

Forest altitudinal vegetation zones in Slovakia and their informative average water balance [29] is explained in Table 5 for better clarity.

In the mountain, watersheds have an important role in riparian stands as an important part of the forests [30, 31]. The riparian stands (riparian vegetation) need systematic tending (Fig. 8). They have many various functions in flood control, also. Functions of riparian stand can be divided into:

– Ecological: soil protection function on the slopes of torrent beds (slowing the discharge and erosion control, landslide control) and water protection functions (filtration, infiltration, water shading, soil drifting control)
– Environmental: biodiversity enhancing, nature protection, and aesthetic effect in the landscape
– Production: wood and other product production

9 The Equations of Water Balance in Watersheds of the High Tatras

Some authorities consider that mountain regions represent, in practical terms, "the blackest of black boxes in the hydrological cycle" [32]. Therefore, it is very important to know the water balance of the mountain watersheds (basins). In the determination of basic elements of the water balance equation for all of 26 analyzed mountain watersheds in the High Tatras, the highest mountain in Slovakia (Fig. 9) used the simplified relationship:

$$\bar{P} = \bar{R} + \bar{E}\ (\text{mm}) \tag{2}$$

where $\bar{P}$ is the mean long-term annual precipitation in the watershed (mm), $\bar{R}$ mean long-term annual runoff in the watershed (mm), and $\bar{E}$ mean long-term annual climatic evaporation in the watershed (mm).

To determination of the elements of Eq. (2) were used the equations which were derived by research [4]. The authors based on the knowledge that the mean annual climatic evaporation $\bar{E}$ can be determined as a function of potential evaporation index EPi (mm) and mean long-term annual precipitation $\bar{P}$ (mm):

$$\bar{E} \cdot \text{EP}_\text{i}^{-1} = f\left(\bar{P} \cdot \text{EP}_\text{i}^{-1}\right)\ (\text{mm}) \tag{3}$$

Authors [4] on the basis of relation (3) and measured data of 54 meteorological stations in the Slovak Republic derived for the conditions of SR the empirical relationships which were used in analysis:

$$\bar{R} = \bar{P} - \frac{\bar{P}}{\sqrt{0.809 + \left(\frac{\bar{P}}{\text{EP}_\text{i}}\right)^2}}\ (\text{mm}) \tag{4}$$

and

$$\bar{R} = \bar{P} \cdot \left(1 - \frac{\mathrm{EP_i}}{\sqrt{0.809 \times \mathrm{EP_i^2} + \overline{P^2}}} \right) \text{(mm)} \tag{5}$$

The potential evaporation index EPi was calculated using the relation:

$$\mathrm{EP_{iSR}} = 260.822 + 37.920\bar{T} + 0.077\overline{T^3} \tag{6}$$

where $\bar{T}$ is the mean long-term annual temperature in the watershed (°C).

The values of mean long-term annual precipitation and mean long-term annual temperature for all of the analyzed watersheds were derived from measured data in eight meteorological stations of High Tatras (Table 6, Figs. 10 and 11). Using the results of Eqs. (4) and (5), respectively, the coefficient $\bar{R} \times S_p$ was calculated which is substantially the component of the numerator in the formula to the calculation of mean long-term annual runoff:

$$Q_a = \frac{\bar{R} \cdot S_w \cdot 10^3}{t} \left(\mathrm{m^3\,s^{-1}}\right) \tag{7}$$

where t is 31,557,600 s (time in seconds for 1 year).

Basic morphological characteristics of the reference watersheds of High Tatras are shown in Table 7. Basic hydrological characteristics of these watersheds are shown in Table 8.

Table 6 The mean annual precipitation and temperature in the High Tatras

Station	H^a (m asl)	$\bar{P}^b$ (mm)	$\bar{T}^c$ (°C)
Tatranská Lomnica	832	833	5.2
Starý Smokovec	1,018	930	–
Vyšné Hágy	1,140	864	4.3
Hrebienok	1,285	1,132	–
Štrbské pleso	1,360	976	3.6
Popradské pleso	1,530	1,319	2.2
Skalnaté pleso	1,778	1,380	1.6
Lomnický štít	2,634	2,634	3.7

[a]Height (m asl)
[b]Average long-term annual precipitation (mm)
[c]Average long-term annual temperature (°C)

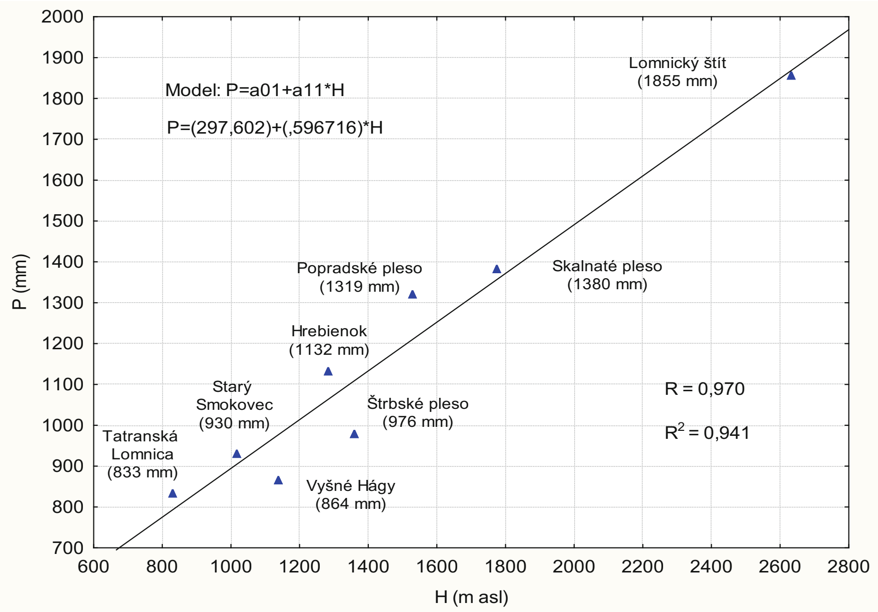


Fig. 10 The mean annual precipitation in the High Tatras

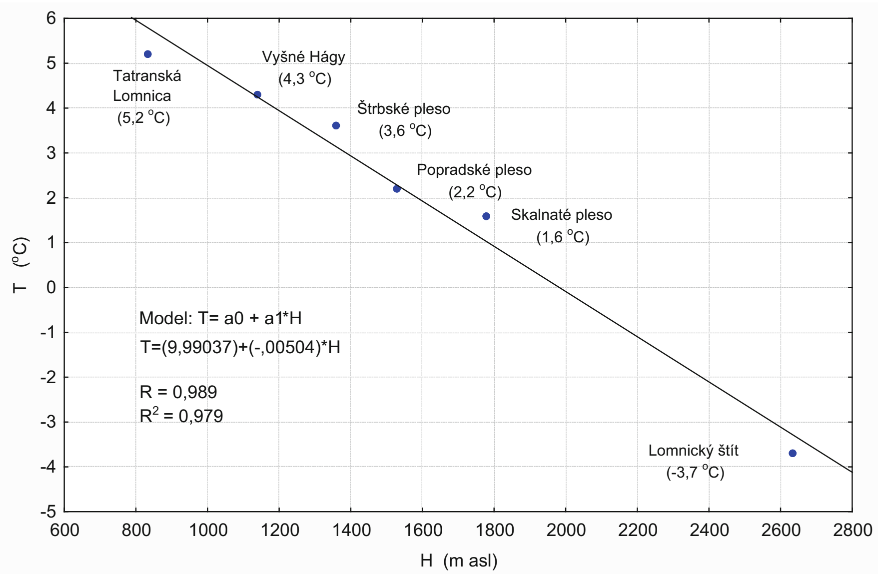


Fig. 11 The mean annual temperatures in the High Tatras

Table 7 Basic characteristics of watersheds and watercourses in the High Tatras

Watercourse	S_w [a] (km^2)	S_f [b] (km^2)	F [c] (%)	H_{minw} [d] (m asl)	H_{maxw} [e] (m asl)	ΔH_w [f] (m)	H_{maxs} [g] (m asl)	ΔH_t [h] (m)
Beliansky potok	3.17	2.00	63.1	1,140	2,494	1,354	2,310	1,170
Tri studničky	0.36	0.36	100.0	1,160	1,510	350	1,295	135
Mlyničná voda	2.18	1.86	85.3	1,160	2,310	1,150	1,320	160
Jamský potok	0.60	0.60	100.0	1,200	1,580	380	1,455	255
Važecký potok	0.25	0.25	100.0	1,210	1,600	390	1,536	326
Biely Váh	10.62	6.11	57.5	1,220	2,494	1,274	1,840	620
Lieskovec	1.57	1.56	99.4	1,200	1,840	640	1,325	125
Mlynica	6.90	2.68	38.8	1,260	2,428	1,168	1,800	540
Poprad	19.34	8.72	45.1	1,200	2,499	1,299	1,740	540
Veľký šum	4.86	4.70	96.7	1,122	2,280	1,158	1,618	496
Malý šum	3.07	2.49	81.1	1,080	2,366	1,286	1,840	760
Háganský potok	0.71	0.68	95.8	1,082	1,490	408	1,323	241
Batizovský potok	5.69	3.86	67.8	1,030	2,654	1,624	1,884	854
Hromadná voda	3.25	2.88	88.6	990	2,640	1,650	1,460	470
Velický potok	6.16	3.45	56.0	993	2,654	1,661	1,860	867
Slavkovský potok	5.31	3.58	67.4	1,010	2,452	1,441	1,260	250
Malý Štiavnik	0.88	0.80	90.9	1,005	1970	965	1,129	124
Veľký Jazyk	1.19	0.91	76.5	998	2040	1,042	1,124	126
Štiavnik	1.64	0.91	55.5	997	2,273	1,276	1,315	318
Päť prameňov	0.98	0.87	88.8	990	1,700	710	1,150	160
Pod Hrebienkom	2.73	2.27	83.2	985	2060	1,075	1,173	188
Studený potok	18.13	8.34	46.0	920	2,633	1,713	2057	1,137
Hlboký potok	4.88	4.46	91.4	860	2,230	1,370	1,440	580
Skalnatý potok	9.37	6.47	69.1	890	2,634	1,744	2,500	1,610
Kežmarská Biela voda	18.29	12.16	66.5	910	2,634	1,724	2,100	1,190
Sedem prameňov	4.58	3.82	83.4	905	1946	1,041	1,420	515

[a]Watershed area (km^2)
[b]Forested watershed area (km^2)
[c]Percentage of watershed forestation (%)
[d]Minimal altitude of the watershed (m asl)
[e]Maximal altitude of the watershed (m asl)
[f]Absolute gradient of the watershed (m)
[g]Altitude of the spring (m asl)
[h]Absolute gradient of watercourse (m)

Table 8 Hydrologic characteristics of experimental watersheds in the High Tatras

Watercourse	$øH_w$[a] (m asl)	$\bar{P}$[b] (mm)	$\bar{T}$[c] (°C)	EP_i[d] (mm)	$\bar{R}$[e] (mm)	$\bar{R}$[e] (%)	$\bar{E}$[f] (mm)	$\bar{E}$[f] (%)	Q_a[g] ($m^3 s^{-1}$)
Beliansky potok	1,614	1,261	1.9	333.40	937	74	324	26	0.094
Tri studničky	1,278	1,060	3.6	400.93	680	64	380	36	0.008
Mlyničná voda	1,544	1,219	2.3	348.97	881	72	338	28	0.061
Jamský potok	1,407	1,137	3.0	376.66	776	68	361	32	0.015
Važecký potok	1,350	1,103	3.2	384.69	736	67	367	33	0.006
Biely Váh	1,812	1,379	0.9	295.01	1,089	79	290	21	0.366
Lieskovec	1,434	1,153	2.8	368.69	799	69	354	31	0.040
Mlynica	1,740	1,336	1.3	310.29	1,032	77	304	23	0.226
Poprad	1,789	1,365	1.0	298.82	1,072	80	293	20	0.657
Veľký šum	1,548	1,221	2.3	348.97	883	72	338	28	0.136
Malý šum	1,665	1,291	1.7	325.66	973	75	318	25	0.095
Háganský potok	1,277	1,060	3.6	400.93	680	64	380	36	0.015
Batizovský potok	1,696	1,310	1.5	317.96	999	76	311	24	0.180
Hromadná voda	1,510	1,199	2.4	352.89	858	72	341	28	0.088
Velický potok	1,736	1,333	1.3	310.29	1,029	77	304	23	0.201
Slavkovský potok	1,655	1,285	1.7	325.66	967	75	318	25	0.163
Malý Štiavnik	1,273	1,057	3.6	400.93	678	64	379	36	0.019
Veľký Jazyk	1,306	1,077	3.5	396.84	700	65	377	35	0.026
Štiavnik	1,528	1,209	2.4	352.89	868	72	341	28	0.045
Päť prameňov	1,239	1,037	3.8	409.14	651	36	386	37	0.020
Pod Hrebienkom	1,308	1,078	3.5	396.84	701	65	377	35	0.061
Studený potok	1,793	1,367	1.0	298.82	1,074	79	293	21	0.617
Hlboký potok	1,304	1,076	3.5	396.84	699	65	377	35	0.108
Skalnatý potok	1,506	1,196	2.5	356.83	851	71	345	29	0.253
Kežmarská Biela voda	1,612	1,259	1.9	333.40	935	74	324	26	0.542
Sedem prameňov	1,241	1,038	3.8	409.14	652	63	386	27	0.095

[a]Mean altitude of the watershed
[b]Average long-term annual precipitation (mm)
[c]Mean long-term annual temperature in the watershed (°C)
[d]Potential evaporation index
[e]Mean long-term annual runoff in the watershed (mm, %)
[f]Mean long-term annual climatic evaporation in the watershed (mm)
[g]Mean long-term annual runoff ($m^3 s^{-1}$)

10 Calculation of Runoff and T-Yearly Discharges in Torrent Watersheds in Forestry Practice of Slovakia

To determine of runoff and T-yearly discharges (if direct measurements from Slovak Hydrometeorological Institute Bratislava are not available) for dimensioning of the beds in torrent control (in forestry practice) we use the most commonly regional equation by the academician Dub:

$$q_{\max} = \frac{A_0}{(S_w + 1)^{n_0}} \cdot (1 \pm o_1 \pm o_2)\left(\mathrm{m}^3\ \mathrm{s}^{-1}\ \mathrm{km}^{-2}\right) \tag{8}$$

where q_{max} is the maximal specific runoff ($m^3\ s^{-1}\ km^{-2}$), S_w watershed area (km^2), and A_0, n_0 regional characteristics for 11 basic watersheds of main rivers in Slovakia with 67 subregions according to geological structures by Branch Technical Standard OTN ŽP 3112-1:03 [33]; the value of coefficient A_0 varies within the range from 1.00 to 25.00; the value of coefficient n_0 varies within the range from 0.136 to 0.641. o_1 is the coefficient expressing the effect of forestation of watershed on the runoff (from −0.25 to +0.25):

$$o_1 = 0.5 \cdot \left(0.5 - \frac{S_L}{S}\right) \tag{9}$$

o_2 is the coefficient expressing the effect of watershed shape on the runoff (from −0.10 to +0.10).

Then we can calculate:

$$Q_{\max =} Q_{100} = S_w \quad \cdot q_{\max} \left(\mathrm{m}^3\ \mathrm{s}^{-1}\right) \tag{10}$$

Based on the calculations for 80 watersheds of mountain torrents with watersheds areas from 0.25 to 50.38 km^2, discharges Q1 from 0.20 to 12.0 $m^3\ s^{-1}$ and Q100 from 1.0 to 145.0 $m^3\ s^{-1}$ in 3 geomorphological units of the SR, we found that the values of maximal specific runoff q_{max} ($m^3\ s^{-1}\ km^{-2}$) for the watersheds in geomorphological unit of Poľana (480–1458 m asl) with watershed areas from 0.384 km^2 to 48.40 km^2 ranged from q_{max} = 0.93 $m^3\ s^{-1}\ km^{-2}$ to q_{max} = 4.84 $m^3\ s^{-1}\ km^{-2}$ (with an average q_{max} = 2.93 $m^3\ s^{-1}\ km^{-2}$). In the geomorphological unit of Kremnické vrchy (270–1317 m asl) with watershed areas from 3.79 km^2 to 21.13 km^2 maximal specific runoff ranged from q_{max} = 1.51 $m^3\ s^{-1}\ km^{-2}$ to q_{max} = 3.23 $m^3\ s^{-1}\ km^{-2}$ (with an average q_{max} = 2.24 $m^3\ s^{-1}\ km^{-2}$). In the Western Tatras (690–2248 m asl) with watershed areas from 1.20 km^2 to 50.38 km^2 in the geomorphological unit of Tatras is this interval from q_{max} = 1.65 $m^3\ s^{-1}\ km^{-2}$ to q_{max} = 3.87 $m^3\ s^{-1}\ km^{-2}$ (with an average q_{max} = 2.92 $m^3\ s^{-1}\ km^{-2}$). In the geomorphological unit of High Tatras (905–2,645.8 m asl), watershed areas from 0.25 to 19.34 km^2 vary from q_{max} = 1.62 $m^3\ s^{-1}\ km^{-2}$ to q_{max} = 5.91 $m^3\ s^{-1}\ km^{-2}$ with an average q_{max} = 3.13 $m^3\ s^{-1}\ km^{-2}$ [14, 15].

11 Conclusions

From the beginning of torrent control activities, many important constructions in the form of various biological and technical measures to the flood and erosion control have been created. These measures protect human lives and health as well as the landscape against devastating floods and erosion. At the same time, they improve the possibilities of securing and using valuable water resources from mountain areas. An indispensable prerequisite for the optimal use of many significant positive benefits of torrents and, at the same time, to limit their harmful activity is the revival of the active activities of torrent control in the Slovak Republic. These activities are currently very limited. The torrents form the highest stretches of watercourses. In these areas (mountain watersheds), the floods begin to form. Although there are large-scale protected areas, there are many ways today, the possibility of sensitive interventions and biotechnical measures, to improve runoff rates while increasing the availability of quality water available for human needs.

12 Recommendations

Recommendations for optimizing on integrated torrent control and torrent watershed management in conditions of the Slovak Republic can be divided into several fields:

– Immediate resumption of torrent control activities
– Improvement of cooperation between the Ministry of Agriculture and Rural Development of the SR and Ministry of Environment of the SR
– Better cooperation between all owners, administrators, and users of torrent watersheds
– Education of university-educated professionals in the field of integrated watershed management
– Expanding scientific research into issues of integrated watershed management, flash floods, torrent erosion impact of forest ecosystems to runoff in mountain watersheds, impacts of climate change to runoff formation, and subsequent implementation of the result into practice

References

1. Composite Authors (1984) 100 Jahre Wildbachverbauung (100 years of torrent control in Austria). Bundesministerium für Land und Forstwirtschaft, Wien, p 283. (In German)
2. Skatula L (1960) Hrazení bystřin a strží (Torrent and gully control). SZN, Praha, p 430. (in Czech)

3. Binder R (1969) Zahrádzanie bystrín a lavín (Torrent and avalanche control). Príroda, Bratislava, p 292. (In Slovak)
4. Szolgay J, Hlavčová K, Parajka J, Čunderlík J (1997) Assessment of the potential impacts of climate change on river runoff in Slovakia. Ministry of Environment of the SR, Bratislava, Slovak-Hydrometeorological Institute, Bratislava, pp 11–108. (In Slovak)
5. STN 75 2102 Rivers and brooks regulations (In Slovak)
6. STN 48 2506 Forestry amelioration – Torrent and gully control (In Slovak)
7. Jakubis M, Janský L (2005) The history and importance of the oldest torrent control in the Slovak Republic. In: Coopey R, Fahlbusch H, Hatcho N, Jansky L (eds) A history of water issues. Lessons to learn. United Nations University, Tokyo, pp 178–186
8. Skatula L (1973) Zkušenosti s použitím úprav bystřinných toků (Experience with use of torrent control). VSŽ, Brno, p 92. (In Czech)
9. Skatula L (1935) Zahradenie sbernej oblasti bystriny Jelenca V Starých Horách (Torrent control in the watershed Jelenec in Staré Hory). Zprávy veřejné služby technické 17:547–551. (In Slovak)
10. Grešková A (2002) Relevantné faktory vzniku a podmienky formovania sa povodňových prietokov v povodí Krupinice v roku 1999 (Relevant factors of the formation and conditions of flood discharges in the Krupinica watershed in 1999). Geographia Slovaca 18:267–294. (In Slovak)
11. Rigo F (1999) Následky júlovej povodne na tokoch v správe OZ povodie Hrona v Banskobystrickom kraji. (Consequences of the July flood on the streams in the area of river Hron watershed in Banská Bystrica region). Vodohospodársky spravodajca XLII(10):12–14
12. Jakubis M (2002) Flood disasters in semimountainous areas – Lessons from failures in history of torrent control in the Slovak Republic. In: Fahlbusch H (ed) Food production under conditions of water scarcity, increasing population and environmental pressures. Transaction/Actes vol 1. History Seminar, ICID, New Delhi, pp 27–34
13. Jakubis M (2013) K problematike protipovodňovej ochrany na Slovensku a úlohách lesníkov v protipovodňovej ochrane krajiny (To the problems of flash floods in the SR and the role of foresters in the flood control of the landscape). In: Jakubis M, Podkonický L (eds) Current state and bases of flood protection in the SR. Technical University in Zvolen, Zvolen, pp 42–50. (In Slovak)
14. Jakubis M (2000) Odtokové charakteristiky bystrín Západných Tatier (Runoff characteristics of the torrents in the Western Tatras). Technical University in Zvolen, Zvolen, p 63. (In Slovak)
15. Jakubis M (2008) Výskum závislostí regionálnej hydraulickej geometrie na príklade vodných tokov CHKO BR Poľana (The research of relations of regional hydraulic geometry on the example of watercourses of the protected landscape area – biosphere reserve Poľana). Technical University in Zvolen, Zvolen, p 116. (In Slovak)
16. Jakubis M (2009) Interval opakovania prietoku plným prietokovým profilom v prirodzených korytách vodných tokov v malých povodiach (The recurrence interval of bankfull discharge in natural watercourse beds in small watersheds). Acta Facultatis Forestalis, Zvolen, pp 77–88. (In Slovak)
17. Jakubis M, Jakubisová M (2011) Frekvencia výskytu prietoku plným prietokovým profilom v prirodzených korytách bystrín Západných Tatier pod zdrojovými zónami (Frequency of bankfull discharge occurrence in natural torrent beds of West Tatras under the source zones). Acta Facultatis Forestalis Zvolen 54(3):121–134. (In Slovak)
18. López Cadenas De Llano D (1993) Torrent control and streambed stabilization. FAO, Rome, p 166
19. Composite Authors (2010) Lesy Slovenska a voda (Forest of Slovakia and water). Technical University in Zvolen, Zvolen, p 129. (In Slovak)
20. Composite Authors (2016) Správa o lesnom hospodárstve Slovenskej republiky za rok 2015 (Report on forestry in the Slovak Republic per year 2015). Bratislava: Ministry of Agriculture and Rural Development of the Slovak Republic, National Forest Centre, Zvolen, p 76. (In Slovak)
21. Majerčáková O, Škoda P (1998) Prívalové dažde na severovýchodnom Slovensku. (Torrential rains in the north–east Slovakia). Vodohospodársky spravodajca XLI(10):18–19

22. Valtýni J (2002) Lesy a povodne (Forest and floods). Technical University in Zvolen, Zvolen, p 46. (In Slovak)
23. Valtýni J (1995) Základy hydrológie a lesníckej hydrológia (Basics of hydrology and forestry hydrology). Technickal University in Zvolen, Zvolen, p 103. (In Slovak)
24. Krešl J (1990) Lesnické meliorace (Forestry amelioration). Vysoká škola zemědělská, Brno, p 226. (In Czech)
25. Minďáš J, Čaboun V (2002) Influence of vegetation on catchment runoff. Final Report of Project VTP 27–64 E0203, LVÚ, Zvolen, p 26. (In Slovak)
26. Bíba M, Oceánska Z, Vícha Z, Jařabáč M (2006) Forest – hydrological research in small experimental catchments in the Beskydy Mts. J Hydrol Hydromech 54(2):113–122
27. Minďáš J (2010) Vodná bilancia lesného ekosystému (Water balance of forest ecosystem). In: Minďáš J, Škvarenina J (eds) Lesy Slovenska a voda (Forest of Slovakia and water). Technical University in Zvolen, Zvolen, p 129. (In Slovak)
28. Krešl J (1989) Lesotechnický systém protierózní ochrany a hrazení bystřin (Forestry-technical system of erosion control in torrent control). In: Novák L (ed) Natural environment and watercourses. Povodí Ohře, Chomutov, pp 52–59. (In Czech)
29. Valtýni J (1986) Vodohospodársky a vodoochranný význam lesa (Importance of the forest for water management and water protection). Príroda, Bratislava, p 68. (In Slovak)
30. Jakubisová M (2009) Starostlivosť o brehové porasty a jej význam v protipovodňovej ochrane krajiny (Tending about riparian stands and their importance in the flood control of the landscape). In: Watercourses (2009) Kostelec nad Černými lesy: Lesnická práce, sro, pp 143–147. (In Slovak)
31. Jakubisová M (2013) Brehové porasty a povodňové prietoky (Riparian stands and flood discharges). In: Jakubis M, Podkonický L (eds) Current state and bases of flood protection in the SR. Technical University in Zvolen, Zvolen, pp 69–76. (In Slovak)
32. Bandyopadhyay J, Rodda JC, Kattelmann R, Kundewicz W, Kraemer D (1997) Highland waters – a resource of global significance. In: Messerli B, Ives JD (eds) Mountains of the world. A global priority. Parthenon Publishing Group, New York, pp 131–155
33. Branch Technical Standard OTN ŽP 3112–1:03 (In Slovak)

Water Demand Management and Its Impact on Water Resources at the Building Level

Z. Vranayová and D. Káposztásová

Contents

Abstract New reports of water scarcity and record droughts due to climate changes are becoming increasingly common. The costs of water infrastructure have risen dramatically. Discussing the water used in a good or bad (waste) way led us to think if we are using water in a sustainable way. A common characteristic of water demand in buildings means its relentless rise over many years and conception of continuous growth over coming decades. The main influencing factors of water demand patterns are population growth, lifestyle change depending on the region, demographic structure and the possible effects of upcoming changes in climate and other health risk factors.

In the European Union, it is common to use well and rainwater source for non-potable purposes (such as irrigation, toilet flushing, etc.). Grey water reuse is in our country still rare. Common household usage consumes a lot of water. There is a need to manage its end use as sustainable as our conditions allow us. Potable water consumption of the Slovak households isn't above average at all, but its use is inappropriate. Questionnaire on water, as one of data collection methods, gives a closer look at water habits of households. The results show that most of our citizens are pro water saving oriented and open to new water ideas – as in the building water cycle.

Z. Vranayová (✉) and D. Káposztásová
Department of Building Services, Faculty of Civil Engineering, Institute of Architectural Engineering, Technical University of Kosice, Kosice, Slovakia
e-mail: zuzana.vranayova@tuke.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 225–250,
DOI 10.1007/698_2017_211,
Published online: 27 April 2018

The main goal of this chapter is to present the background for the water use, regulations and legislative framework in the context of a water conservation strategy and discuss water types in building water cycle connected to water-energy nexus in the wider environment.

There is a gap for water regulation and water supply of grey and rainwater systems. This chapter pointed out the challenges and recommendations to strengthen and enhance future of alternative water sources based on the scientific findings, policy, economic and social impacts.

Keywords Building water cycle, Questionnaire, Sustainability, Water sources

1 Introduction

It is increasingly obvious that the current use, development and management of the planet's water resources, and the services they provide are unsustainable. At the United Nations Conference on Sustainable Development in 2012 (Rio + 20), governments recognized that water is "at the core of sustainable development as it is closely linked to a number of key global challenges" [1].

While the world's population tripled in the twentieth century, the use of renewable water resources has grown sixfold. Within the next 50 years, the world population will increase by another 40–50%. This population growth – coupled with industrialization and urbanization – will result in an increasing demand for water and will have serious consequences on the environment [2].

The total volume of water in the world remains constant. What changes are its quality and availability. Water is constantly being recycled, a well-known system as the water or hydrological cycle [3].

According to the World Water Assessment Programme (WWAP) [4, 5], about 70% of water use in the world is used for irrigation, about 22% for industry and about 8% for domestic use. In many countries, the hydrological cycle is managed to provide enough water for industry, agriculture and domestic use. It requires the management of surface and groundwater resources, treatment and supply of water, its collection, reusing and returning back to the cycle. These facts lead us to start with the support of the "small" water cycle at the building level, by creating the building water cycle (see more in the following chapter).

It means that the freshwater – blue water – does not have to be the first choice for a water source [6]. People use a lot of water for drinking, cooking, washing and irrigating landscapes, but even more for producing food, materials products and manufactured items such as clothes and to run buildings [7].

As has already been mentioned, 8% of total world water resources are used for domestic purposes. Average water uses per person in selected countries are described in Fig. 1.

In Slovakia, the average consumption is around 109 L/per person/day, and it can be classified according to end purpose (Fig. 2).

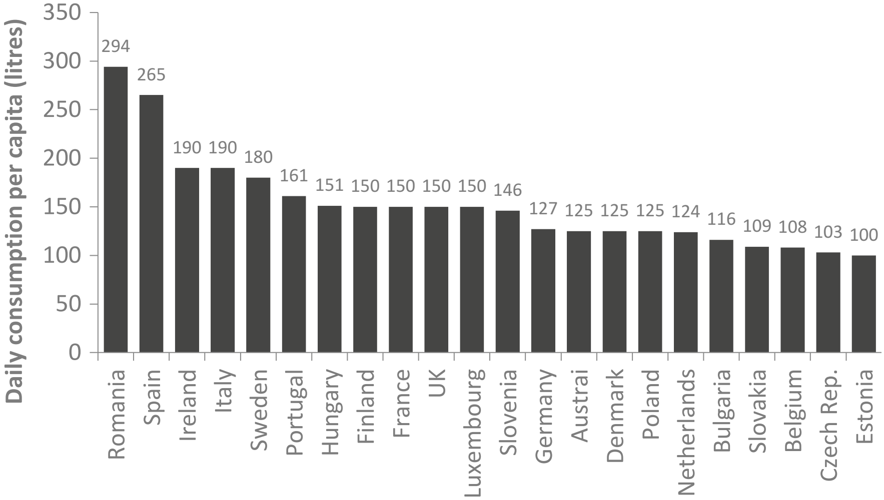


Fig. 1 Average water use per person [8]

According to the Population and housing census results 2011, there was an increase of built houses around 3.2%. From the 2011 census results with an average of six inhabitants per household, average water use per household per day in Slovakia was 843,343,200 L/ day. Moreover, therefore only households are yearly consuming around 308,000,000 m^3/ year of potable water. It shows that about 55% of drinking water may be replaced by alternative water source as rainwater, grey water or water from well, etc.

This fact gives credit to reuse of potable water in building water cycle. We need very fast to change the thinking of all society which will be in the balance with nature to be more sustainable.

2 Regulation and Legislative Framework

In this part, we introduce basic information about the legislation in the water industry in general. Most of the directives deal with water quality since the main target of all legislations and standards is to obtain sustainable water quality globally. The main directive in Europe is the Water Framework Directive (WFD) 2000/60/EC [2] which establishes a legal framework to protect and restore clean water across Europe and ensure its long-term sustainability [4]. It is the most far-reaching piece of environmental legislation ever introduced by EU and will change the way in which water is perceived and managed in Europe forever [3].

This directive also sets rules for groundwater, and according to Davies and Butler implementation of the directive has more uncertainties, for instance, what

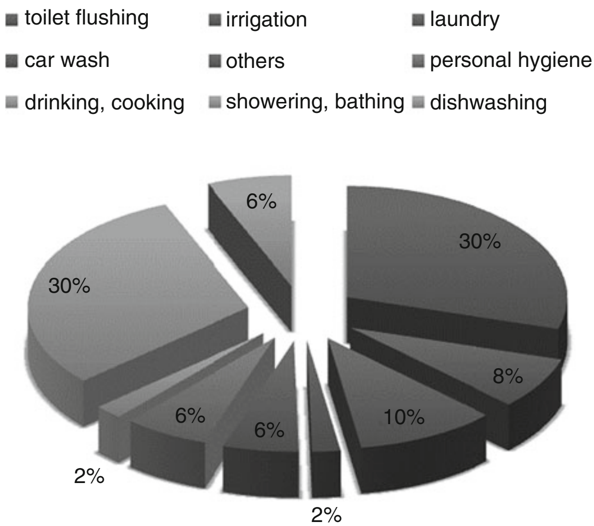


Fig. 2 Average consumption of potable water in Slovakia according to end purpose water use per person [9]

implications will a prohibition of discharge to groundwater have on infiltration-based sustainable drainage systems [10].

The document similar to European WFD is the Clean Water Act (CWA) in the United States which was implemented in the early 1970s and has resulted in significant efforts to improve the quality of water bodies, much of which has included improvements to stormwater management [11]. Other related European directives or “WFD daughters” are the Urban Waste Water Treatment Directive 91/271/EEC, the Groundwater Directive 2006/118/EC, the Bathing Water Directive 2006/7/EC and the Flood Directive 2007/60/EC.

Quality control of drinking water and the health security in Slovakia is performed through a set of 82 indicators of water quality defined by Government Regulation Nr. 8/2016 Coll., setting down requirements for water intended for human consumption and control the quality of water intended for human consumption according to European Council Directive 98/83/EC on the quality of water intended for human consumption. The limit values of water quality parameters are according to their health significance distinguished as the recommended value, indicative value and the limit of a maximum limit value. The most serious health consequences of the crossing are the highest margins, which excludes the use of water as drinking.

The water legislation is covered by following acts and regulations. The first is the Water Act, Act No. 303/2016 Coll. on water sources and on the amendment of the Act of the Slovak National Council No. 372/1990 Coll. on offences in the wording of latter provisions. Water Act is the basic legal framework regulating water protection in Slovakia.

The Government Regulation No. 296/2010 Coll. establishes qualitative objectives for surface waters and limit rates of wastewater and special waters pollution indicators.

The Act No. 442/2002 Coll. on Public Water Systems and Public Sewage Systems and on amendment and supplement of the Act No. 150/2017 Coll. on Regulation of Network Industries states that “the owner of the sewage system can deny connection of property to public sewage system if for example the capacity of system or WTP is already exceeded or is possible to dispose runoff water from stormwater out of public sewage”.

Regulation of the Ministry of Environment No. 684/2006 is about technical requirements of design, project documentation and public water supply and public sewage construction.

Regulation of the Ministry of Environment No. 209/2013 sets out details about measuring the amount of supplied water and quantity of discharged wastewater and surface runoff.

Act No. 303/2016 Coll. on Flood Protection establishes measures how to prevent floods. The Slovak government approved the Programme of Landscape Revitalization and Integrated Watershed Management in the Slovak Republic by the decree No. 744/2010. The objectives of this programme regarding the topic of the thesis are flood protection and retention of stormwater in the country and support of stormwater management projects.

A series of European Standards aims to provide requirements and recommendations for all materials in contact with drinking water. Whether you have responsibilities for local authority mains, building sites or public and private buildings, these publications need to be consulted.

The design applies to new installations, pipework as well as alterations and repairs. STN EN 806 Specifications for installations inside buildings conveying water for human consumption divided into five parts were fully adopted by the Slovak Republic.

3 Water Types and Quality

In the environment exist many types of water as defined by Kinkade-Levarios [6]:

- *Atmospheric water* – as rain and fog
- *Blue water* – water from lakes, rivers
- *Green water* – soil moisture
- *Stormwater* – rainwater that has hit the ground
- *Grey water* (light or dark) – wastewater from laundry, bathtub, shower, basin
- *Alternate water* – water that has been used previously
- *Black water* – water from toilets and kitchen sinks
- *Reclaim water* – water that has gone through a sewer treatment process and has been filtered and processed for reuse in various ways
- *Sea water* – from desalination

We would like here to concentrate on four water types that are the most common and available source in buildings, mostly family houses (Fig. 3):

1. *Potable water* – water from tap, source of water for potable purposes

2. *Water from well* – a source of water for potable and non-potable purposes
3. *Rainwater* – collected water from the roof during precipitation; source of water for non-potable purposes
4. *Grey water* – wastewater from bathtubs, shower and basin; source of water for non-potable purposes

At the building level, we are using the fastest, easiest and most reliable source of water that we have – the water from municipal water supply system that goes through the highest level of testing. Of course, there are many cases when this source of water is unavailable (no water supply, water supply failure, damage, technical problems, disasters, etc.). Most people do not think about water storage or what would happen if there is no water available.

There are also many issues that need to be taken into account when considering the water source and its quality (see Table 1).

Water quality consists of several issues:

- *Aesthetic parameters (colour, odour and turbidity)*
- *Microbiological content (bacteria and photogenic organisms)*
- *Chemical and physical parameters (pH, dissolved solids, disinfectants,* etc.*)* [13].

Aesthetic parameters vary significantly between rainwater, grey water, potable water and water from well. The acceptability of reclaimed water depends on personal preferences and the end use (filtration can help in this problem) [13].

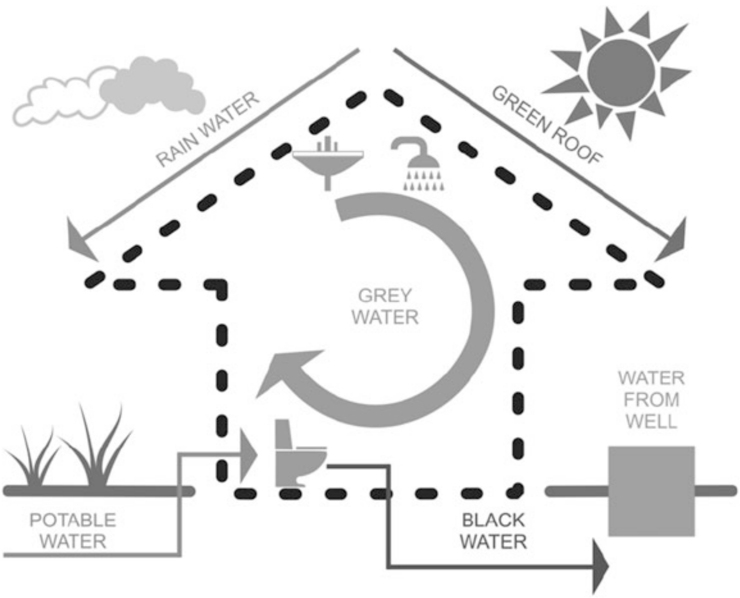


Fig. 3 Sources of water at the building level [12]

Table 1 Comparison of guidelines for drinking water and bathing water quality

Water	Potable water	Bathing water
According to	Directive 98/83/CE	Directive 2006/7/CE
Colony count 22°C	100/mL	–
Colony count 37°C	20/mL	–
Total coliforms	0/100 mL	–
Escherichia coli	0/100 mL	Between 500 and 1,000 UFC/100 mL
Enterococci	0/100 mL	Between 200 and 400 UFC/100 mL
Anaerobic sulfato-reducing bacteria	0.5/mL	–
Legionella	1,000 UFC/L	–
Pseudomona aeruginosa	0/250 mL	–
Staphylococcus	0/100 mL	–
Surface active substances		Between 0.3 mg/L and no lasting foam
Ammonia nitrogen	0.1 mg/mL	–
Conductivity	<2,500	–
Colour	Acceptable to consumers and no abnormal change	No abnormal change
Turbidity	1 NFU	–
Taste and odour	Acceptable	–
Hardness	>15°F	–
Nitrates	50 mg/L	–
Nitrites	0.5 mg/L	–
Oxidizability	5 mg/L O2	–
pH	Between 6.5 and 9	Between 6 and 9
Iron	200 μg/L	
Mineral oils	–	Between 0.3 mg/L and no visible film on water surface
Phenols	–	0.005 mg/L
Transparency	–	Between 1 and 2 m
Dissolved oxygen	–	Between 1 and 2 m
Floating residues	–	–

Microbiological quality should be controlled on the high level. Thus there is no recorded mortal case caused by rainwater or grey water, but it can cause illnesses and in extreme cases death when it is used in no appropriate way [13].

Chemical and physical parameters should follow the requirements set by local standards and Water Framework Directive. Parameters as pH and dissolved solids may not only be relevant to the end user, but may have an impact on disinfection processes and the life of the whole system. Metals from rainwater or grey water could make reclaimed water not suitable for irrigation purposes [13].

Table 2 Water quality according the end use [14]

Category	Maintenance	Irrigation	Flushing toilet
Total coliforms c/100 mL	10	1,000	1,000
Escherichia coli c/100 mL	1	250	250
Enterococci c/100 mL	1	100	100
Legionella cfu/L	100	100	100
Residual chlorine ppm	< 0,5	<0,5	< 2
Residual bromine ppm	Not applicable	Not applicable	< 2
Dissolved oxygen	>10% of saturation or >1 mg/L of oxygen (which is smaller)		
Floating residues	Visually clear without floating residues		
Colour	Not unsatisfactory	Not applicable	Not unsatisfactory
Transparency	<60% for 254 nm	Not applicable	<60% for 254 nm
Turbidity	<10	Not applicable	<10
pH	6.8	6.8	6.8

According to EA (Environmental Agency) guidance on how microbiological composition should be either rainwater or grey water for further use is not drinkable [14] should be used Table 2.

4 Questionnaire on Water Use

Massive use of rainwater or reused water for non-potable purposes in buildings promotes the conservation of natural resources, water, and thus the overall sustainability in water management.

Potable water consumption of the Slovak households is not above average at all as was mentioned before but we use it in inappropriate ways. We used the Questionnaire on Water, as one of data collection methods gives a closer look at water habits of households.

As a first step, existing methodologies, standards and guidelines have been analysed. Therefore questionnaire has been sent out to the respondents to identify the water habits in their countries from all over the world (Fig. 4).

In 2014 the questionnaire was completed by the group of 200 people from different spheres of society divided to 85 male and 115 female respondents. The average age of respondent is 43 years. The 75% of them live in the family houses. The questionnaire consisted of ten questions. The last our question was about their opinion on water-energy nexus.

The most important and serious fact is that 80% of respondents use potable water for all domestic purposes such as flushing toilets and watering the garden or washing their cars.

A brief overview of final results will show the attitude and differences between the Slovak respondents and respondents from foreign countries. As described in Fig. 5 in Slovakia, no grey water use was identified, and part of houses are not

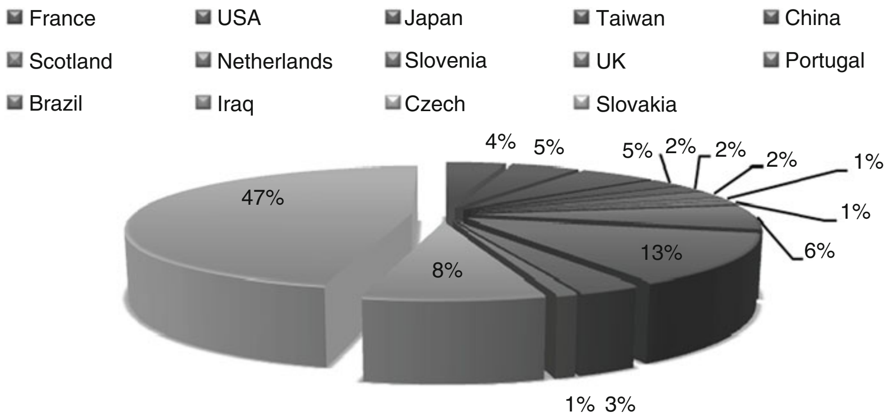


Fig. 4 Countries of respondents' origin

connected to main water supply for different reasons (good quality of the water in the well, no water supply connection).

Our respondents were asked if they were afraid of grey and rainwater use. In fact, Slovaks were more afraid of grey water than rainwater, due to the lack of information about such system of application. Respondents from foreign countries were not so afraid of reusing grey and rainwater (Fig. 6).

It is interesting that even though Slovaks are afraid of reuse of water around, 85% of them would think about sustainable solutions (Fig. 7) if they built a new house.

About 55% of all respondents would consider installing such system if the return on investment is from 6 to 10 years (Fig. 8).

The main reasons for water saving measures application were the water bill reduction – in 49% of respondents, 41% for sustainability and reservoirs saving only 10% (Fig. 9).

Our foreign respondents see the biggest potential in installing the grey water system in industrial buildings than other types (Fig. 10).

The last question of our questionnaire was about the relatively newest idea: the water-energy nexus.

Our respondents have expressed their opinions, e.g., in the following way:

- *The nexus between energy and water has not been understood by general population and decision makers yet. This must be fully discussed by all.*
- *It is an equation that should always be weighed against the shortage of drinking water on the planet. However, it should be environmentally friendly energy sources used for that also they do not become a problem.*
- *It is the way we need to follow.*
- *Reducing the grey water treatment will reduce the energy necessary for its treatment.*
- *Further studies need to be conducted in order to evaluate the real cost of water usage in energy production and* vice versa *(financial and environmental).*
- *It is a future. This theme is very interesting; I work in this area* [12].

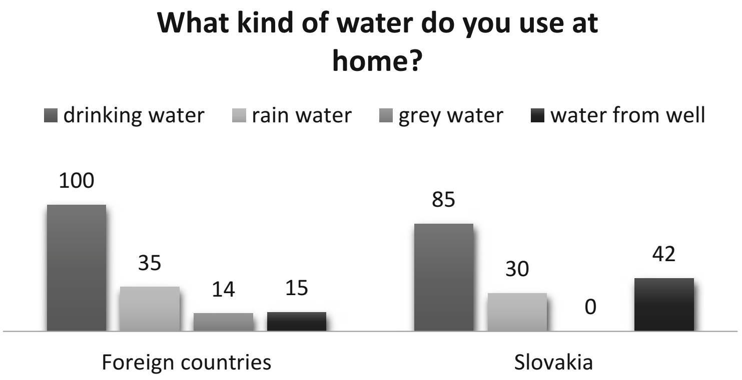


Fig. 5 Comparison of water types used in Slovakia and abroad

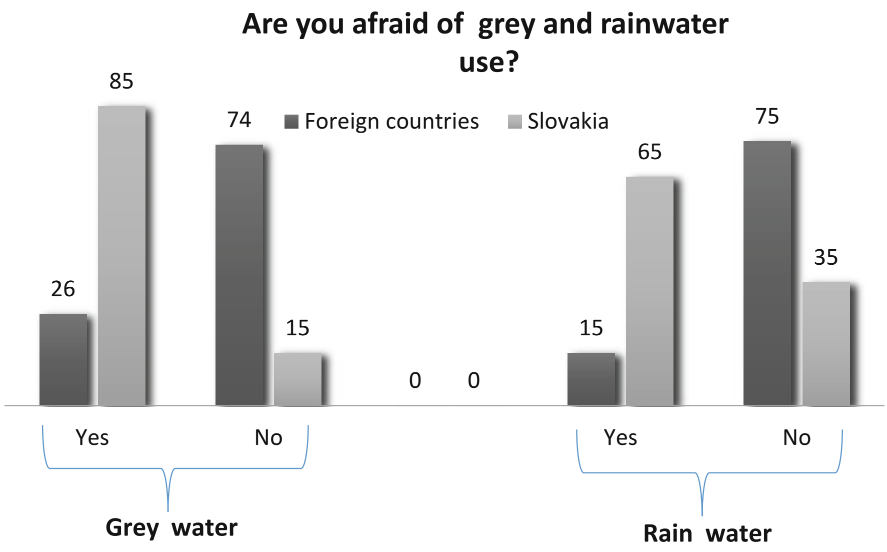


Fig. 6 Comparison of afraid of grey and rainwater systems

The questionnaire shows people's willingness to use an alternative water source for different non-potable purposes rather than potable water. Its results give us a closer look at people's attitude to sustainable water resources for building supply as well as water consumption habits of water users.

The gratifying conclusion is that most of our citizens are pro water saving oriented and very open to new water ideas as closed in-building water cycle. In Slovakia, this area has not been so developed yet. It is necessary very fast to define regulation and set standards for designing such hybrid systems (see Sect. 5.3), e.g., according to foreign national standards and performed experiments in Slovak conditions.

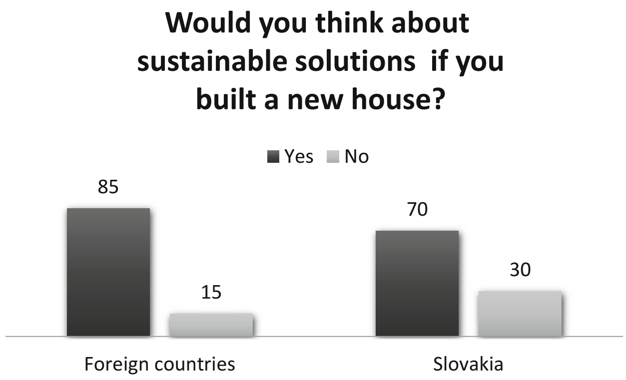


Fig. 7 Sustainable solutions volition

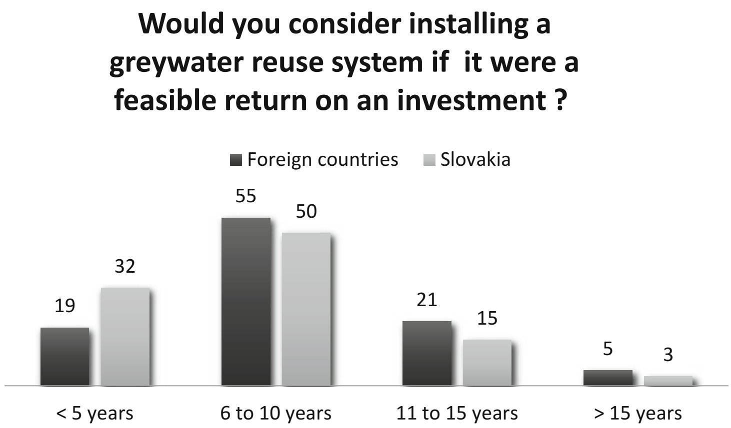


Fig. 8 An acceptance of return on an investment

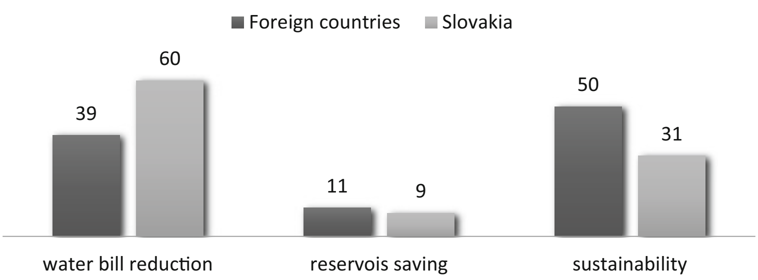


Fig. 9 Reasons for water saving

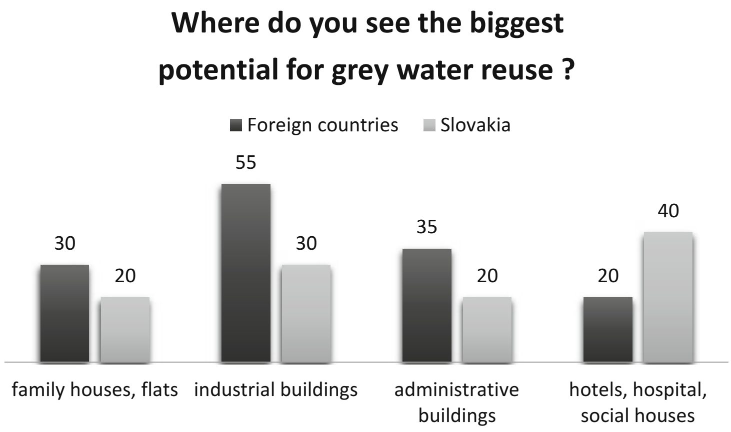


Fig. 10 Potential for grey water reuses according to building type

5 Water in Building Cycle

The quantity of water used by European households has increased significantly over the past decades and now represents approximately 70% of the total water use in buildings [15]. A report by the Office of Community and Economic Development [5] estimates that 35–40% of household water consumption is used for personal hygiene (shower and bath), 20–30% for toilet flushing and 10–20% for laundry.

The research has shown that replacing high water-using devices with water-efficient alternatives can reduce annual water consumption by 32–50% [7, 15]. Focusing on household water consumption and, in particular, the use of water-efficient devices offers significant potential for water savings.

Water can create a building water cycle. An installation of the rainwater harvesting system and system of grey water reuse or the use of water from well or other alternative is bringing many advantages, but also if not treated well the disadvantages and possible risks. When recycling water, it is essential to protect the health of both the public and the environment, and a risk management approach is the best way to achieve this.

As prof. Afonso presented at the Symposium of CIB in Brazil 2014, it can be stated that water efficiency, which implies conservation of water, is the best way to contribute to policies for sustainable use of water [16].

Expressed by his words:

The interventions leading to an efficient use of water in the building cycle can be systematized by a guiding principle called "the 5R principle" (Fig. 11).

The 1st R
Reduce consumption includes the adoption of efficient products and devices, without prejudice to other measures of an economic, fiscal or sociological nature. For this, the labelling of the water efficiency of products similar to strategies for energy efficiency is considered as an essential measure to provide information to consumers.

Fig. 11 5R principle content (according [12] and [16])

The 2nd R
Reduced losses and waste may involve interventions such as the monitoring of losses in building networks (in flushing cisterns, sprinklers, etc.) or the installation of circulation and return circuits of sanitary hot water.

The 3rd and 4th R
The reuse and recycling of grey water/wastewater, meaning a use in "series" or the reintroduction of water at the start of the circuit after treatment, can be relevant in relation to the use of grey water, not excluding the possibility of using treated wastewater for some purposes, such as watering gardens.

The 5th R
The last resort is alternative sources. This may involve the use of rainwater, groundwater and salt water. These measures can be easily considered for new or refurbishment buildings. For existing buildings, water efficiency audits and risk management methods are a more appropriate procedure, as is the case with energy efficiency [17].

It is known that around 60% of drinking water may be replaced by an alternative water source (rainwater, well water, grey water). This fact gives credit to reuse of potable water in building water cycle and better percentage weight in building environmental assessment [18]. Water management field in the environmental assessment system (BEAS) used in Slovakia has a percentage weight of 8.88% (see chapter Vilcekova et al.). Buildings that have attained a specific green building level of LEED Certification or any of similar certification are meeting the future sustainable challenge, which means we can reduce our water footprint.

Following sections will give us a closer look at different water types used in building cycle and the brief description of such systems.

5.1 Building Potable Water Sources

Household water use is water used for indoor purposes from drinking, food preparation, washing clothes and dishes, bathing and showering, flushing toilets to outdoor purposes such as garden watering. Domestic water use includes potable and non-potable water provided to households by a public water supplier or domestic deliveries and self-supplied water [12].

Drinking or potable water is water safe enough to be consumed by humans or used with low risk of immediate or long-term harm. In most developed countries, the tap water supplied to households, commerce and industry meet the water quality and portability standards.

Most of the population in Slovakia (86%) is supplied from public water mains. In Slovak republic, downward trend in the consumption of drinking water from public water supplies is recorded last years. More and more people preferred the water from their own source – wells or buying bottled water.

Potable water could be to the building supplied from several possible sources:

- Municipal water supply (1)
- Water wells (2)

1. *Tap water* (or running water, city water, municipal water, etc.) is water supplied to all taps or valves in the house. Its typical uses include washing, toilets and irrigation. Indoor tap water is distributed through indoor plumbing (Fig. 12). This type of installation has existed since antiquity but was available to very few people until the second half of the nineteenth century. Water used for abstraction of drinking water is now covered by the Water Framework Directive (WFD). The Directive does not itself set mandatory standards but relies on national and other legislation. In the most of EU countries directives and guidelines, the value limits are given more straighten that are set in WFD [3].

2. *Water from wells* is water supplied from groundwater sources. It could be used for both potable and non-potable purposes according to its quality (Fig. 13).

Today about 14% of the Slovak population is individually supplied from well water. Eighty to eighty-five percent of water resources for individual supply does not meet the hygiene requirements or has poor sensory properties and are a permanent risk to user's health. The most common case is a faecal pollution, nitrate and iron. Water quality in individual water sources is affected by the poor technical condition of wells, lack of depth and/or poor disposal of sewage in the neighbourhood. High risk of infectious diseases is increasing especially in times of flood and in case of drainage failures.

Right well construction and continued maintenance are keys to the safety of building water supply. State water-well contractor licensing agency, local health department or local water system professional can provide information on well construction for users [19].

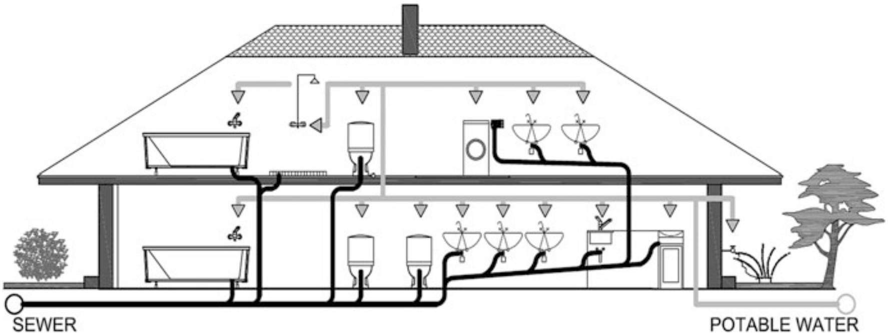


Fig. 12 Potable water in building water cycle [12]

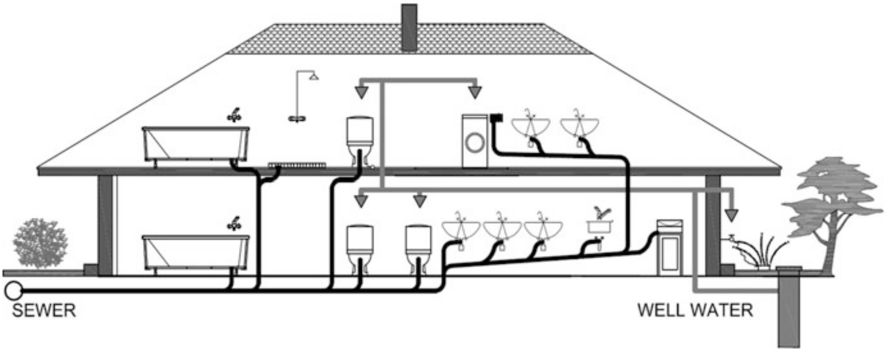


Fig. 13 Water from well in building water cycle [12]

Quality check of raw water sources and water quality control in the distribution network ensures the owners/operators of public water supplies. Operators of public water may be water companies, municipalities or other legal/natural persons having trade licence to operate a public water supply.

These two types of water described above are suitable for all domestic purposes, but this is not a sustainable solution for today situation.

Common vision in leading foreign countries is the use of all source of water that consumer have at his property. Reclaimed water is water that has been collected and treated, so it is suitable for its indented use.

5.2 *Non-potable Water Sources*

Non-potable (reuse) systems typically have lower water quality than potable systems. The level of water treatment varies depending on the end use. Non-potable reuse usually requires a dual distribution system – it means separate systems of pipes for distributing potable and non-potable water. Depending on the extent of a community's water distribution system, non-potable reclaimed water can be used mainly for flushing toilets, watering parks or lawns, supplying fire hydrants, washing cars and streets, filling decorative fountains and many other purposes.

Rainwater and grey water are both water sources for reclaimed water for non-potable end use, and they need to be well labelled. Watering or washing devices, indoor or outdoor, must be marked with warnings similar as in Fig. 14, together with appropriate symbols, and their taps fitted with a detachable handle to prevent the improper use [20].

As presented in Portuguese study by prof. Afonso [17], it is considered that reclaimed water can be used in flushing of toilets, washing clothes and watering gardens, all after appropriate treatment.

The quantitative characterization and a physicochemical and microbiological analysis of light grey water were presented, e.g., in Aveiro Symposium of CIB W062 by C. Matos and I. Bentes. Grey water use at the domestic level may well be the simplest form of water reuse and should be investigated as a means to reduce the impact of residential developments on water resources worldwide [21]. Reuse of grey water can also reduce the load on septic tanks and drain fields. In the United States, they have the Green Plumbing and Mechanical Code Supplement (IAPMO) that in the chapter titled "Decision Analysis Tool for Appropriate Water Source in Buildings" by D. Káposztásová and Z. Vranayová in this volume, deeply describes the construction, alteration and repairing of grey water systems [22].

Grey water refers to water sourced from the kitchen (depending on national regulation), laundry and bathroom drains, except toilets. Grey water may contain urine and faeces from nappy washing and showering, as well as kitchen scraps, soil, hair, detergents, cleaning products, personal-care products, sunscreens, fats and oils [17, 23–25].

We called domestic wastewater (excluding faecal matter and urine) from bathrooms, basins and showers *light grey water*. We called contaminated or difficult-to-handle grey water, such as solids-laden kitchen sink water or from laundry, *dark grey water*.

Grey water systems depend significantly on the behaviour of the people using the appliances, as well as the quality and volume of water collected (Fig. 15). There exist many different methods used to filter and treat collected grey water, which ranges in complexity and the level of treatment.

Fig. 14 Label of non-potable water tap

Grey water systems consist of one or more storage tanks, pump, filtration unit, chemical dosing and connecting pipework (Fig. 16).

Grey water according to treatment could be:

- Reused – that water has not undergone treatment.
- Recycled – this water has undergone at a minimum through the filters and disinfection.

Rain – a form of precipitation is the first form of water in the natural hydrological cycle. It is a primary source of water that feeds rivers, lakes and groundwater aquifers, and they became the secondary source of water [6].

Rainwater may be collected from any hard surface, such as concrete or stone patios, and asphalt parking lots. However, once the rain hits the ground, it is no longer referred as rain, but as the *stormwater* (Fig. 17). The landscape can also be contoured to retain the stormwater runoff. Rainwater harvesting captures precipitations and uses it as close as possible to where it falls [26].

The potential of rainwater harvesting depends on location and weather. Precipitation monitoring is a very a common process all around the world. In Slovakia monitoring is provided by the Slovak Hydro-meteorological Institute (SHMU).

Stormwater management has been changing throughout years, and it was caused by extensive urbanization which changed stormwater runoff and infiltration patterns. Rainwater harvesting supports sustainability in stormwater management which in principle means managing stormwater as a resource and as close to the source as possible [27].

Rainwater harvesting system is much more sophisticated today since our demand is higher and necessity of water quality is taken into consideration. We usually collect water from impervious surfaces (roofs, paths and parking lots). It is further transported by gauges and downpipes through filter or screen to prevent organic material particles and debris reaching the system.

Very important part of the system is the first flush device. This equipment retains initial runoff because of the stored water quality. It is possible to instal the system

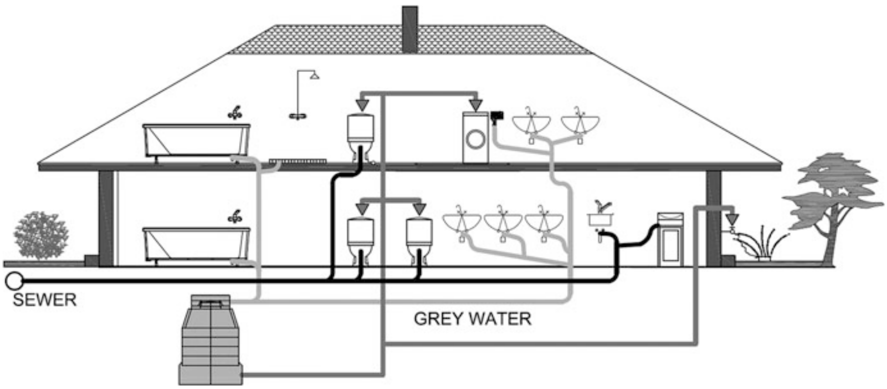


Fig. 15 Grey water in building water cycle [12]

Fig. 16 Most used grey water system parts [12]

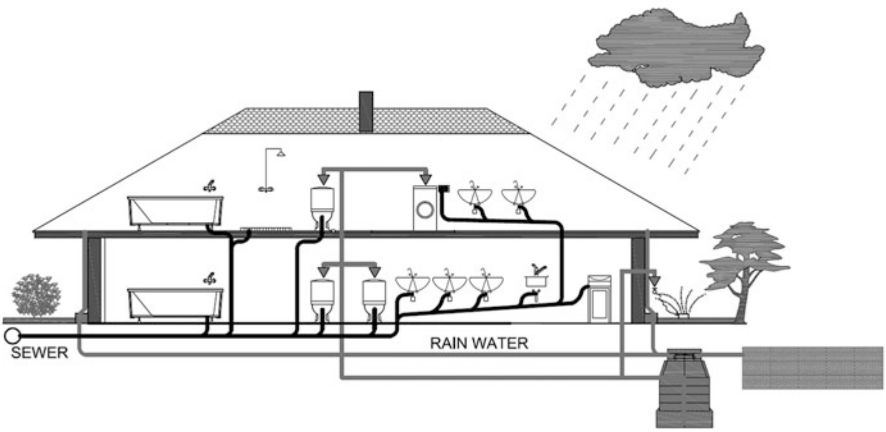


Fig. 17 Rainwater in building water cycle [12]

different types of filters and treatment devices. The level of treatment of the stored water depends on the purpose for what the water will be used. There are different disinfection devices using, for instance, UV radiation, chlorine or activated carbon filters on the market (see Fig. 18).

Pumps and pipes, necessary for transporting the water to the consumer, are inseparable parts of the system and cannot be interconnected with potable water network [28, 29].

Keeping rainwater and grey water isolated from each other and/or combining the reclaimed water prior to use is another option. This means that two separate systems are required, and higher costs and maintenance will be necessary.

While undertaking a water audit, it may be identified that rainwater and grey water are insufficient on their own to meet a part of the water demand in the building. It may be possible to combine rainwater, grey water, water from well and potable water to provide a viable water source to cover the whole water demand at the building level (see following chapter).

Fig. 18 Most used rainwater harvesting system parts [12]

5.3 Hybrid Systems

Grey and rainwater systems vary significantly in their complexity and size and can be grouped according to the type of filtration or treatment they use as follows as described in British standard BS 8525-1:2010 [30]:

1. Direct reuse systems (no treatment).
2. Short retention systems.
3. Basic physical/chemical systems.
4. Biological systems.
5. Biomechanical systems, the most advanced for domestic grey water reuse, combine biological and physical treatment, e.g., removing organic matter by microbial cultures and solid material by the settlement. They encourage bacterial activity by bubbling oxygen through the collected water
6. Hybrid systems – integrated with rainwater, or other water sources.

The hybrid system represents the vision of building water cycle. Potential uses for grey and rainwater depend on the quantity and quality of water available. Each case must be assessed by the individual plan to design the most efficient and green sustainable water system (see Fig. 19).

Figures 20 and 21 describe a real scheme and technical drawing of a hybrid system for a building.

When recycling water, it is essential to protect the health of both the public and the environment, and a risk management approach is the best way to achieve this issue. The quality of water is very important and depends on the end use.

According to the critical review from Sapkota et al. [31], the fact that hybrid water supply systems are not free of challenges can't be ignored. The question is if these calls for extensive collection and distribution systems are necessary for reclamation and reuse of waste water, especially in the case of centralized, non-potable systems that need separate distribution of drinking and non-potable water. The need for dual water supply systems signifies increase in cost and energy consumption for our urban area and for the transfer of waters. There are no known impacts of water hybrid supply systems on aspects such as flow changes, nutrient and sediment regimes, greenhouse gas emissions and impacts on rivers,

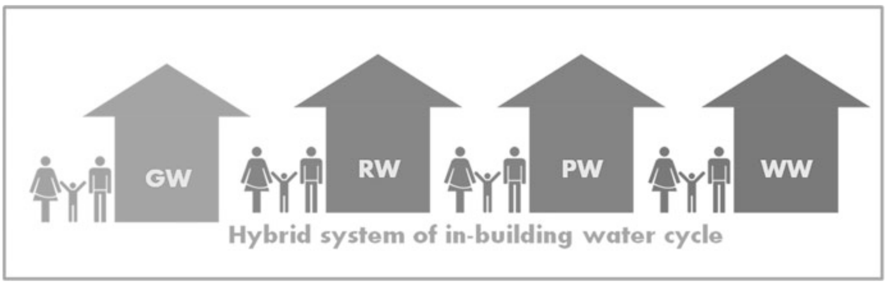


Fig. 19 Hybrid system of in-building water cycle [12]

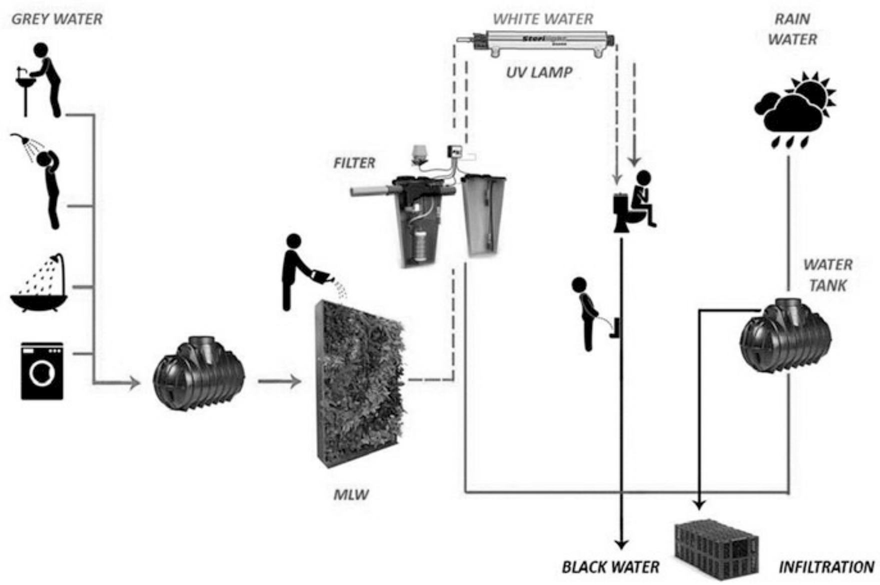


Fig. 20 Hybrid system of in-building water cycle – combined application using grey water, rainwater, vegetated wall and infiltration

aquifers and estuaries. A sophisticated sewage treatment technology requires a considerable amount of energy. It is, however, possible to use sludge from wastewater treatment to the current generation of energy.

6 Conclusion and Recommendations

Water harvesting is not so much different than renewable energy – opportunities abound in the building to capture a free resource and turn it into an economical solution. The key is to have the right systems in place.

Energy efficiency and sustainability are key drivers of water reuse, which is why water reuse is so integral to sustainable water management. The water-energy nexus recognizes that water and energy are mutually dependent – energy production requires large volumes of water, and water infrastructure requires large amounts of energy [32].

Therefore, sustainable water management can be defined as water resource management that meets the needs of present and future generations. A "net-zero" water building is an innovative strategy that pushes our buildings to be fully responsible for generating its potable water needs and treating all discharge waste.

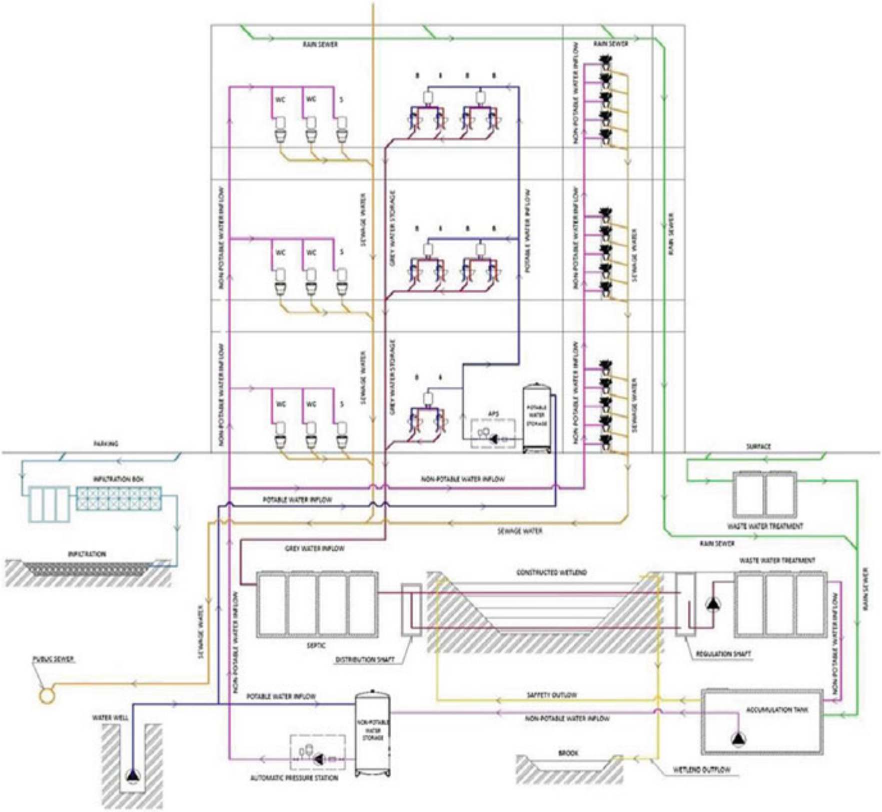


Fig. 21 Hybrid system of in-building water cycle – combined application using grey water, rainwater, well water and infiltration

Water reuse is integral to sustainable water management because it allows water to remain in the environment and be preserved for future uses while meeting the water requirements of the present. Water and energy are interconnected, and sustainable management of either resource requires consideration of the other. Water reuse reduces energy use by eliminating additional potable water treatment and associated water conveyance because reclaimed water typically offsets potable water use and is used locally. Although additional energy is required to treat wastewater for reclamation, the amount of energy required for treatment and transport of potable water.

The energy required for capturing, treating and distributing water and the water required to produce energy are inextricably linked. Water reuse can achieve two benefits: offsetting water demands and providing water for energy production (Fig. 22).

Understanding that reuse is one of the tools that urban water/wastewater/stormwater managers have at their disposal to improve their existing systems' energy efficiency. EPA

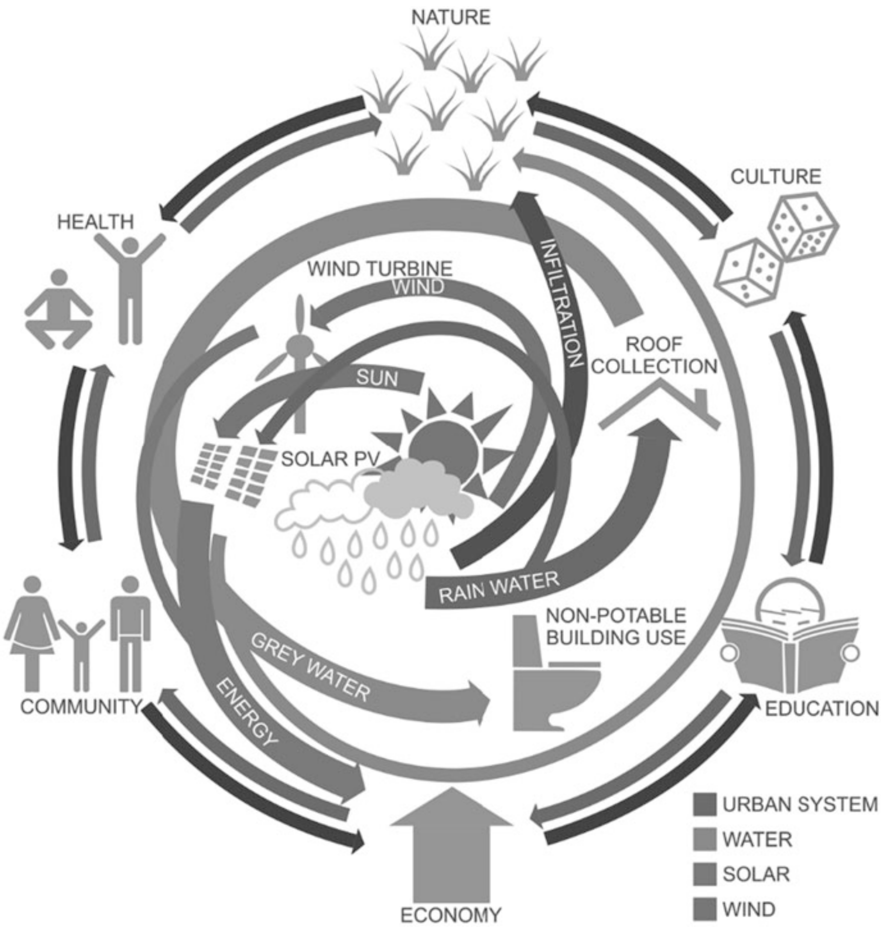


Fig. 22 Water-energy nexus (according to [32])

is currently developing a handbook titled Leveraging the Water-Energy Connection – An Integrated Resource Management Handbook for Community Planners and Decision-Makers, envisioned to be an integrated water management-planning support document. The manual will address water conservation and efficiency as well as alternative water sources (reclaimed water, grey water, harvested stormwater, etc.) as part of capacity development, building codes for improved water and energy-use efficiency and renewable energy sources from/for both water and wastewater systems.

These results in Portugal underscore the importance of water efficiency in buildings, not only as a means for rational use of water but also for its significant contribution to the energy efficiency of buildings and reducing the emission of greenhouse gases [17].

Acknowledgment This work was supported by project VEGA n. `/0202/15: Sustainable and Safe Water Management in Buildings of the 3rd Millennium.

References

1. UN-Water (2014) Water for a sustainable world. Annu Rep. https://sustainabledevelopment.un.org/content/documents/2071ANNUAL_REPORT_2014_Final.pdf
2. Global Goal for Water. Synthesis of key findings and recommendations from UN-Water. Executive summary: a post 2015. [Online]. [Cit. 2014–10-15]. http://www.unwater.org/fileadmin/user_upload/unwater_new/docs/Topics/UNWater_technical_advice_post_2015_global_goal_ES_final_highres.pdf
3. Gray NF (2010) Water technology. 3rd edn. IWA Publishing, London, 747 p
4. World Water Assessment Programme. http://www.worldwatercouncil.org/library/archives/water-crisis/
5. http://www.unesco.org/new/en/natural-sciences/environment/water/wwap/wwdr/2017-wastewater-the-untapped-resource/
6. Kinkade-Levario H (2007) Design for water. New Society, Gabriola Island, p 240
7. Stec A, Kordana S, Słyś D (2017) Analysing the financial efficiency of use of water and energy saving systems in single-family homes. J Clean Prod 151:193–205
8. Human Development Report (2006) [Online] [Cit. 2014–07-15]. http://hdr.undp.org/en/content/human-development-report-2006
9. http://ec.europa.eu/eurostat/statistics-explained/index.php/Water_statistics
10. Butler D, Davies D (2015) Urban drainage. 3rd edn. Spon Press, Taylor and Francis Group, London, New York, 543 p
11. Ashley RM et al. (2008) Active learning: building the capacity to adapt urban drainage to climate change; 11th international conference on urban drainage, Edinburgh, Scotland, UK
12. Kaposztasova D (2015) Integrated water management at the building level, Habilitaton work, Technical University of Kosice, p 180
13. Rainwater and Greywater, Decision-Making for Water Conservation (PR80) CIRIA (2001) Project website: http://web.stanford.edu/group/narratives/classes/08-09/CEE215/Projects/greendorm/water/GraywaterCD/greywater/pr80.pdf
14. Environment Agency (2010) Harvesting rainwater for domestic uses: an information guide [online]. 30 p. [cit. 2015–02-15]. http://webarchive.nationalarchives.gov.uk/20140328084622/http:/cdn.environment-agency.gov.uk/geho1110bten-e-e.pdf
15. European Commission (2009) A report by the Office of Community and Economic Development. http://ec.europa.eu/environment/water/quantity/pdf/Water%20efficiency%20standards_Study2009.pdf 2009
16. Silva-Afonso A, Rodrigues C (2008) Water efficiency of products and buildings: The implementation of certification and labelling measures in Portugal. In: Proceedings CIB W062 2008 34th international symposium of water supply and drainage for buildings. HKPU, Hong-Kong
17. Silva-Afonso A et al (2011) Grey water in buildings. The Portuguese approach. In: Proceedings of 37th international symposium CIB W062 on water supply and drainage for buildings. Aveiro
18. Krídlová Burdová E, Vilčeková S (2013) Building environmental assessment system in Slovakia. LAP LAMBERT Academic Publishing, Saarbrücken, p 114
19. EPA Basic Information (2015) [Online] [Cit. 2015–03-05]. http://water.epa.gov/drink/info/well/basicinformation.cfm
20. ANQIP (2011) ETA 0905 systems of reuse and recycling of grey water in buildings (SPRAC). Portuguese Association for Quality in Building Installations, Aveiro, Portugal
21. Matos C, Bentes I (2011) Water supply and drainage in buildings considering grey water use. In: Proceedings of 37th international symposium CIB W062 on water supply and drainage for buildings. Aveiro
22. Green Plumbing and Mechanical Code Supplement (2012) IAPMO, chapter 5 [Online] [Cit. 2014–10-15]. http://www.iapmo.org/Documents/2012GreenPlumbingMechanicalCodeSupplement.pdf
23. Eriksson E, Auffarth K, Henze M, Ledin A (2002) Characteristics of grey wastewater. Urban Water J 4:85–104

24. Novotny V, Ahern J, Brown P (2010) Water centric sustainable communities: planning, retrofitting, and building the next urban environment. Wiley, Hoboken, NJ, p 606
25. Penn R, Hadari M, Friedler E (2012) Evaluation of the effects of greywater reuse on domestic wastewater quality and quantity. Urban Water J 9:137–148
26. Lancaster B (2012) Rainwater harvesting for drylands and beyond. Tucson, Arizona, p 282
27. Słyś D, Stec A, Zeleňáková M (2012) A LCC analysis of rainwater management variants. Ecol Chem Eng 19(3):359–372. www.scopus.com
28. Fryer J (2012) The complete guide to water storage: how to use gray water and rainwater systems, rain barrels, tanks, and other water storage techniques for household and emergency use 2012, Atlantic Publishing Group Inc., p 336
29. Hlavínek P et al (2007) Hospodaření s dešťovými vodami v urbanizovaném území. Brno ARDEC s.r.o., p 164
30. British Standard BS 8528-1 (2010) Geywater systems – part 1: code of practice. BSI, UK
31. Sapkota M, Arora M, Malano H et al (2015) An overview of hybrid water supply systems in the context of urban water management: challenges and opportunities. Water 7:153–174
32. Conceptual creating the nexus by Payette (2015) [Online] [Cit. 2015-03-08]. http://www.payette.com/post/1391669-conceptual-creating-the-nexus

Water Distribution System in Building and Its Microbiological Contamination Minimization

D. Káposztásová, Z. Vranayová, and P. Purcz

Contents

Abstract Today we are facing the need to ensure water quality, so the basic requirement of today's civilization is to assess the water quality and perform the necessary treatment, adapt, transport, and heat it. The water pipes as a major part of the entire water distribution system have undergone considerable technical and technological development. Today we know that the various piping materials that have been used to transport water throughout historical development had a great impact on water quality. Drinking water must not cause any health problems to users. Microbiological contamination of drinking water and the health risk caused by pathogens that colonize the technical systems, however, occasionally causes serious problems. These include, for example, some cases of epidemic outbreaks of deaths

D. Káposztásová (✉) and Z. Vranayová
Institute of Architectural Engineering, Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia
e-mail: daniela.kaposztasova@tuke.sk

P. Purcz
Institute of Construction Technology and Management, Faculty of Civil Engineering, Technical University of Košice, Košice, Slovakia

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 251–268,
DOI 10.1007/698_2018_312,
Published online: 31 August 2018

that have occurred in the past 10 years in various parts of the world (e.g. cholera, typhus). Legionnaires' disease *legionellosis* also belongs to such newer diseases. The first case of *Legionella* infection from water distribution system was recorded in a patient's kidney transplantation. Since then, *Legionella* has begun to be tracked in water systems in different types of buildings, including hotels, homes, factories, and ships. This bacterium was found throughout the water system, from the water source to the outflow fittings. The goal of this chapter is to present hot water tank – a mathematical model which simulates temperature profile of hot water tank and works on obtained approximated function. Temperature and water stagnation are one of the factors that caused microbiological contamination of water, and by knowing the temperature profile, we can reduce the possible risks. While respecting the basic parameters of hot water, it is required for a water supplier and operator of a building to ensure the prescribed quality and water temperature at each sampling site and avoid the *Legionella* growth.

Keywords Contamination, Hot water tank, *Legionella pneumophila*, Mathematical model, Water distribution system

1 Introduction

After the first outbreak of the Legionnaires' disease in 1976, a bacterium called *Legionella pneumophila* was isolated. *Legionella* is commonly found in natural and artificial aquatic environments, in the soil, and in compost and can cause *legionellosis*. At least 61 different *Legionella* species have been isolated. Twenty-six strains were infected with human strains. *Legionella pneumophila* distinguishes at least 15 different serological groups; 9 other species may also be further divided into at least 2 separate serological groups. From a public health point of view, *Legionella* monitoring is important for identifying environmental resources that may represent a potential risk of *Legionella*, such as evaporating cooling towers, cold and hot water distribution systems in buildings, and associated facilities such as swimming pools and whirlpools, dental kits, maxing units, and so on. Monitoring is also important for the validation of control measures and the ongoing verification of the effectiveness of these measures [1].

The discovery of Legionnaire's disease has created a completely new problem in the field of drinking water hygiene [2]. Drinking water hygiene microbiology has so far been limited to separating the impact of sewage waste in the production, pre-storage, and supply of drinking water, and the microorganisms present in this water have produced only food-borne diseases [2–4]. As for *Legionella*, they are able, under certain conditions, to colonize the whole system and cause epidemics. So far, however, no data could be found that could be the basis for establishing a clear *Legionella* or *Legionella* limit value in potable hot and cold water – all values are determined in relation to the risk of water users from distribution systems. It must be borne in mind that water systems with potable water are absolutely unidirectional from the point of production of this water to the consumer's tap, that is, any quantity of water withdrawn in the main water inlet. In the supplied facility, a plurality of distribution sites used in parallel lead to problems with climbing pipes, a stagnant potable water cold that heats up and stagnant potable water hot, which on the contrary cools, and if the continuous circulation of the circulating pump is not ensured, the water flow is really undirectional. If hot water does not flow uninterruptedly throughout the system, excellent conditions for bacterial colonization are created [5]. In our previous research, we explored a range of factors that encourage the bacteria to grow [2, 4, 6], and we continue to check the systems that provide a high risk of *Legionella* colonization.

2 Contamination of Water Systems

The development of *Legionella* and other microorganisms in water distribution system is supported by the whole complex of factors [7]. Due to the health significance of these organisms, attention needs to be paid to the issue, particularly in terms of the design and implementation of preventive health and technical measures. On the part of the water supplier and the building operator, there is the responsibility to ensure in the hot water system the prescribed water quality and temperature at each delivery point while respecting the basic parameters of the hot water.

Recent technological developments have brought other hot water heating options. In principle, however, the preparation of hot water is divided into direct (primary) and indirect (secondary). Secondary heating is known to be more demanding in terms of energy demand, which in particular results in higher thermal or pressure losses.

In the secondary preparation, hot water is obtained by local, central, or combined heating. Local heating is a source of hot water in the immediate vicinity of the collection point. At the central heating, all or part of the collection points in the facility are supplied from one source.

Preparation of hot water is most often divided by:

- The heat transfer method
- Heat locations
- Construction of the equipment
- Number of primary energy sources

The division of the hot water preparation method also relies on the construction of a device that generates hot water. According to the design, we recognize storage tank and instantaneous and mixed heater. The water storage tank rests on heating the water into the tank. The capacity in the tank must cover the uneven distribution. In the instantaneous heater, the heating begins when the consumption begins, and there is no supply to cover the unpredictable consumption tip. Compared to the storage heater, it has the advantage of space requirements. However, the disadvantage is greater demand for power. In the case of combined heating, the standard hot water operating requirement is provided by an instantaneous heater, and an adequate storage [8] is assured by the collection peaks. From the bacterial colonization, storage – water tank – and distribution pipes are the most risky. The water pipes are the parts of technical systems currently used by people to ensure the supply of potable cold and hot water. Also important is its quality, which can be affected by piping material, but also by the chemical composition of water or by bacterial colonization. There is another factor in potable water hot, namely, the water heating technology, which can also be a source of bacteriological colonization. When water is heated in the storage tanks, there are ideal conditions for the growth of bacteria, e.g. if they are not dislimed, or in the water mains by plate exchangers. Here it is not possible to capture the sludge or to remove it. The sludge is one of the factors that promote bacterial growth. However, the main point is the occurrence of biofilm on the walls of the distribution pipeline and the influence of the material. Inside the water supply distribution networks, the *Legionella* colonizes the inner sides of the pipeline, the fittings and their seals, the mixing batteries, the hoses, and the shower heads.

2.1 **Legionella** ***in Water Pipes***

In water mains, *Legionella* colonizes especially the corroding surfaces and rubber seals, as well as parts of some plastic materials. Formation of biofilms with more than 50% *Legionella* share was the most massive on plastic materials at a water temperature of 40°C; at a water temperature of 20°C, it was minimal. On the contrary, copper surfaces inhibited *Legionella* adhesion and biofilm formation [9]. Experiments prove that already after 1 week, *Legionella* microbes are found on all surfaces except copper pipes (Table 1).

Within 3 weeks, biofilms begin to form. *Legionella* lives in these biofilms in relation with a typical micro bacteria, algae, and amoebae. As a good shelter in these communities, the use of mineral deposits on the inner walls of the pipeline along with the higher resistance of *Legionella* to chlorine is the main reason why it is practically impossible to eliminate them from the water mains [10].

Factors and critical points contributing to contamination of water systems are (Fig. 1):

Table 1 Pipeline material and colonization by *Legionella* [9]

Material	Colonization (number of colonies 103 per 1 cm^2)	
	Total microflora	*Legionella pneumophila*
Copper	70	0.7
Glass	150	1.5
Polybutylene	180	2.0
Polyethylene	960	23
Hard PVC	1,070	11
Ethylene – propylene	27,000	500

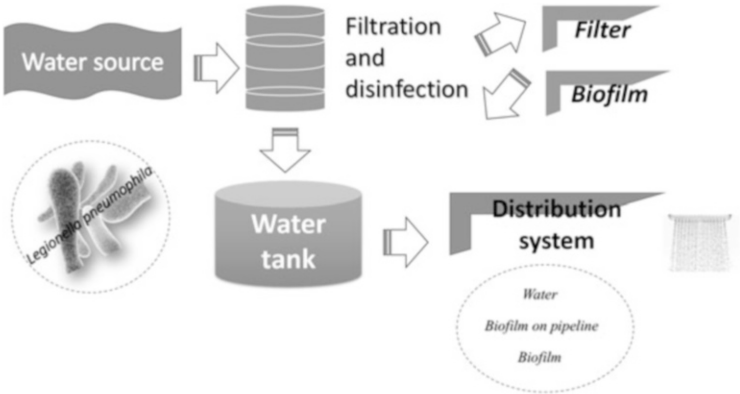


Fig. 1 Microbiological contamination of water supply system

- Temperature between 20 and 45°C and low water pressure
- Stagnant and low-flow sections of the water supply network
- Fittings with difficult accessibility to eradication interventions, regularly contaminated
- Accumulation of organic matter and microorganisms (tanks, heaters, blind arms)
- Large volumes of hot water storage tanks (water stagnation, overcapacity, low temperature in the bottom part, sediments, sludge)
- Low temperature at the outlets
- Age of heaters (incrustations, biofilms, sediment, sludge)
- Size of objects, length of installations (stagnation, difficult accessibility of disinfectant), lack of maintenance, treatment of water distribution system (desliming, network flushing, incrust removal, corrosion of pipelines, development of biofilms) [11].

The Centre for Disease Control and Prevention (CDCP) recommends thermal disinfection at 71°C with 5 min runoff (the original design of the method was 30 min washed, which is very difficult both financially and technically, although very effective – % positivity drops to zero).

The method is called “Superheat and flush”, and the temperature and flushing time of the distribution outlets are essential. The effect is short-lived and must be repeated periodically to avoid repeated colonization by *Legionella* [12]. In practice, other thermal disinfection procedures, e.g. periodic increase in potable water hot over 70°C with 10 min flush with water over 60°C reduce the percent of the positives of the effusions to zero and restores the contamination to the original level in 30–60 days.

The German document DVGW W551 and W552 [13] state: operational and technical measures in drinking water pipes lead to success if the water temperature in the entire system does not drop below 55°C.

- Preheating systems need to be heated up to 60°C once a day.
- Periodically (e.g. once a week) it is necessary to thermally disinfect and set the heaters above 70°C so that the outflows from the mains are at least 3 min. 70°C hot water flowed off.

Impact of disinfection is unable to reliably ensure the current requirements, so strategies tend to permanent disinfection. It is also important to focus on other ways of protecting water. The advantage of using ozone or chlorine dioxide is the high microbiological efficiency at low concentrations without affecting the sensory properties of water. Even in their long-term use, bacteria cannot be adapted, and decontamination of the distribution system is possible without interruption of operation. The advantage of these systems is also the long service life and low maintenance costs.

2.2 Time Analysis of Risk

In a dry environment, the *Legionella* bacteria are not viable. They require the presence of an aqueous aerosol or mist. When showering or bathing, suitable conditions for bacteria are created, and the risk of infection increases. Based on the research, it is known that the bacterium passes into the lungs, limiting the dangerous health area to the area of inhalation.

To determine the most likely time interval for the risk of *Legionella* infection, a form of subjective evaluation – using questionnaires – was chosen. A representative sample of the population consisted of 60 respondents, of which 50% were men. The mean age of respondents was 39 years. Before evaluating, people were instructed how to complete the questionnaire correctly. The evaluation took place during September, October, and November. A representative working week was determined, based on which conclusions were drawn. The respondents had the task of determining during the working week the period of use of a shower or a bath for personal hygiene. In the reporting period, 90% of respondents preferred a shower to bath. Women prefer bath over weekends. As the most frequent times, 80% of respondents identified the time from 6.00 to 7.00 in the morning and from 8.00 to 10.00 in the evening. Irrespective of the length of stay in the shower, these times were considered the most risky. Because of the potential risk of infection, it is important that water is hygienically suited and protected against *Legionella* and other bacteria. To reduce the risk of infection to the lowest possible level, different ways of securing water distribution are used. This also ensures the elimination of risk [14].

3 Aims and Methods

Insufficient storage temperature, as well as possible water stagnation, is one of the factors that caused microbiological contamination of water. The question arises in which layer the temperature is inadequate and where the stagnation of water in the tank occurs. Based on the results of the risk analysis that confirmed the hot water tank [2, 14] as a possible source of microbiological contamination in many studies, we performed measurements of the course of temperatures in the storage tank in laboratory conditions. The measurements were carried out in the laboratory of Brno University of Technology. The main aim of these measurements was to obtain input values for creating a mathematical model of the regression task of the correlation number. This is the creation of a general model, where based on the measured temperatures in the five tank sensors, the functional dependence is determined. By substitution in the calculation are approximated the temperatures at other points (not measured) at any time (in the set interval $<0, 60>$) [14].

3.1 General Mathematical Model of Regression Task

The process of variation in temperature in the hot water tank to which heat is supplied at certain specified locations is, in fact, a physically technical process that can be roughly described using a mathematical model based on the heat equation. We can write it down as follows:

$$\frac{\partial u}{\partial t} = \frac{\partial}{\partial x}\left(\lambda \frac{\partial u}{\partial x}\right) + \frac{\partial u}{\partial y}\left(\lambda \frac{\partial u}{\partial y}\right) + \frac{\partial u}{\partial z}\left(\lambda \frac{\partial u}{\partial z}\right) \tag{1}$$

where u $(t1, x, y, z)$ is the searched sufficiently smooth function (of heat) in a given area of a cylindrical shape, which in our case suitably represents the shape of the considered storage tank and λ is the coefficient of thermal conductivity [W m^{-1} K^{-1}].

After entering all the necessary input values – boundary conditions, i.e. the temperature variation at the edges and at the beginning of the process – it is possible to solve this task with multiple approaches, including the explicit differential method and the least squares method.

3.2 Methodology

The target was to measure out the input values for creating a mathematical model to get the view of temperature profile in hot water tank (Fig. 2).

The required input parameters were received by four measurements in 8 days. Each measurement was planned for 2 days. The boundary conditions of each

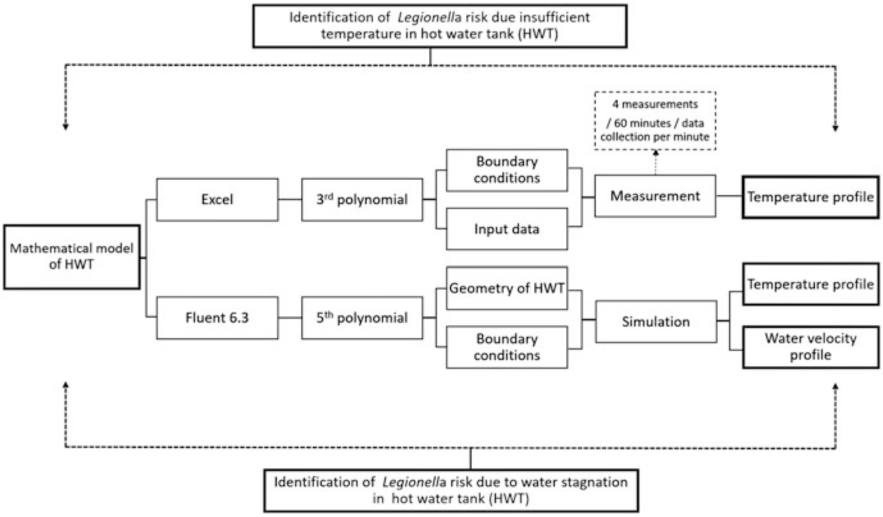


Fig. 2 Flow chart of methodology

measurement are described in Table 2. With the ALMENO 5590 measurement unit, the temperature in the tank was recorded – measuring time was set for 60 min.

The measures were repeated to eliminate the deviations and to get enough relevant input data. We needed the time for cooling down the systems, before starting the new measurement. The NTC sensors were located at the five characteristic points of the tank, as shown in Fig. 3. The sensor was provided with a connecting cable and an ALMEMO® plug. The accuracy of the temperature sensor was in the range of validity 0–70°C, and the limiting deviation is ±0.2 K.

3.3 Method of Least Squares

To correlate the results, the correlation dependence using the least squares method was calculated. When examining the correlation dependence, we solved two basic tasks:

- Characterization of the course of this dependence, that is, an estimate of the functional relationship, according to which the dependent variable varies when changing the independent variables
- Determination of the dependence tightness, i.e. the determination of the characteristic, informing to what extent of consideration the independent variables explain the variability of the dependent variable [15].

Table 2 Input parameters of experimental measurements [14]

Measurement	Characteristics	Input temperature of water [°C]	Output temperature of water [°C]	Average flow [L/m]	Time [min]
1	Boiler (three-cell – for max. power), Alfa Laval plate heat exchanger, Wilo pump	14	40	3	60
2		14	60	3	60
3		28	40	3	60
4		28	60	3	60

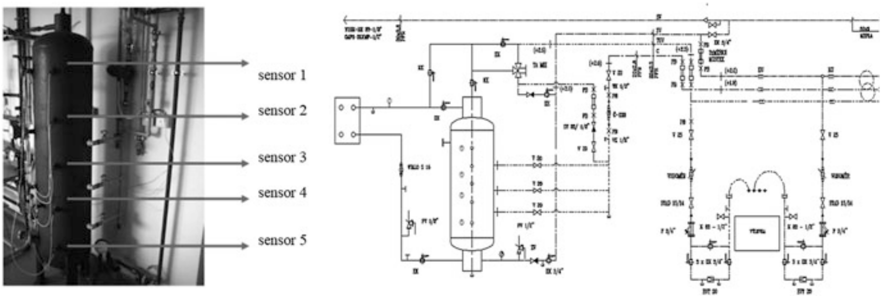


Fig. 3 Experimental hot water tank

Based on the relationship of variables, a point (correlation) diagram (Fig. 4) was created, where the measured temperatures in the tank are *y* (dependent variables) and the time is *x* (independent variables).

The functional dependence according to the point diagram on polynomial of third degree was set, which is characterized by the equation:

$$y = b_3x^3 + b_2x^2 + b_1x + b_0 \tag{2}$$

where *y* (dependent variable), measured temperatures [°C]; *x* (independent variable), time [min]; and b_3, b_2, b_1, b_0, constants.

A very common task in physical measurements is the determination of constants (in this case b_3, b_2, b_1, b_0) in empirical equations. In this case, the calculated value must be as close as possible to the actual value.

Therefore, for the calculation the least squares method was chosen, where it is necessary to look for the maximum sum of squares of deviations when searching for the value closest to the experiment. By substitution of the variables in Eq. (3), where (Figs. 4, 5, 6, and 7) *y*, measured temperatures, and *x*, time in minutes, we calculated the constants – directives *a*, *b*, and *c* – and assigned a functional dependence. Each graph shows the measured values from which the functional dependence *f* (*x*) (Figs. 4, 5, 6, and 7) and the resulting polynomial dependence were done, which are plotted according to the calculated equation shown in the graph. One example for each measurement is presented; the total results are in Ocipova [14].

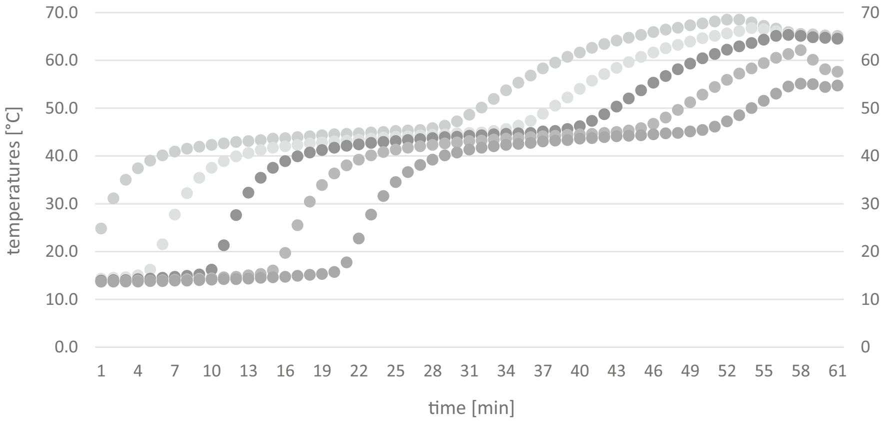


Fig. 4 Point diagram of dependence – time and temperature

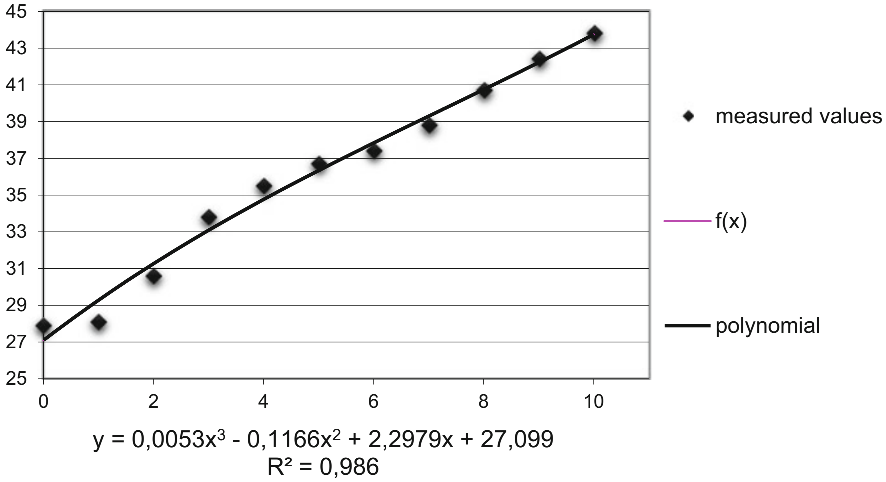


Fig. 5 Measurement 1 – sensor 2 resulting polynomial dependence (Table 3 – Sensor 2)

4 Discussion and Limitations

To confirm the most risky parts of the water tank due to the relevance of the resulting calculations, the dependence of tightness Rxy (correlation coefficient) was examined. The correlation coefficient takes values in the interval <0; 1>; the greater is its absolute value, the tighter is the linear dependence. It is valid that the degree of interrelation is:

- Mild if $0.3 \leq |\,Rxy < 0.5$
- Significant if $0.5 \leq |\,Rxy < 0.7$

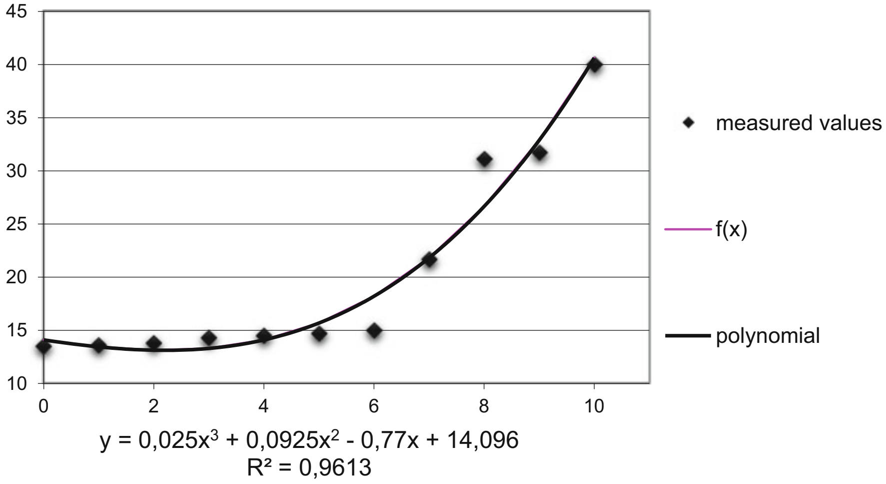


Fig. 6 Measurement 2 – sensor 5 resulting polynomial dependence (Table 4 – Sensor 5)

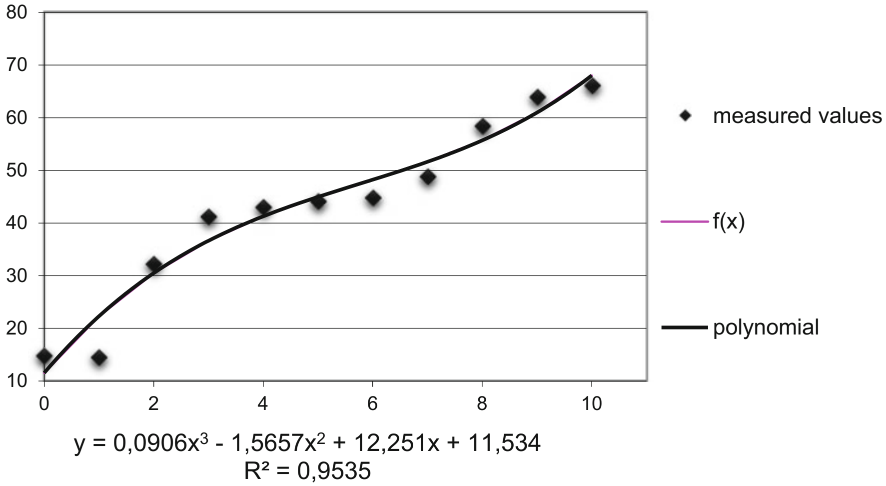


Fig. 7 Measurement 3 – sensor 2 resulting polynomial dependence (Table 5 – Sensor 2)

- High if $0.7 \leq |\,Rxy < 0.9$
- Very tight if $0.9 \leq |\,Rxy$

The correlation coefficient was computed using Eq. (3) which has the value of $|Rxy| = 0.9788$. It follows that a linear dependence and mathematically determined values are relevant as Rxy is higher than 0.9.

$$\text{Rxy} = \frac{n\sum_{i=1}^{n} x_i y_1 - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\left[n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2\right]\left[n\sum_{i=1}^{n} y_i^2 - \left(\sum_{i=1}^{n} y_i\right)^2\right]} \tag{3}$$

where Rxy, correlation coefficient; y (dependent variable), measured temperatures [°C], x (independent variable); time [min]; and n, number.

By putting variables into the equation, where y, measured temperatures, and x, time in minutes, the constants were calculated – directives a, b, and c – and assigned a functional dependence. In the Tables 3, 4, 5, and 6 are used the measured values of which was calculated the functional dependence $f(x)$ and the resulting polynomial dependence (Figs. 5, 6, 7, and 8).

This method can be used to similar hot water tanks; in another case the calculation must be customized. While limitation in this calculation the polynomial of third degree was used, we decided to use software Fluent 6.3 to simulate conditions in the water tank (Fig. 9) using the polynomial of the 5th degree [2].

It is a 3D non-isothermal model with the consideration of thermal radiation. In the simulation, the RNG k-epsilon model of the turbulence was used, and the heat radiation was modified into the radiation model. Two conditions were simulated:

- *A* – normal operation
- *B* – thermal disinfection

Table 3 Table of measured temperatures – measurement 1 (Fig. 5)

Sensors *X* (min)	1 *Y* (°C)	2 *Y* (°C)	3 *Y* (°C)	4 *Y* (°C)	5 *Y* (°C)
0–0	28.3	*27.9*	28.1	28	27.9
1–6	30.5	*28.1*	28.1	28	28
2–12	34.3	*30.6*	28.3	28.1	28.1
3–18	35.7	*33.8*	31.3	28.5	28.1
4–24	37	*35.5*	34.3	31.7	28.7
5–30	37.8	*36.7*	35.9	34.5	31.9
6–36	39	*37.4*	37	35.9	34.5
7–42	41	*38.8*	37.7	36.9	35.9
8–48	42.6	*40.7*	39.2	37.7	36.9
9–54	44.1	*42.4*	41.2	39.3	37.8
10–60	45.1	*43.8*	42.7	41.2	39.9

The italic values are measured values (temperature). In Tables 3–6 are used the measured values (in tables in italic font) of which was calculated the functional dependence $f(x)$ and the resulting polynomial dependence (in Figs. 5–8).
So these values were used in figures for final calculation – match to each table (measurement, sensor).

Table 4 Table of measured temperatures – measurement 2 (Fig. 6)

Sensors *X* (min)	1 *Y* (°C)	2 *Y* (°C)	3 *Y* (°C)	4 *Y* (°C)	5 *Y* (°C)
0–0	15.5	14.5	13.7	13.5	*13.5*
1–6	22.4	14.2	13.9	13.7	*13.6*
2–12	33.2	25.3	14.6	14.1	*13.8*
3–18	32	31.5	28	14.7	*14.3*
4–24	31.8	31.4	28.7	14.9	*14.5*
5–30	31.8	31.4	28.2	15.1	*14.7*
6–36	36.7	31.4	31.3	19.4	*15*
7–42	37	35.7	31.7	31.1	*21.7*
8–48	35.4	35.1	35	31.6	*31.1*
9–54	36.3	35	35.1	34.9	*31.7*
10–60	42	40	40	40	*40*

The italic values are measured values (temperature). In Tables 3–6 are used the measured values (in tables in italic font) of which was calculated the functional dependence *f*(*x*) and the resulting polynomial dependence (in Figs. 5–8).
So these values were used in figures for final calculation – match to each table (measurement, sensor).

Table 5 Table of measured temperatures – measurement 3 (Fig. 7)

Sensors *X* (min)	1 *Y* (°C)	2 *Y* (°C)	3 *Y* (°C)	4 *Y* (°C)	5 *Y* (°C)
0–0	17.1	*14.8*	14	13.9	13.8
1–6	31.1	*14.5*	14	13.8	13.7
2–12	41.5	*32.2*	14.9	14.2	13.9
3–18	43.3	*41.2*	35.4	15.3	14.5
4–24	44.5	*43*	41.7	36.3	15.7
5–30	45.3	*44.1*	43.3	41.7	36.6
6–36	48.6	*44.8*	44.2	43.1	41.3
7–42	58.3	*48.8*	45.1	44.1	43
8–48	64.1	*58.4*	50.3	45	44.1
9–54	67	*63.9*	59.3	51.2	45.1
10–60	67	*66.1*	65.1	60.5	59.1

The italic values are measured values (temperature). In Tables 3–6 are used the measured values (in tables in italic font) of which was calculated the functional dependence *f*(*x*) and the resulting polynomial dependence (in Figs. 5–8).
So these values were used in figures for final calculation – match to each table (measurement, sensor).

To verify simulations, we used the images from the thermal camera. Based on the simulation of temperature stratification in Fig. 10a, the bottom of the tank is in the temperature range of 35–45°C, which is at risk. In conjunction with the deposits and incrustation located at the bottom of the tank, the most risky places become a closed throat and the drinking water supply area.

Table 6 Table of measured temperatures – measurement 4 (Fig. 8)

Sensors *X* (min)	1 *Y* (°C)	2 *Y* (°C)	3 *Y* (°C)	4 *Y* (°C)	5 *Y* (°C)
0–0	27.2	26	25	*24*	23
1–6	32.8	26.8	26.2	*24.4*	23.4
2–12	42.2	33.4	27.2	*26.3*	24.6
3–18	47.3	42.3	35.4	*27.7*	26.4
4–24	50.8	47.3	43.4	*36.4*	28.2
5–30	53.2	50.6	47.9	*43.8*	37
6–36	56.6	52.9	51	*48*	43.9
7–42	62.4	56.2	53.1	*50.8*	47.8
8–48	67.7	62.1	56.8	*53*	50.7
9–54	67.8	66.7	62.8	*56.9*	53
10–60	65.9	65.4	64.5	*60.5*	59.1

The italic values are measured values (temperature). In Tables 3–6 are used the measured values (in tables in italic font) of which was calculated the functional dependence $f(x)$ and the resulting polynomial dependence (in Figs. 5–8).
So these values were used in figures for final calculation – match to each table (measurement, sensor).

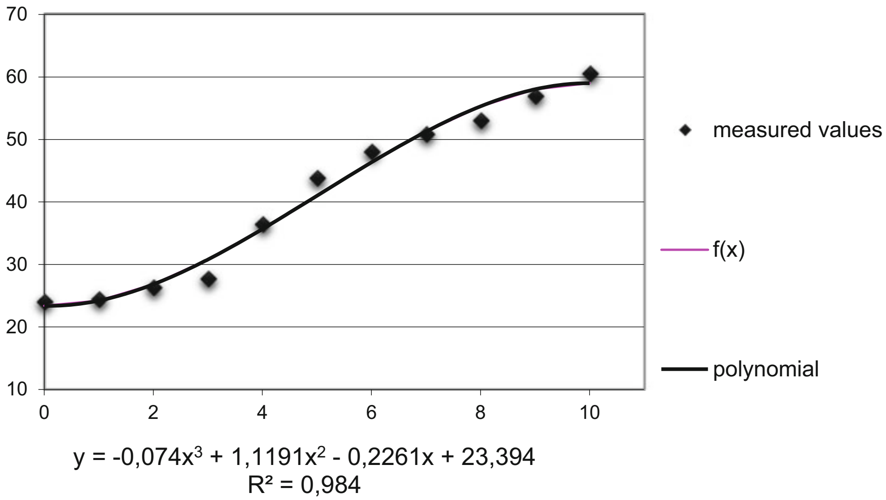


Fig. 8 Measurement 4 – sensor 4 resulting polynomial dependence (Table 6–Sensor 4)

We can see that water stagnation concerns also water tanks. Simulations show the stagnation of water in blind connections (one left, three right, and one on the symmetry axis) due to almost zero velocity (Fig. 11). By removing death ends and unused outflow sites, stagnation of water in the distribution pipes can be avoided.

By simulating the thermal disinfection, the temperature stratification has changed, but the risk points have not changed. In the closed throat, the temperature is about 3–4 K lower than the temperature in the tank. It is therefore very probable that in

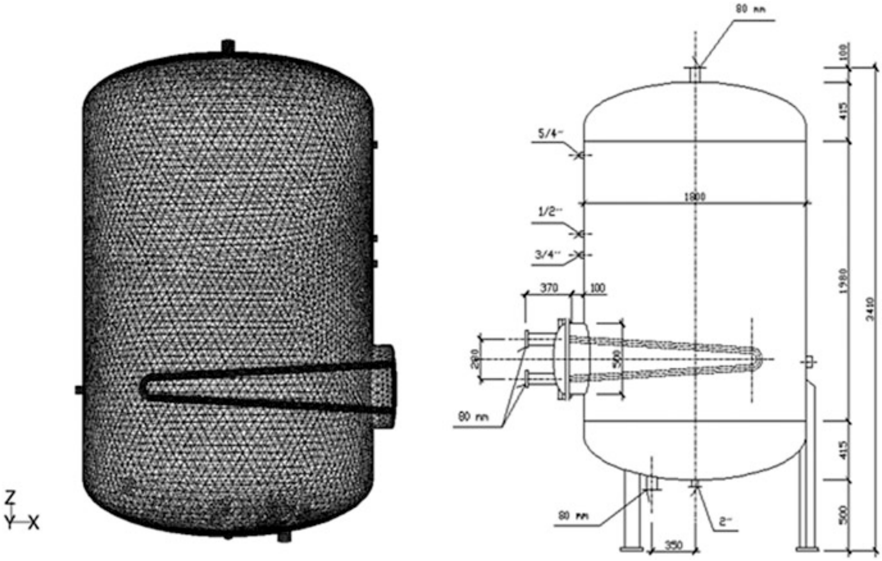


Fig. 9 Geometry of hot water tank

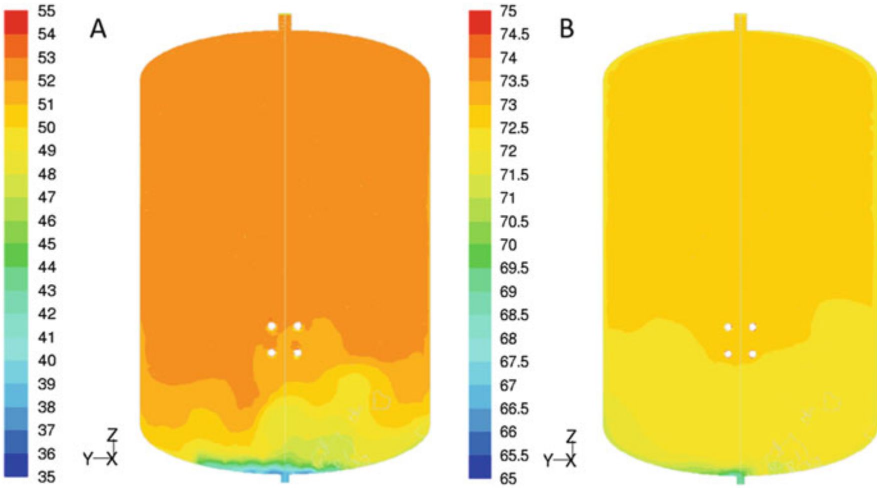


Fig. 10 Simulation of water temperature stratification (**a**) normal operation, (**b**) during thermal disinfection [14]

these places the bacteria can survive and after the thermal disinfection, the system will continue to colonize.

The results of simulation provided a view of water flow with heat transfer in a water tank in terms of temperature and water stagnation. The proposed general

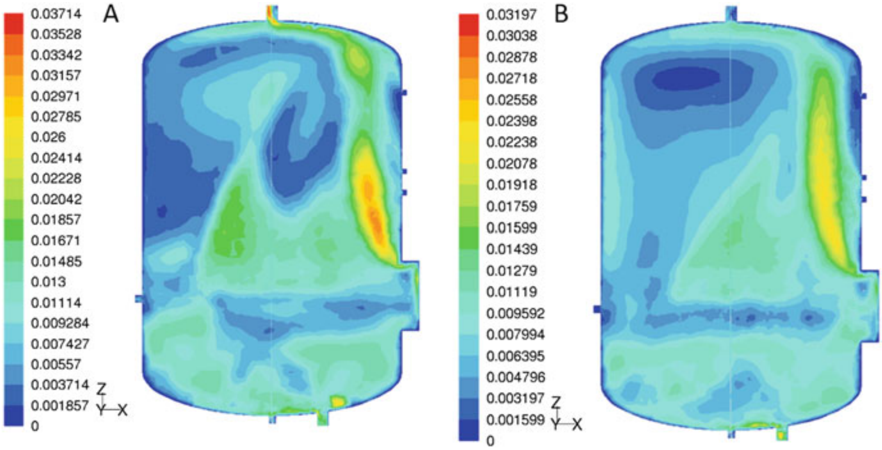


Fig. 11 Simulation of water velocity (**a**) normal operation, (**b**) during thermal disinfection [14]

model of stack temperature distribution can be applied to all similar tray types (tolerance ±2°C) [16] of the temperature distribution for heater tanks, but the geometry of the tank is very important to obtain real results.

5 Conclusion and Recommendations

Legionella pneumophila discovery, its classification, and its influence on installations inside buildings are relatively young. Using methods of risk management can lead to the safety of potable water and human health protection by completing water quality assessment for consumers to control the processes involved in the drinking water quality. Prevention is the most important part of water distribution management and could not be overlooked. The results of both calculations provide a view of heat transfer in a water tank in terms of temperature and water stagnation. Because of the stagnation of water by a very slow flow and at the same time insufficient overheating during thermal disinfection, the most risky place is clearly the lower part of the tank – casting throat. Here the conditions for the growth of *Legionella* bacteria are maintained, and, in the event of a drop in temperature in the tank, they can colonize the whole system [17, 18]. The proposed general models of temperature distribution can be applied to all similar storage tanks. Based on a tight correlation dependence, we can determine the temperature distribution in the storage tank at any point and at any time by substitution in a mathematical model based in excel or the use of the software, where the geometry of the tank is needed. Another possibility to determine the approximate temperature distribution in the tank is an explicit differential method that is more complex to determine boundary conditions. In the future, it would be interesting to solve the tasks also with this method and compare the results with both measured and computational values.

Acknowledgement This work was supported by the Slovak Research and Development Agency under the contract No. VEGA 1/0697/17 Hygienic water audit platform as transition tool to *Legionella* free water and HVAC systems in hospitals.

Thanks to Regional Health Center of Kosice for help with the sample collection and for many useful suggestions.

References

1. STN EN ISO 11731: 2017. Water quality. Enumeration of Legionella
2. Ocipova D, Vranayova Z, Sikula O (2012) Negative impact of bacteria Legionella pneumophila in hot water distribution systems on human health. World Acad Sci Eng Technol 6:670–674
3. Health and Safety Executive. http://www.hse.gov.uk/legionnaires/what-is.htm. Accessed 20 Jan 2018
4. Vranyova Z, Kaposztasova D (2017) System solutions in the fight against infection caused by bacteria Legionella, water supply and drainage in buildings. In: CIB conference, TVVL, Amsterdam, pp 485–494
5. Pospichal Z (2005) Ochrana vnitřního vodovodu z pohledu mikrobiologie (Protection of the internal water supply from the point of view of microbiology). In: Designer workbook – work basics. Společnost pro techniku prostředí–STP, Bratislava
6. Ocipova D (2007) Hot water system contamination in the frame of central heat supply. In: Budownictwo o zoptimalizowanym potencjale energetecznym. Wydawnictva Politechniki Czestochowskiej, Czestochowa, pp 406–411. ISBN 978-83-7193-357-8
7. TNI CEN/TR 16355:2012. Recommendations for prevention of Legionella growth in installations inside building conveying water for human consumption
8. Valasek J et al (2001) Sanitary installations and installations in buildings, 1st edn. Bratislava Jaga group, v.o.s., Bratislava. ISBN 80-88905-52-4
9. Information for designers, Legionella protection news – translation from the German original Hungarian Copper Promotion Center, Apr 2005
10. De Cuyper K (2002) Efficiency of anti-Legionella treatments in situ: an investigation of the use of water-electrolysis and chlorine dioxide. In: CIB W062 symposium, Romania
11. Krescanko M (2006) Legionnaire disease – threat of water. In: TZB-HausTechnik, 2/2006 ProMinent Slovensko
12. Kosicanova D (2007) The energy efficiency of thermal disinfection. In: Proceedings from the 12th international conference Sanhyga 2007, Trenčianske Teplice, 30 and 31 Oct 2007, pp 53–58
13. DVGW 551 and 552. https://www.dvgw.de/themen/wasser/wasserqualitaet/legionellen/. Acessed 19 Jan 2018
14. Ocipova D (2010) Theoretical and experimental analysis of hot water distribution systems. Dissertation thesis, Technical University of Košice
15. Bucko M (1981) Probability and mathematical statistics. University textbook
16. Ocipova D, Vranayova Z, Sikula O (2011) Risk management methods in hot water distribution systems to negate health risks from microbiological contamination. Environ Eng 1:1–3
17. Bartram J, Chartier Y, Lee JV, Pond K, Surman-Lee S (2007) Legionella and the prevention of Legionellosis. World Health Organization, Geneva
18. Health and Safety Executive (2018) http://www.hse.gov.uk/legionnaires/what-is.htm. Accessed 20 Jan 2018

Decision Analysis Tool for Appropriate Water Source in Buildings

D. Káposztásová and Z. Vranayová

Contents

Abstract To attain sustainability of water resources involves taking economic, environmental, and socially feasible measures without detrimental consequences for the time to come. Providing adequate water supply and sanitation is a challenging task throughout the world. We are facing the need to ensure water quality by using technical systems, and thus a one of the necessary requirements of life for today's civilization is becoming water saving, treatment, and its management. Lots of aspects may contribute to the solution on how to collect, produce, and finally use alternative water sources. Massive use of reused water for non-potable purposes in buildings promotes the conservation of natural water resources. While respecting the basic parameters of alternative water sources, it is required for the end user or building manager to ensure the prescribed quality of water depending on the purpose.

This chapter's aim is to present decision analysis tool on alternative water use at the building level. Water management strategies and presented 11 portfolios should provide general guidance on the issues and information to support decisions on alternative water use and make it more attractive to public. The evaluation of the two

D. Káposztásová (✉) and Z. Vranayová
Department of Building Services, Faculty of Civil Engineering, Institute of Architectural Engineering, Technical University of Košice, Košice, Slovakia
e-mail: daniela.kaposztasova@tuke.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 269–284,
DOI 10.1007/698_2017_223,
Published online: 19 May 2018

main criteria, as economic and environmental, could be used to change the water habits or help investor to make the right decision for the best water management portfolio. Presented costs and benefits of the portfolios are scored and compared to screening criteria calculated by analytical hierarchy process. The decision analysis tool could fill the information gap on sustainable water strategies in Slovakia by better understanding the building water cycle and help to change the thinking of the society to be in balance with the nature.

Keywords AHP, Building water cycle, Decision analysis tool, Reused water, Water sources

1 Introduction

Water is a global challenge of the twenty first century, both in terms of available resource management and the world's population access to drinking water and sanitation. We are facing the need to ensure water quality by using technical systems, and thus a basic requirement of life for today's civilization involves treatment, transport, heating, and purification of water. It is all about the water. Recognizing that water-related problems are one of the most essential and immediate challenges to the environment and public health, it is vital to act now [1]. The total volume of water in the world remains constant. What changes is its quality and availability [2]. Water scarcity and water pollution are some of the crucial issues that must be addressed within local and global perspectives. One of the ways to reduce the impact of water scarcity as well as minimizing water pollution is to expand water and wastewater reuse [1]. Many researchers confirmed that the importance of water savings is rising every day (Fig. 1).

Implementing appropriate urban water policies will be achieved through an increased understanding of urban water cycle (water supply, wastewater, and storm water infrastructures). Within this framework, we pay particular attention to energy-water relationships, water scarcity, and the development of tools and techniques to implement integrated water and energy resource management. Contributions to meeting this challenge should consider levels of service and reliability, risk of service failure, and risk acceptability [3]. Particularly considering climate change, it is crucial to improve the sustainable use of water and energy while minimizing the carbon footprint as well as to plan and promote climate change adaptations in a phased way [4]. Water, energy, and waste are essential parts of the environmental assessment of buildings with an expected impact on the residents' quality of life – in the rigorous application of measures resulting from risk management. We assume that inhabitants living in new green buildings which focus on environmental sustainability will report higher life satisfaction than in the "traditional" buildings (without the "progressive technologies"). There is no documented transformation impact of buildings on green building as a living system on the quality of life of users living in these buildings. Ken Yeang, father of bioclimatic skyscraper, claims that green design is the blending of four infrastructure strands into a seamless system [5].

Fig. 1 Water challenge

2 Suitability and Availability of Water

According to the World Water Assessment Programme (WWAP), about 70% of water use in the world is used for irrigation, about 22% for industry use, and about 8% for domestic use. In many countries the hydrological cycle is managed to provide enough water for industry, agriculture, and domestic use. Common household uses consume much water. There is a need to manage its end use as sustainable as our conditions allow us [6]. In the European Union, it is common to use well and rainwater source for purposes such as irrigation, toilet flushing, etc. Gray water reuse is in our condition still rare [7].

We can reduce water in household by:

- Efficient water use in buildings.
- Alternative water supplies (rainwater, etc.)
- Recycling and reuse of water (gray water, etc.) [8].

It is essential to foster the aptitude of various water types to meet the correct amount of water requirements for different end uses within the building. Public should be educated in water efficient usage and the potential implication of their consumption [8] (Fig. 2).

The Water Framework Directive (WFD) supports sustainability in water management. The primary objective of the WFD is to create a suitable mechanism that can establish the basic principles of sustainability in water policy and subsequently

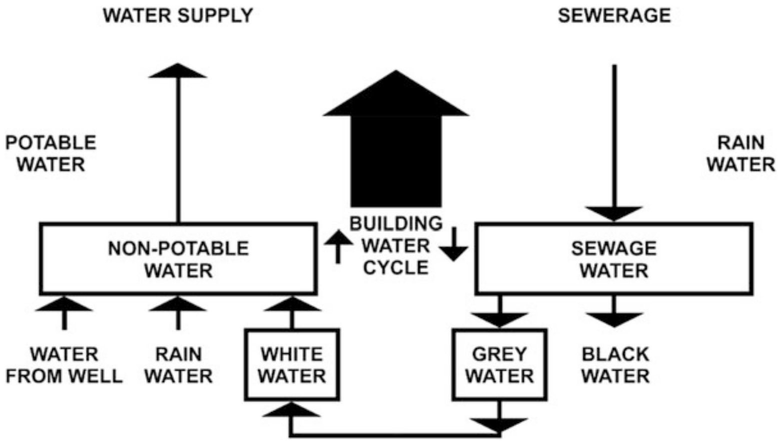


Fig. 2 Water in building water cycle

water management [9]. A significant step toward sustainability in Europe is that water and wastewater treatment are no longer seen in isolation but as integral part of the urban water cycle, which itself forms a part of the natural hydrological cycle [2].

The water management options that are combined and described in this section are as follows (systems are more in-depth described in previous chapter):

- Main water supply
- Well water supply
- Rainwater harvesting system
- Gray water reuse system

Most of the water management options would reduce demand on the potable water system. These reduced demands could result in cost savings for the potable water system in terms of smaller infrastructure needs and lower operating costs. These water management options could be directly implemented by customers [10]. The water efficiency labeling of products has been implemented voluntarily in various countries. For example, in some countries, efficiency is not graded, but efficiency label is awarded when consumption is less than a specific amount. This is the labeling system in use in the USA and Scandinavia, for example. In Australia and Ireland (Dublin), however, the label indicates a classification that varies with the product's efficiency [11]. Using these appliances will lead to the change of habits and less gray water production and result that gray water system could be not viable. The ability of supply to meet demand will always need to be evaluated on a case-by-case basis. A balance evaluates how water is used in a building and can help identify opportunities for water savings.

In ETA 0808 – specifications for assigning ANQIP water efficiency labels to taps and flushing valves [12] – and in ETA 0905, systems of reuse and recycling of gray water in buildings, the water balance in residential buildings with efficiency devices [13] was presented. A common vision in foreign countries is to use efficiently all sources of water that you have at your property. It can be stated that water efficiency is the best way to contribute to policies for sustainable use of water.

3 Decision Analysis Tool for Appropriate Water Source in Buildings (DATAWs)

This chapter describes decision analysis tool for appropriate water source in buildings (DATAWs). The target of the integrated water management is to take into account water management evaluation criteria which were set up by the expert group and might increase the water sustainability and reliability [7, 14]. The main aim for creating the DATAWs was to help customer and designer to make the right decision when designing new house to fulfill all their requirements and support the sustainable water use at the building level. We used the Analytical Hierarchy Process (AHP) procedure to decompose the decision problem into a hierarchy that consists of the most critical elements of the decision problem. The hierarchical structure is represented by descending from general objective to more specific arrangement of the elements in order to reach the top level of the final determination. However the findings indicate that the specific arrangement of structural elements and their mutual influence can determine the solution to a particular decision problem [7, 15].

The DATAWs methodology consisted of three main steps:

Step 1: Evaluation of Water Habits

The first step was to find the pattern of water use by the evaluation of different groups of end users. Four main water types were used as described in Fig. 2. The evaluation was made by sophisticated decision analysis based on Saaty methodology – AHP (Fig. 3). Chosen method as an algorithm was successfully implemented on the platform Excel using the programming tools of the Visual Basic.

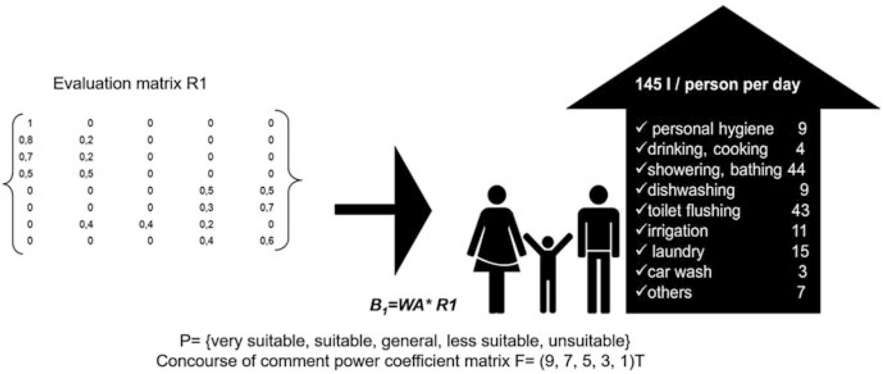


Fig. 3 Evaluation matrix R1 and nine purposes of water use

The fuzzy comprehensive evaluation of water habits was described step by step in [16].

It was basic to start with findings on how the water is used and what we should do to raise the customers' awareness of the water savings. According to the medium results of G1 (classic user) and G2 (different user), there are a lot of options on how to encourage the people to change their water consumption habits. It is well-known that the companies G4 that work with water saving systems have had the best practices. As the Slovak pattern is insufficient, we will need to learn from them and adapt a better pattern of usage [7, 16]. So the importance of DATAWs was confirmed, and we have continued with Step 2 dedicated on all possible water portfolios and their combination.

Step 2: Description of Water Portfolios and Possible Combinations
This step defines and evaluates combinations of water management options, referred to as water management portfolios. The 11 case portfolios were prepared in two alternatives – connected to main water supply and without the connection (four water sources and nine end-use purposes) (Fig. 4).

The portfolio means the combination of possible water sources and their limitation in alternative 1 where eight portfolios were set. "The same approach is used in alternative 2 but potable water is replaced by water from well. In this case we have four portfolios: Well water, W+R, W+R+G, W+G" [17]. The detailed description of portfolios is in [7], and they are giving the customer the options that are ideal for his case. Each portfolio must be actualized according to the inputs dedicated to his situation (rainfall data, roof area, fixtures, etc.).

The equation of the water audit shows that the entering volume of water in the building is the same as the volume at the exit. In terms of addressing water efficiency issues, it is necessary to take into consideration all changes in water use in order to

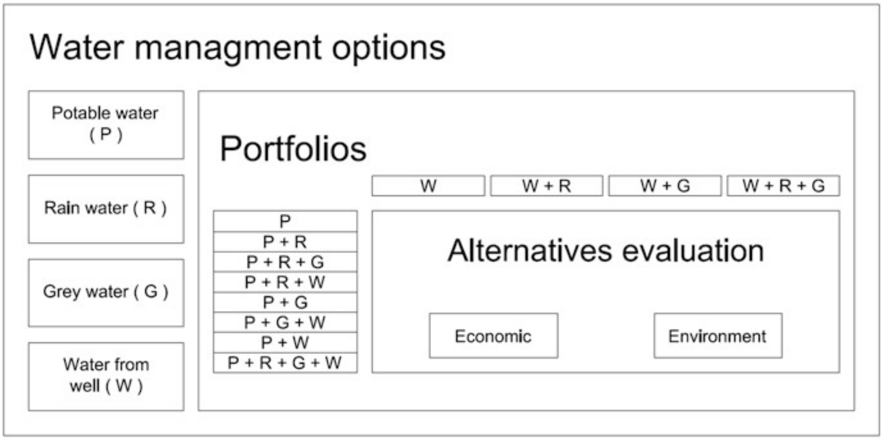


Fig. 4 Water management options [14]

take the final decision whether to put a rainwater, well water, or gray water system to use [8].

According to the presented nine purposes, all possible combinations with four or three sources were calculated (Fig. 3). To define all possible combinations of water management options referred to as water management portfolios for both alternatives, the classical combinatorial task of determining the number of combinations was used (1).

Alternative 1

- 63 combination
- 66l fixed for potable purposes
- Connected to main water supply

Alternative 2

- 26 combination
- 66l fixed for potable purposes
- Not connected to main water supply

$$\binom{n}{k} = \frac{n!}{(n-k)!n!} \tag{1}$$

Step 3: Economical and Environmental Impact
The main aim of authors is to present methodology of economic and environmental impact, presented in Step 3.

3.1 Environmental and Economic Approach

This part presents and describes the most essential part of DATAWs – the screening criteria used to rank the water management portfolios described above. Screening criteria are grouped into two major categories: environmental and economic. Each category of screening criteria has subcategories of criteria that make up the details of the more extensive criteria.

- *Environmental approach*
  In environmental view, other motives are considered, such as wishing to conserve water, helping the environment, and saving the water.
- *Economics approach*
  The economics include the present worth cost of the capital and operations and maintenance costs and the cost of water.

To demonstrate the best solution to a customer according to his preferences, it is inventible to consider hypothetical economic or environmental approaches (Fig. 5). It can be done by AHP. Two calculation methods could be used.

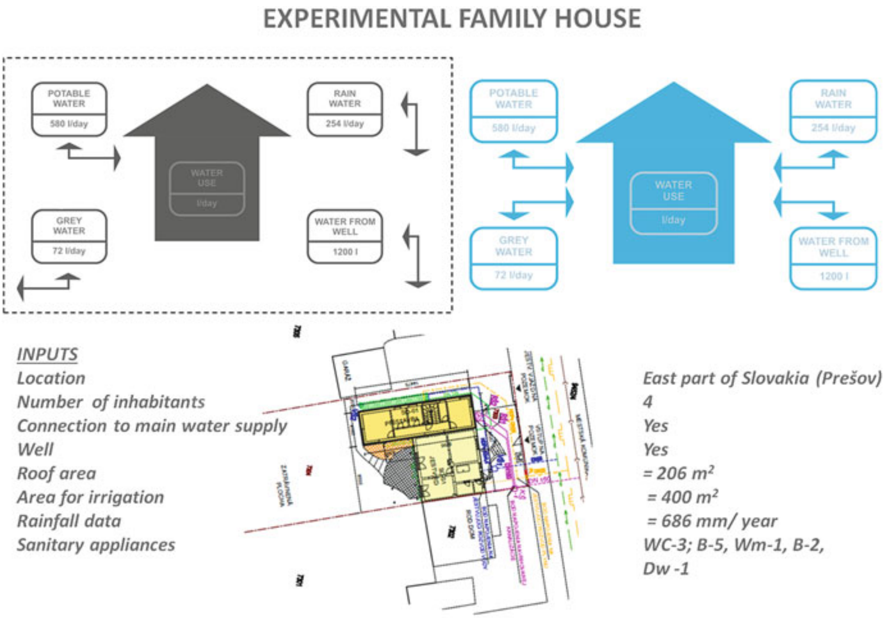


Fig. 5 Inputs for examination of experimental family house

The problem involves evaluating a set of proposed water management portfolios in two alternatives (Alternative 1, 1–8 and Alternative 2, 1–4) for customer on the basis of economic and environmental approach.

The objectives are measured in terms of five criteria: (1) *investments*, (2) *payback period*, (3) *impact on health (risks)*, (4) *water source*, and (5) *water saving*.

The first step after identifying all portfolios suitable according to the customer request is to identify whether the environmental or economic point of view is preferred. Also when using the expert method, the weights are calculated according to the expert's experience and knowledge. The other possible way on how to calculate the weights is by setting only opinions of the customer and calculates the weights by normalizing vector matrix. One can expect that any human judgment is to some degree imperfect (or inconsistent). Therefore, it would be useful to have a measure of inconsistency associated with the pairwise comparison matrixes. In order to measure the degree of consistency, we can calculate the consistency index that could be used in evaluation [18].

3.2 Methodology of Evaluation

The AHP methodology consists of pairwise comparison as the basic mode. The reduction of conceptual complexity is set by only two components at any given time.

Set by 3 steps: "(i) developing a comparison matrix at each level of the hierarchy, beginning at the top and working down, (ii) computation of the weights for each element of the hierarchy, and (iii) estimation of the consistency ratio" [8, 18]. After the comparison, the summarized preferences get the relative importance.

This can be achieved by computing a vector of the weights and priorities and attributes associated with the objectives. This can be accomplished by normalizing the eigenvector associated with the maximum eigenvalue of the pairwise comparison matrix [18]. In this framework, we shall assume that the two first steps of the AHP have been achieved, which are formation of the hierarchical structure and calculation of the relative weights of the elements (objectives and attributes) of the hierarchy by conducting pairwise comparisons (Fig. 6). The overall goal here is to identify the best portfolio to customer. This requires assessing the relative importance (weights) of the elements at each level of the decision hierarchy. This could be done by experts or normalizing by program [19].

The economic objective has been judged to be three times as important as the environmental objective in this case. This results in assigning weights of 0.71 and 0.29 to the two objectives (Table 1). The economic objective is measured by three attributes, investments, payback period, and risks. Table 2 shows the pairwise comparison matrix and calculated weights for the attributes of economic objectives.

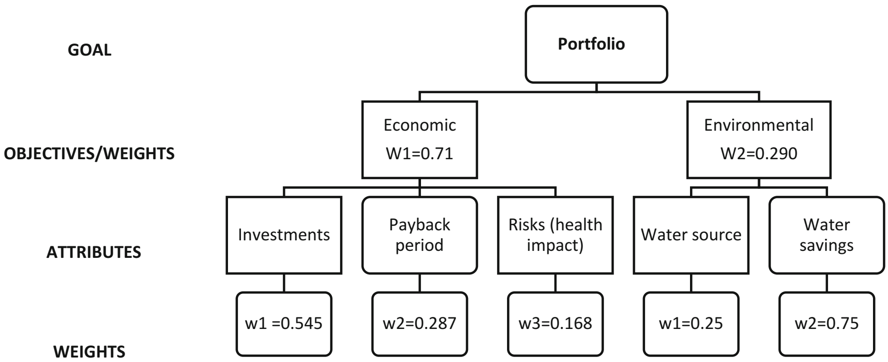


Fig. 6 Formation of the hierarchical structure and calculating the relative weights of the elements

Table 1 Pairwise comparison matrix of the level of objectives and calculated weights

	Economic	Environmental	Weight
Economic	3	1	0.71
Environmental	0.5	1	0.29

Table 2 The pairwise comparison matrix and calculated weights for the attributes of economic objectives

	Investments	Payback period	Risks	Weight
Investments	1	2	3	0.545
Payback period	0.5	1	2	0.287
Risks	0.333	0.5	1	0.168

Table 3 Pairwise comparison matrix of environmental attributes and calculated weights

	Water saving	Water source	Weight
Water saving water source	3	1	0.75
Water source	0.333	1	0.25

Fig. 7 Rating and ranking of portfolios: results in proposed case

The environmental objective is measured in terms of two attributes, water source and water savings. The water saving attribute has been estimated to be three times more important than water source. Consequently, weights of 0.75 and 0.25 have been assigned to water source and savings, respectively (Table 3).

This model demonstrated how, by applying different quantifiers, a decision-maker could obtain a wide range of decision strategies and scenarios for customer.

From the calculation, we can see the difference between method 1 (Wp8) and normalized method 2 (Wp8n). The suitability of the method is set according to the customer requirements (Fig. 7).

$$\mathrm{Wp8} = [0.846623 \quad 0.419978 \quad 0.408059 \quad 0.408059 \quad 0.846623 \quad 0.419978 \quad 0.408059 \quad 0.408059]$$
$$\mathrm{Wp8n} = [0.796233 \quad 0.753635 \quad 0.693129 \quad 0.796233 \quad 0.753635 \quad 0.693129 \quad 0.753635 \quad 0.693129]$$

According to the proposed case (Fig. 7 portfolio 1), 80% is the most suitable from the economic view. This strategy could be applied very quickly to show the customer the potential from both economic and environmental approaches.

4 Discussion and Limitations

Consideration of both capital and annual maintenance and operating costs is necessary to provide the complete picture of the actual cost of a portfolio. The principle of linear regression was used and prediction model created for savings from year 2015 to 2031.

Following tables shows the possible water bills reductions per year by replacing the around 55% of water demand by alternative water source (Tables 4 and 5). Of course when calculating savings, we need to take into account the total installed

Table 4 Example water savings: rainwater system [16]

Without RWH system						With RWH system					
Year	Metered water charges (€ VAT)		Σ € VAT	Water consumption (m^3/year)	PW price (€/year)	RW consumption (m^3/year)	RW price (€/year)	RW price + energy (€/year) 1 m^3	RW price (€/year)	Price P + R (€/year)	Savings (€/year)
2015	1.57	1.08	2.65	211.70	561.43	116.435	125.75	0.49	183.15	435.79	125.63
2016	1.90	1.28	3.18		673.56		148.84	0.51	208.18	511.28	162.28
2017	2.00	1.34	3.34		707.73		156.45	0.52	217.12	535.60	172.13
2018	2.10	1.41	3.50		741.90		164.07	0.53	226.11	559.96	181.94
2019	2.19	1.47	3.67		776.06		171.69	0.54	235.14	584.36	191.70
2020	2.29	1.54	3.83		810.23		179.31	0.56	244.21	608.81	201.42
2021	2.38	1.61	3.99		844.39		186.93	0.57	253.33	633.31	211.09
2022	2.48	1.67	4.15		878.56		194.55	0.58	262.50	657.85	220.71
2023	2.58	1.74	4.31		912.72		202.17	0.60	271.71	682.44	230.28
2024	2.67	1.80	4.47		946.89		209.79	0.61	280.98	707.08	239.81
2025	2.77	1.87	4.63		981.05		217.40	0.63	290.30	731.78	249.28
2026	2.86	1.93	4.80		1,015.22		225.02	0.64	299.67	756.52	258.70
2027	2.96	2.00	4.96		1,049.39		232.64	0.66	309.10	781.33	268.06
2028	3.05	2.06	5.12		1,083.55		240.26	0.67	318.59	806.19	277.36
2029	3.15	2.13	5.28		1,117.72		247.88	0.69	328.13	831.11	286.61
2030	3.25	2.19	5.44		1,151.88		255.50	0.71	337.74	856.08	295.80
2031	3.34	2.26	5.60		1,186.05		263.12	0.72	347.40	881.13	304.92

PW potable water, *W* water, *WW* white water, *RW* rain water, *WW* water form well

Table 5 Water savings – gray water system [16]

Without gray water						Gray water reuse system					
Year	Metered water charges (€ VAT)		Σ € s VAT	W cons. (m ^{3}/year)	PW price (€/year)	White water consumption (m^3/year)	PW price (€/year)	White water (€/year) 1 m^3	WW price (€/year)	WP white + gray (€/year)	Savings (€/year)
2015	1.57	1.08	2.65	211.70	561.43	116.435	492.48	0.41	47.83	540.31	21.12
2016	1.90	1.28	3.18		673.56		590.84	0.42	49.45	640.29	33.27
2017	2.00	1.34	3.34		707.73		620.81	0.43	50.56	671.37	36.36
2018	2.10	1.41	3.50		741.90		650.78	0.44	51.69	702.47	39.42
2019	2.19	1.47	3.67		776.06		680.75	0.45	52.87	733.62	42.44
2020	2.29	1.54	3.83		810.23		710.72	0.46	54.08	764.80	45.43
2021	2.38	1.61	3.99		844.39		740.69	0.48	55.33	796.02	48.37
2022	2.48	1.67	4.15		878.56		770.66	0.49	56.62	827.28	51.28
2023	2.58	1.74	4.31		912.72		800.63	0.50	57.96	858.58	54.14
2024	2.67	1.80	4.47		946.89		830.60	0.51	59.33	889.93	56.96
2025	2.77	1.87	4.63		981.05		860.57	0.52	60.75	921.31	59.74
2026	2.86	1.93	4.80		1,015.22		890.54	0.53	62.21	952.74	62.48
2027	2.96	2.00	4.96		1,049.39		920.50	0.55	63.72	984.22	65.16
2028	3.05	2.06	5.12		1,083.55		950.47	0.56	65.27	1,015.75	67.80
2029	3.15	2.13	5.28		1,117.72		980.44	0.57	66.88	1,047.32	70.40
2030	3.25	2.19	5.44		1,151.88		1,010.41	0.59	68.53	1,078.95	72.94
2031	3.34	2.26	5.60		1,186.05		1,040.38	0.60	70.24	1,110.62	75.43

PW potable water, *W* water, *WW* white water, *RW* rain water, *WW* water form well costs including the water reuse system with all storage, pipework, disinfection, power supply, and commissioning requirements. The fact is that for retro-fitted system the costs will be higher [8].

4.1 Description of the Used Methodology

To assess the investment options, we used the method of net present value (NPV). The net present value is a dynamic method to assess the effectiveness of investment options. The effect of investment is cash income from the project (expected profit after tax, depreciation, respectively, other income; in our case it was water saving). It is calculated as the difference between the discounted cash inflows and (discounted) capital expenditures. In the calculations, among others, technological factors reflected mainly the time factor, which affects the value of an investment and its life. Using this method, we get the real value of savings, which reflects a lifetime. The difference between savings and investment costs gives the current value. At the moment when the NPV is positive, there is a return on investment in the technology [20].

Of course, the NPV of the influence of several facts, not just time. Also noteworthy is the interest rate or inflation. Therefore, for each variant, we assume inflation of 1.5 and 3%. Interval or values that we have set are based on several studies, the statistical office. Inflation developed over the last 10 years, and the prediction shows that it is highly likely that inflation will continue in the coming years in the interval. The evolution of prices (the linear regression was used), or even monitor inflation in industrial production (energy prices, etc.). Slovakia is moving in the same range, therefore, was as optimistic model set at 1.5% and pessimistic at 3%.

The payback period varies, depending on factors including:

- Number of users to a system
- Volume of reclaimed water generated
- Cost of the system, operation, and maintenance
- Current and future metered water charges [8]

Domestic rainwater and gray water systems for typical home are similar in price, can be installed, and are relatively low compared to building price. According to the studies in the world, it is known that rainwater systems are cheaper to operate and maintain per cubic meter of reclaimed water than gray water systems.

The indicative life expectancy of these systems is an essential factor while assessing the economics. The life expectancy of gray water system varies from 15 to 18 years depending on the quality of components. The table below shows some indicative life expectancy.

A big study was taken in Innsbruck about the feasibility of advanced gray water systems for the single-family house. Within the small single household, the onsite MBR is the most popular among the suppliers. In this study, the high payback periods were calculated for the experimental house. The similar results were

Table 6 Payback period results for experimental house [16]

Payback period		Water system			Well			
	Gray water		Rain water		Digging		Drilling	
Inflation (%)	cca (€) first year return	Year	cca (€)	Year	cca (€)	Year	cca (€)	Year
1.50	200	20	200	18	180	6	134	6
3	188	25	190	20	80	6	75	6

conducted by Jaboring. The payback period for the gray water system installed in family house was calculated to 15 years if the water consumption is around 600 L/day. Also, the project report [6] states that economics for gray water system is much less specific – around 20 years. The research results from the Czech Republic also confirm the extended payback period [21]. Table 6 describes payback period for single-family house – experimental house.

Rainwater systems are more effective in big buildings compared to small buildings. For example, in the administrative building, they can replace 30% of water consumption. To sum up, these systems at the single-family house are likely to be less economical than larger systems.

5 Conclusions

The provision of safe water and sanitation has been more effective than any other interventions in reducing infectious disease and increasing public health. The water management field in the environmental assessment system (BEAS) used in Slovakia has a percentage weight of 8.88%, which has a significant role in the environmental assessment compared to other fields [22]. The public expects to have safe water and sanitation; therefore, when recycling water, it is essential to protect public health and the environment [23]. DATAWs is a tool that helps to understand the water building cycle set on the pattern of water user in Slovakia. The classic pattern consists of potable use for all purposes, and sometimes the well water is used for irrigation. The questionnaire results just confirmed the real situation and the needs for water audits. The change of a classic family house to house that saves water using the alternative water sources led to a reduction of water bills. The saved costs for water in the year 2018 could be around 190€, but the main aim was to give as much as possible information to the customer to change his thinking to a sustainable solution even when they are not so cost-effective. We can assume that better understanding of building water cycle and suitable water use by inhabitants can help us to save the water globally, and it is showing us a new way on how to fight water scarcity starting at the building level.

6 Recommendations

There is a need of deeper financial analysis of proposed systems by prediction models. The AHP_OWA methodology for environmental and economic evaluation could give the more precise results. This methodology has potential for water industry with the prediction scenarios for future. Evolving the application for smart phones to raise people awareness about water systems is also a part of future goals.

Acknowledgment This work was supported by project VEGA n. 1/0202/15: Sustainable and Safe Water Management in Buildings of the 3rd Millennium.

References

1. Eslamian S (2016) Urban water reuse handbook, 2nd edn. CRC Press, Boca Raton, p 1114. ISBN 9781482229158
2. Gray NF (2010) Water technology, 3rd edn. IWA Publishing, London, p 747. ISBN 978-1843393030
3. Stec A, Kordana S, Słyś D (2017) Analysing the financial efficiency of use of water and energy saving systems in single-family homes. J Clean Prod 151:193–205
4. Alegre H, Matos R (2009) Paving the way for a sustainable asset management of urban water infrastructures: outcomes of the 5th World Water Forum. Water Asset Manage Int 5:19–20
5. Yeang K, Spector A (2011) Green design: from theory to practice. Black Dog Publishing, London, pp 7–12
6. Zelenakova M, Purcz P, Gargar IAK, Helena H (2013) Comparison of precipitation trends in Libya and Slovakia. River basin management 7. WIT Press, Southampton, pp 365–374
7. Kaposztasova D et al (2015) Water conservation at the building level. Recent advances in environmental and earth sciences and economics, pp 155–159. http://www.inase.org/library/2015/zakynthos/bypaper/ENG/ENG-23.pdf
8. Rainwater and greywater, Decision-Making for Water Conservation (PR80), CIRIA (2001) http://web.stanford.edu/group/narratives/classes/0809/CEE215/Projects/greendorm/water/GraywaterCD/greywater/pr80.pdf
9. WDF (2000) The Water Framework Directive, Directive 2000/60/EC of the European Parliament and of the Council
10. World Water Vision Report (2015) http://www.worldwatercouncil.org/library/archives/water-crisis/
11. Silva-Afonso A, Rodrigues C (2008) Water efficiency of products and buildings: the implementation of certification and labelling measures in Portugal. Proceedings CIB W062 2008 34th international symposium of water supply and drainage for buildings. HKPU, Hong-Kong
12. ANQIP (2012) ETA 0808 specifications for assigning ANQIP water efficiency labels to taps and flushing valves (version 2). Portuguese Association for Quality in Building Installations, Aveiro
13. ANQIP (2011) ETA 0905 systems of reuse and recycling of grey water in buildings (SPRAC). Portuguese Association for Quality in Building Installations, Aveiro
14. Kaposztasova D et al (2015) Integrated building water management options. WSEAS Trans Environ Dev 11:282–288. ISSN: 2224-3496. http://www.wseas.org/multimedia/journals/environment/2015/a625815-083.pdf

15. Saaty TL (1980) The analytic hierarchy process: planning, priority setting, resource allocation. McGraw-Hill, New York, p 437
16. Kaposztasova D (2015) Integrated water management at the building level, Habilitaton work. Technical University of Košice, Košice
17. Kaposztasova D et al (2016) Water management options – portfolios for safe water utilization in buildings. J Civ Eng Environ Archaeol 63(2/II/16):165–174. http://doi.prz.edu.pl/pl/pdf/biis/594
18. Boroushaki S, Malczewski J (2008) Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. Comput Geosci 34(4):399–410. ISSN 0098-3004. http://www.sciencedirect.com/science/article/pii/S0098300407001471
19. Yager RR, Kelman A (1999) An extension of the analytical hierarchy process using OWA operators. J Intell Fuzzy Syst 7(4):401–417
20. Mesaros P, Mandicak T (2015) Information systems for material flow management in construction processes. IOP Conf Ser 71(1):1–5. ISSN 1757-8981
21. Racek J (2015) Testing the prototype of system of use greywater. Juniorstav 2015. Brno University of Technology, Brno-střed
22. Kridlová Burdova E, Vilcekova S (2013) Building environmental assessment system in Slovakia. Lambert Academic Publishing, Saarbrücken, p 114. ISBN 978-3-659-31723-0
23. Hlavinek P et al (2007) Hospodaření s dešťovými vodami v urbanizovaném území. Brno ARDEC s.r.o. ISBN 80-86020-55-X (in Czech language)

Hydrological and Hydraulic Aspects of the Revitalization of Wetlands: A Case Study in Slovakia

Andrej Šoltész, Lea Čubanová, Dana Baroková, and Michaela Červeňanská

Contents

Abstract The presented contribution was developed based on the results of a research project within the frame of the INTERREG Initiative between the Hungarian and Slovak Republics. It was concentrated on the Medzibodrožie region located in the south-eastern part of the Slovak Republic. This project, initiated by water board companies in Hungary and Slovakia, was focused on a creation of a possibility for the design of technical measures for the revitalization of the rivers in the area of interest, which dried out.

The first step consisted of an analysis of the recent hydrological state of the surface water, groundwater, and soil water in the area of interest and finding of a water source for the revitalization of the old river bed and branches. The next phase concentrated on modelling the hydrological and hydraulic processes of the surface (using HEC-RAS and MIKE-11) and subsurface flows (using TRIWACO software for groundwater modelling).

At the end of the project solution, two technical alternatives were proposed. The recommended variant considers the construction of a inflatable rubber weir in the

A. Šoltész (✉), L. Čubanová, D. Baroková, and M. Červeňanská
Department of Hydraulic Engineering, Faculty of Civil Engineering, Slovak University of Technology in Bratislava, Bratislava, Slovakia
e-mail: andrej.soltesz@stuba.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 287–306,
DOI 10.1007/698_2017_227, © Springer International Publishing AG 2018,
Published online: 27 April 2018

Latorica River, which enables the revitalization of the Tice River and its dead branches and the creation of conditions for a better quality of life of the inhabitants in the villages affected.

Keywords Cross-border project, Revitalization, Surface and groundwater interaction, Water management

1 Introduction

The INTERREG project was concentrated on the Medzibodrožie region, which is located between the Latorica River on the north, the Tisa River on the south, the Bodrog River on the west, and the Slovak-Ukraine border on the east (Fig. 1). The confluence point of the Tisa and Bodrog rivers is the famous wine-producing town of Tokaj. The main reason for the proposed project was that five flowing rivers were "alive" in this region 60 years ago. In addition to the Latorica, Bodrog, and Tisa rivers mentioned above, there were two other rivers – the Tice and the Krčava – which, due to water management measures in the years 1946–1964, more or less dried out [1]. The construction of protective dykes on the Latorica and Tisa rivers and the consequent decrease in the groundwater level in the region between these two rivers due to the decreased recharge of groundwater from the surface flows caused the drying out of the rivers. The goal of the project was to analyse the hydrological and hydraulic conditions and to create a possibility for the design of technical measures for the revitalization of the Tice and Krčava rivers [2].

The research work was performed by the Slovak University of Technology in Bratislava, the Water Research Institute, and the Institute of Hydrology of the Slovak Academy of Sciences. EKÖVIZIG (the North-Eastern Direction on Water and Environmental Issues in the River Basin in Miskolc) headed the project on the part of Hungary and the Slovak University of Technology in Bratislava on the party of the Slovak Republic [3, 4].

The project had quite a few vital goals to be solved, but the most important were briefly characterized as follows:

- Water management – ecological (with an appropriate technical solution)
- The landscape (depending on the water management solution)
- Socio-economic (closely connected to the previous two goals)

Priority was given to the first goal. For the research team, the primary and most important goal was the solution of the water management control, from the quantitative as well as the qualitative points of view [5, 6].

The first task for the working team was to analyse the recent hydrological state of the surface water, groundwater, and soil water in the given area and to find a water source for the water management solution to revitalize the old river bed and branches of the Tice River [7]. The interregional point in common was a water source, which is mostly located on the Slovak side. The next specific aspect of the project involved already-realized water management measures on both sides of the Medzibodrožie

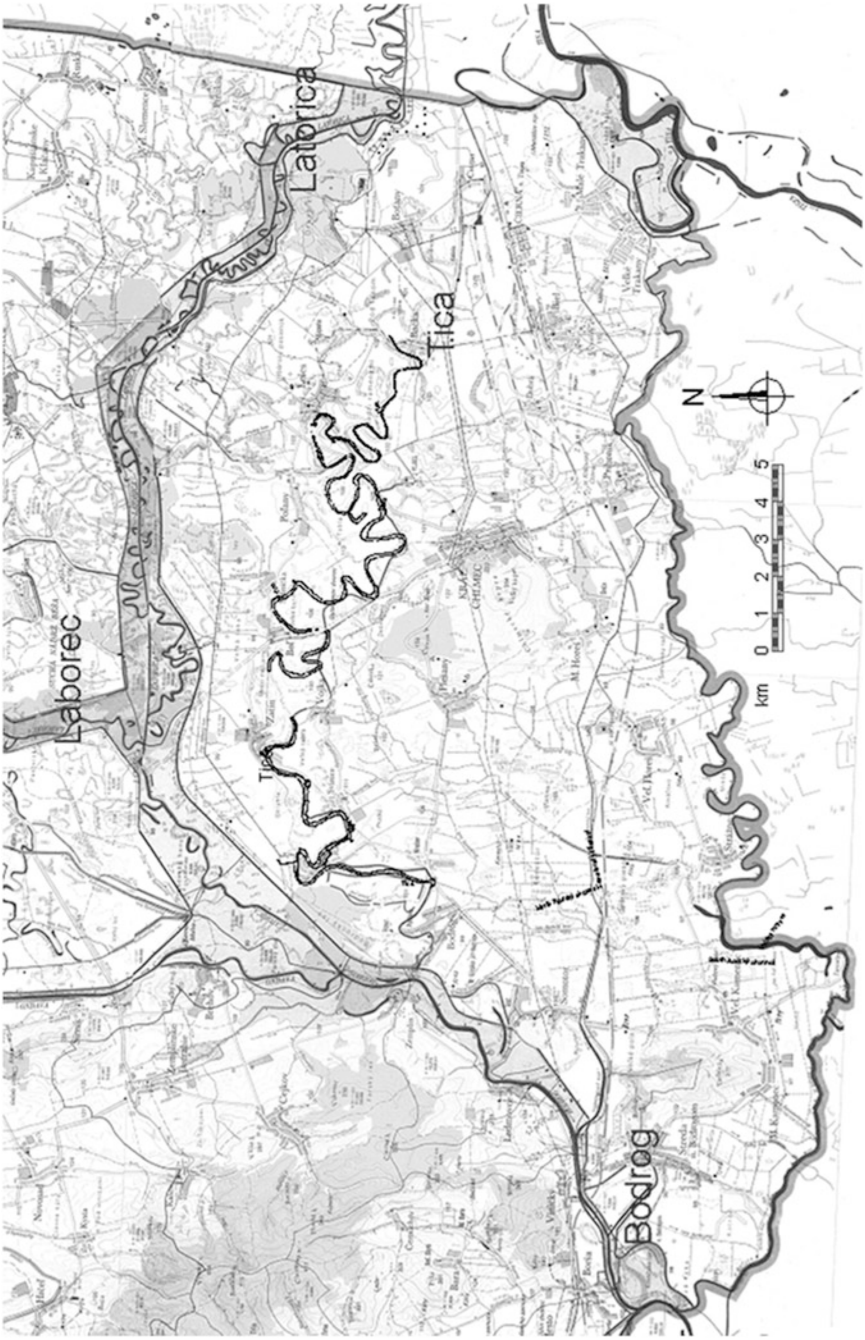


Fig. 1 Medzibodrožie region on the Slovak and Hungarian borders (Slovak side)

region. They are not relevant and do not coincide with this project [8]. By utilizing the proposed water management measures achieved in the project, it could be possible to achieve a symbiosis in the water management on both sides of the border.

The project itself was divided into seven phases, which involved:

- The water management part of the project
- A detailed analysis of the hydrological conditions of the entire Medzibodrožie region
- The hydraulic and morphological conditions [9] of the surface flows (the last passports were developed almost 40 years ago)
- The hydrogeological conditions [10–12] of the whole region
- The hydro-pedological conditions [13] of the Medzibodrožie region

The “interregional” aspect of the project means that the water knows no political or regional restrictions and flows without any respect for the border between the two states [14, 15].

2 Present State of the Research Results

After finishing its analytical work, the working team firmly concentrated on modelling the hydrological and hydraulic processes of the surface and subsurface flows. These works, of course, were very intimately connected with the results of airborne scanning to achieve a digital terrain model (DTM) of the area investigated. The results of the scanning were still very rough for a morphological analysis of the floodplain region of the rivers. It was not precise enough for the mathematical modelling of the hydraulic processes, and, most importantly, it was not precise enough for designing the technical measures which were involved in the project as well as the environmental impact assessment. Water management in this region was developed as one hydrological unit despite the existing border between Slovakia and Hungary (Fig. 1). The most important water bodies on the Slovak side of the Medzibodrožie region are shown there, as well.

The technical solution for the revitalization of the Tice River was assumed to be capable of being realized through the outlets of the protective dyke on the left-hand side of the Latorica River (see Fig. 2). The problem is that an overflow can occur at the discharge $Q = 55\ \mathrm{m}^3\ \mathrm{s}^{-1}$ on the Latorica River, which happens approximately 30 days per year. This overflow mostly appears at a time when the overflowing of the Tice River is not necessary or unreasonable from the point of view (the flood situation) of the water quality in the Latorica River.

To obtain more information about the Latorica River bed, detailed geodetic measurements in the floodplain were performed together with consequent discharge measurements in the Latorica River (Fig. 3). The results of the measurements were compared with the river passport information from 1969 and used for modelling the water level regime in the Latorica River for different discharges to recommend an

Fig. 2 The outlet structure of the protection dam on the left-hand side of the Latorica River

optimum water level regime for the river. A mathematical model of the Latorica River was developed based on input data from the longitudinal and cross-sectional profiles. For modelling the surface water, the HEC-RAS 1-D computational program as well as MIKE-11 (in a GIS environment) was used [16, 17].

The model contained the Latorica River section from the Kapušany bridge to the state border with Ukraine (rkm 21.615–rkm 31.493, rkm means river kilometre) with 57 cross-sections; the total length of the model was 9.878 km. The calibration of the hydraulic model was performed according to measurements in situ. The water level in the first profile (Kapušany bridge) and the corresponding discharge (31 $m^3 s^{-1}$) from the rating curve in the Veľké Kapušany profile were used (see Fig. 4) as boundary conditions. The calibrated values of the Manning roughness coefficient were different for the floodplain (this part of the Latorica River is densely overgrown with vegetation) and different for river bed sections [14, 18]:

- Floodplain, $n = 0.7$ – forest, trees, and bushes
- River bed, $n = 0.045$ – rough surface, irregular profile (rkm 21.615–22.015; rkm 23.022–27.681; rkm 30.116–31.493)
- Natural channel covered by vegetation, $n = 0.03$ (rkm 22.111–22.798)
- Channel with bushes on banks, $n = 0.048$ (rkm 27.858–29.922)

These calculations were followed by analyses and forecasts of the groundwater level regime at this time on the Slovak part of the Medzibodrožie region. Several

Fig. 3 Measurement of the actual cross-sections of the Latorica River

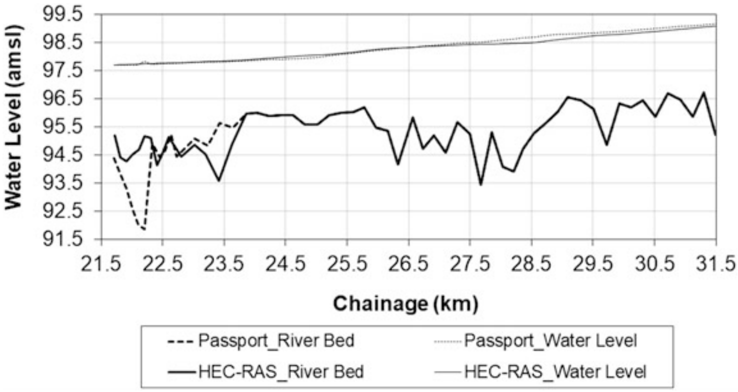


Fig. 4 Calibration of the model of the Latorica River for a discharge of 31 $m^3 s^{-1}$

results from analysing the groundwater level regime were achieved for different discharges in the Latorica River as well as for the proposed surface water level regime after introducing technical measures in the Latorica River bed. The numerical modelling of the groundwater flow was realized using TRIWACO (Royal Haskoning Software), which is based on the finite element method. Different modifications were undertaken (Fig. 5) to achieve the best computation of the finite

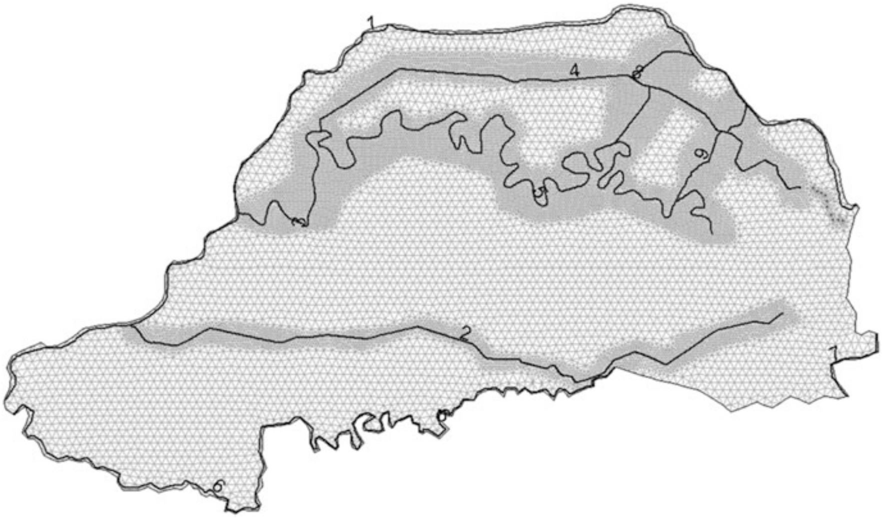


Fig. 5 Illustration of the finite element computational mesh for the 2-D groundwater flow after introducing the technical measures using the TRIWACO software

element mesh with the most important surface flows, i.e. the rivers, drainage channels, and proposed surface flows. The purpose of the proposed surface flows will be the connection of the natural flows with artificial channels to supply the Tice River on the Slovak side. This will be done by means of outlets on the protective dyke on the left-hand side of the Latorica River as well as the Krčava River on the Slovak-Hungarian border. All the other activities such as the calibration, verification, and sensitivity analysis were utterly realized and are shown in Fig. 6. The situation shown in this figure is the groundwater level regime after realizing the technical measures in the Latorica River bed and replenishing the Tice River bed [3].

These modelling calculations of the surface and groundwater level regimes [19] were accomplished using soil moisture measurements in the Medzibodrožie region and modelling in the unsaturated zone; they were realized by the Institute of Hydrology of the Slovak Academy of Sciences in Bratislava [20–22].

3 Technical Solution

The proposed technical solution involved the 44.4-km-long Tice River in securing a relatively steady discharge regime in some parts of its branch system. There is the possibility of a specific control of the water level due to the requirements and needs of the ecosystem and the population of the individually affected villages. For this

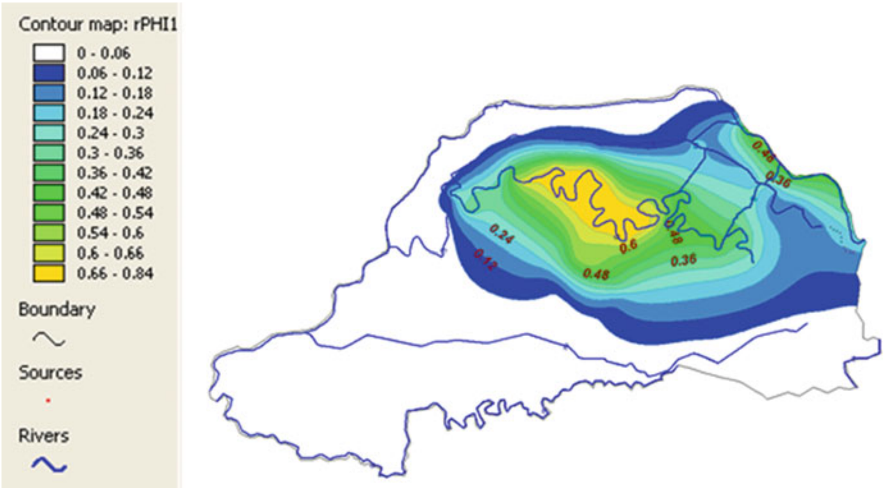


Fig. 6 Course of the groundwater level differences (m) after introducing technical measures in the Latorica River bed with the contemporary replenishing of the Tice River by means of artificial channels Nos. 8 and 9 (see Fig. 5)

reason, it was necessary to solve the following hydrological, hydraulic, and technical problems [14, 23]:

- A hydraulic solution and a technical proposal for a gravitational offtake of the required water quantity from the Latorica River in such a way that even in dry periods, there would be enough water for the creation of a satisfactory water level regime in the revitalized Tice River
- A hydraulic proposal and an appropriate technical solution involving necessary measures in the Latorica River for securing the required offtake water into the Tice River (Fig. 7)
- A hydraulic solution and technical proposal for a gravitational offtake discharge from the Tice River into the river Krčava on the border (Fig. 8)
- Securing flood protection in the vicinity of the revitalized Tice River using a controlled inflow into the Tice River
- A hydraulic solution and technical proposal for the measures and structures in the revitalized Tice River to enable the possibility of water control for relatively stable discharges
- Utilization of the existing channel system in the region for solving the inflow problem into the Tice River and proposal of necessary measures for the channel system and gates
- Determination of the marginal operation discharges Q_{min} and Q_{max} and determination of the minimum and maximum operational water levels in the Tice River and in the channel system, as well
- Review of the impact of evaporation from the water level and seepages into the groundwater on the discharge balance in the Tice River and the need for a supply of water from the Latorica River

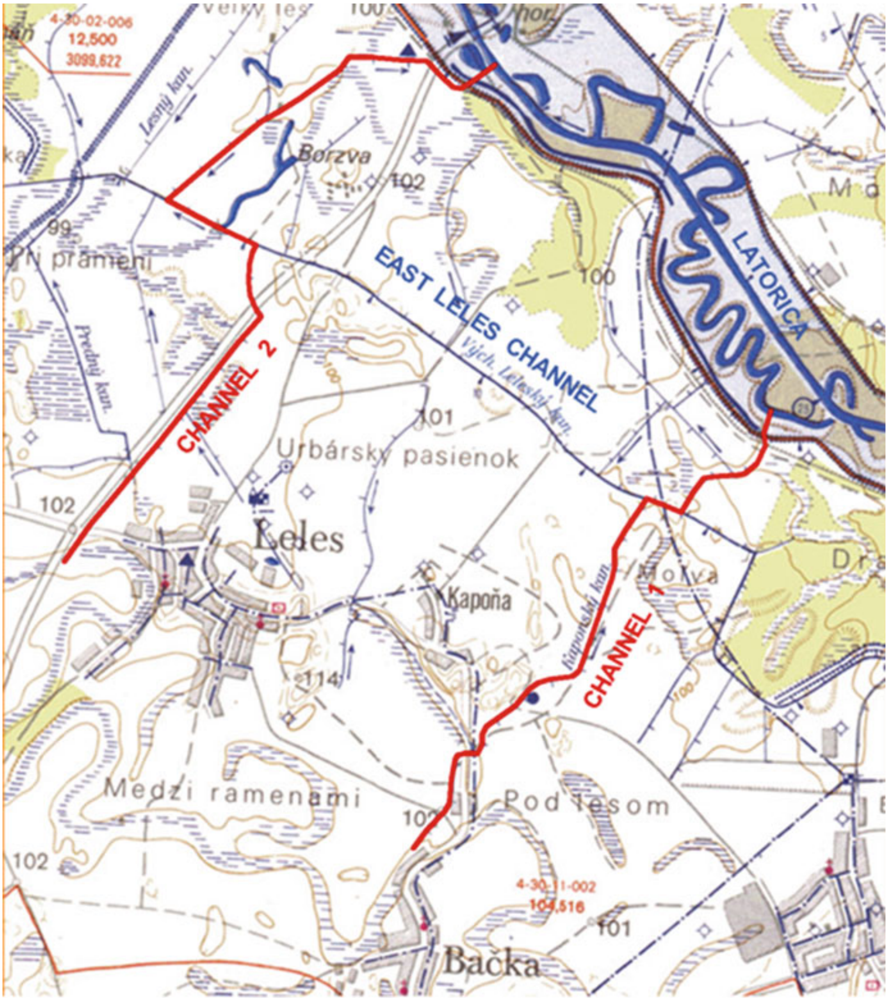


Fig. 7 Northern branch of the connection of the Latorica River through the existing Leleský channel into the Tice River bed

4 Description of the Hydraulic System and Its Operation

During its operation, the system will secure the required functions of the restored Tice River's flow; it consists of the following relatively separate parts:

- *The construction of a weir* on the Latorica River is a component of the technical solution. It should be situated at rkm 21.680 of the Latorica River in a profile approximately 60 m above the bridge on the road connecting the towns of Veľké Kapušany and Kráľovský Chlmec. It will secure the backwater level on the

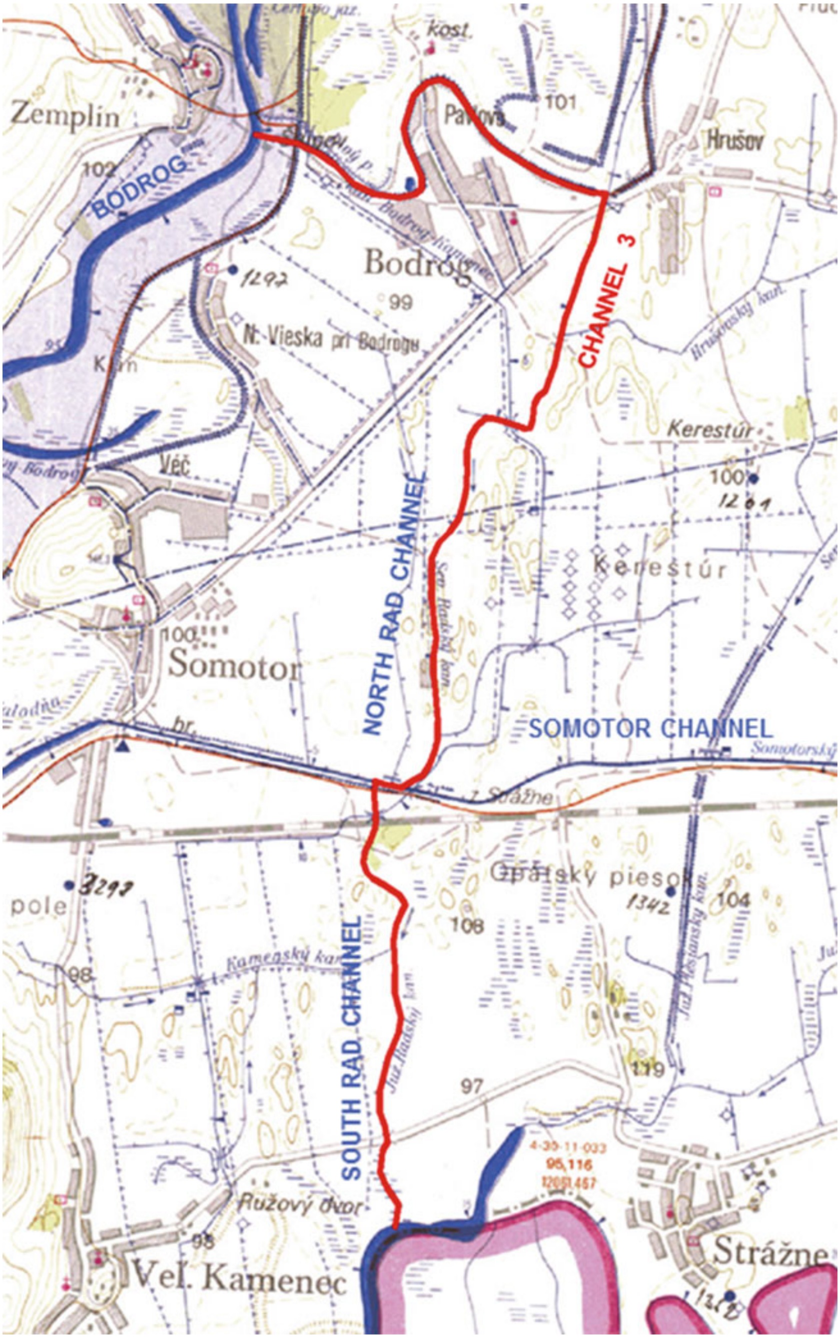


Fig. 8 Southern branch of the water connection from the Tice River through the Radský channel into the Krčava River

operating level of 99.5 m amsl, whereby conditions for the gravitational inflow into the Tice River will be created even with a minimum discharge in the Latorica River.

- *Channel 1* will be created using parts of the existing Leleský, Kaponský, and Bačka channels with some corrections and the completion of a new channel situated near the outlet in the left protective dam of the Latorica River at rkm 24.751 up to the Leleský channel. The total length of channel 1 is 4,617 m, and its discharge capacity under the most inconvenient hydrodynamic conditions is approximately 1.0 $m^3 s^{-1}$.
- *Channel 2* consists of the existing Pri prameni, Leleský, and Veľký les IV channels and an unnamed channel. Its total length is 5,800 m, and it is connected with the Latorica through the outlet structure of the protective dam on the left-hand side in its river chainage rkm 21.750. This channel enables the transport of water gravitationally into the Tice River, and its discharge capacity under the most inconvenient hydrodynamic conditions is approximately 1.25 $m^3 s^{-1}$.
- *The revitalized Tice River* is 44.4 km long, and its route is unaffected by any corrections in its width and length. The revitalized flow will be supported by the Latorica River using the channels mentioned above. The water level regime will be controlled by sluice gates on culverts at six natural (earth-fill) damming profiles on the river. These are designed to be situated in the successive cross-sections [14, 18, 23]:

  – Damming in rkm 0.000 at the mouthing into the Northern Radský channel
  – Damming in rkm 4.940 at the field road crossing in the eastern part of the village of Rad
  – Damming in rkm 11.030 at the state road crossing from Zatín to Svinice
  – Damming in rkm 17.910 at the state road crossing from Kráľovský Chlmec to Boľ on the southern part of the village of Boľ
  – Damming in 26.100 at the tapering part of the flow that meanders in a northerly direction from the town of Kráľovský Chlmec
  – Damming in rkm 38.170 at the field road crossing in a south-westerly direction from the village of Leles (Fig. 9)

- *Channel 3*, which secures the gravitational water flow from the Tice River down to the Veľká Krčava River, is 8,479 m long and is created by the connected channel system of the Northern Radský, Somotorský, and Southern Radský channels. Its discharge capacity is 2.3 $m^3 s^{-1}$.

5 Rivers, Channels, and Their Structures

For obtaining the determined goals and for replenishing the former river bed of the Tice River, it is necessary to execute the following technical measures in individual rivers and channels and modify the operating rules on the rivers and their structures.

Fig. 9 Illustration of the positioning of the culverts on the Tice River

5.1 The Latorica River

In the profile above, the bridge on the Latorica River on the state road from Veľké Kapušany to Kráľovský Chlmec, it is necessary to build a weir structure (Fig. 10). The weir will secure the required water level in the vicinity of the two outlets mentioned above of the protective dam on the left-hand side of the Latorica River even at minimum discharges. The weir was designed as a inflatable rubber weir with an operating water level of 99.50 m amsl. It will be a two-field weir with a width of 12.0 m [24]. The height of the backwater will be 3.30 m. Due to the operation of the inflatable rubber weir, the appropriate water level will be secured.

5.2 The Tice River

The Tice River currently appears as a system of wetlands which are connected and that water sometimes flows through (see Fig. 11). The river bed is fully mature with water flora and trees. The width of the river varies from 20 to 100 m and locally up to 150 m. The bottom is clogged with mud and quite a few contaminants. The whole head of the river bed's bottom on the 44.4-km-long river reach is approximately 3.51 m, which has a mean longitudinal slope of the bottom $i_0 = 0.000079 = 0.079‰$.

The revitalization of the river requires minimum technical measures to improve the river bed, including its cleaning and the creation of conditions for securing a permanent discharge in the river [3, 15]. The reconstruction also requires building six culverts where the water level is connected by two pipes (diameter D = 1,000 mm) with sluices for the water control. These damming profiles are also used at road crossings of local importance and on-field roads.

The total area of the water level in the revitalized 44.4-km-long Tice River is approximately 2.8 mil. m^2, and the whole water volume in the Tice River at its maximum operating levels in the individual reaches is 2.95 mil. m^3 of water.

The discharge regime in the revitalized Tice River is provided mostly:

- By the possibilities of water offtake from the Latorica River in low water periods and at discharges close to the values of the minimum discharges when the offtake should not exceed a 0.5 $m^3\ s^{-1}$ value
- By the discharge capacity of transport channels Nos.1 and 2, which should be, under the most inconvenient hydrodynamic conditions, a minimum head at the beginning and at the end of the channel: for channel 1 1.0 $m^3\ s^{-1}$ and for channel 2 1.25 $m^3\ s^{-1}$
- By the discharge capacity of culverts on the individual damming profiles that utilize the control capability of the sluices on these pipes, which will mainly be

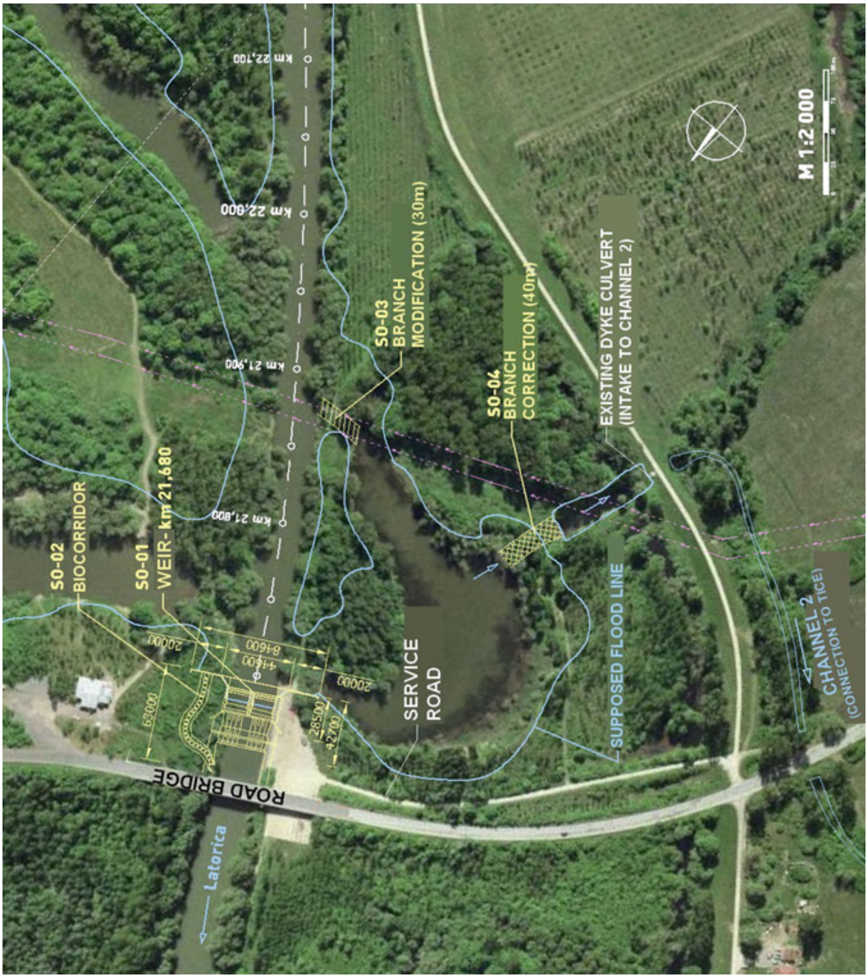


Fig. 10 Position of the inflatable rubber weir structure on the Latorica River above the bridge

Fig. 11 Wetland conditions on the Tice River

used during the first replenishment of the system as well as during low discharges in the Latorica River

- By the discharge capacity of channel 3, which is 2.3 $m^3 s^{-1}$

The discharges in the Tice River will vary at intervals from $Q_{\min} = 0.5$ $m^3 s^{-1}$ up to $Q_{\max} = 2.3$ $m^3 s^{-1}$. The water levels will be controlled using the sluices in the damming profiles. The possibilities for control are shown by the longitudinal profiles in Fig. 12.

The discharge regime in the Tice River is determined by the possibilities of the water uptake from the Latorica River and by the possible capacity of transport channel No. 3. The discharges in the Tice River will vary in limits from.

$$0.5 \ m^3 \ s^{-1} \leq Q_{\text{oper,T}} \leq 2.3 \ m^3 \ s^{-1}.$$

The mean operating discharge, which will be supported by the Latorica River, is $Q_{\text{oper,T}} = 2.25$ $m^3 s^{-1}$. The water losses from the revitalized Tice are given by the seepage of the water into the groundwater and by evapotranspiration. The losses were computed for the maximum evapotranspiration and were evaluated by the value of $Q_{\text{evap}} = 0.13$ $m^3 s^{-1}$.

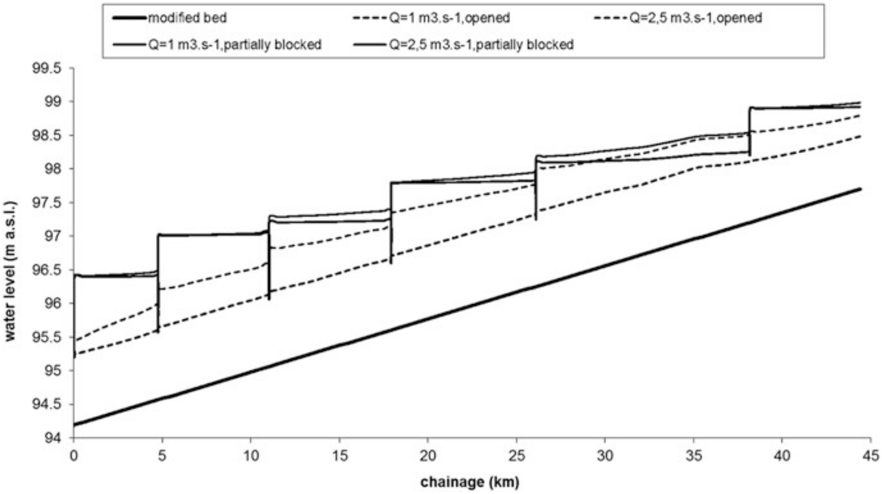


Fig. 12 Water level regime of the Tice River

The losses due to seepage from the Tice river bed into the groundwater were calculated using mathematical modelling and were determined after the replenishment of the Tice river bed at a value of $Q_{\mathrm{seep}} = 60\ \mathrm{L\ s^{-1}} = 0.06\ \mathrm{m^3\ s^{-1}}$. After estimating the water losses, the discharges in the Tice River will be.

$$Q_{\mathrm{oper,Tice}} = Q_{\mathrm{oper,T}} - Q_{\mathrm{seep}} + Q_{\mathrm{evap}} = 2.25 - 0.06 - 0.13 = 2.06\ \ \mathrm{m^3\ \ s^{-1}}.$$

6 Evaluation of Solution Variants

In the contribution presented, a proposed water supply into the Tice River and its prospective replenishment is given using two alternative technical solutions:

The first variant solution considers the construction of a inflatable rubber weir with an operating water level at 99.50 m amsl in the Latorica River above the bridge on the state road from Veľké Kapušany to Kráľovský Chlmec with water transported into the Tice River and its consequent transport into the Krčava river bed. This variant of the solution enables the replenishment of the Tice and controlling the water at the required level as well the replenishment of dead branches of the river. The system can operate during the whole year except for a short period when the main drainage function of the Leleský and Somotorský channels has to be fulfilled.

The second variant differs from the first one only by the fact that in the Latorica River, a natural surface water level regime will be secured, and no weir will be realized. Other elements will be the same as in the first variant. The required operating discharge would be secured in just 35–40 days in a mean year; in dry years the possibility to improve the water level regime in the Tice will only be possibly 2–5 days per year.

The authors recommend the realization of the first variant of the solution, which enables the revitalization of the Tice River and its dead branches and the creation of conditions for a better quality of life of the inhabitants in the villages affected.

7 Conclusions

The results presented of the INTERREG project deal with interdisciplinary and interregional problems of water and land-use management in the Medzibodrožie region. It is not the first research project resolving the water management in this region but is undoubtedly the first project which, in a broad spectrum and across the border, attempts to resolve the water management problems of the Medzibodrožie region on both sides of the border between Slovakia and Hungary.

After the analysis of the recent hydrological state of the surface water, groundwater, and soil water in the area of interest, the water source for the revitalization of the old river bed and branches was found. This was done by using modelling of the hydrological and hydraulic processes of the surface (using HEC-RAS and MIKE-11) and subsurface flows (using TRIWACO software for groundwater modelling).

Two alternative technical solutions were proposed. The recommended variant considers the construction of a inflatable rubber weir in the Latorica River, which enables the revitalization of the Tice River and its dead branches and the creation of conditions for a better quality of life of the inhabitants in the villages affected.

In the future the research will be utilized with respect to the hydrological conditions for the creation of sustainable environment in lowlands of East Slovakia.

Acknowledgements The contribution was developed within the frame and based on the financial support of the APVV-15-0489 project "Analysis of droughts by multi-criterial statistical methods and data mining from the viewpoint of prevention structures in a landscape".

The contribution was developed within the frame of and based on the financial support of the APVV-16-0278 project "Use of hydromelioration structures for mitigation of the negative extreme hydrological phenomena effects and their impacts on the quality of water bodies in agricultural landscapes".

References

1. Bella V (1971) Water management of East Slovak lowlands. Alfa, Bratislava
2. Červeňanská M, Janík A, Šoltész A, Baroková D, Gramblička M (2016) Determination of input data for utilization of drainage channel system on improvement of water regime in wetland systems. Acta Hydrol Slovaca 17:133–139

3. Šoltész A (2008) Hydraulic aspects of cross-border cooperation in river restoration project. Zagreb
4. Pálinkášová Z, Šoltész A (2012) Hydrologic and hydraulic evaluation of drainage system in eastern Slovak lowland. Pollack Period 7:91–98. https://doi.org/10.1556/Pollack.7.2012.3.9
5. Gomboš M, Kandra B, Vasiľová I (2014) Quantification of substantial soil water regime elements during important dry periods. Int Multidisc Sci GeoConf Surv Geol Min Ecol Manag 1:563–570
6. Pelikán P, Miloslav Š (2011) Methodology for the establishment of physical and geometric properties of a drainage basin. Acta Univ Agric Silvic Mendelianae Brun 59:265–270
7. Šoltész A, Baroková D, Červeňanská M, Janík A (2016) Hydrodynamic analysis of interaction between river flow and ground water. Int Multidisc Sci GeoConf Surv Geol Min Ecol Manag 1:823–830. https://doi.org/10.5593/SGEM2016/B11/S02.104
8. Zeleňáková M, Purcz P, Soľáková T, Demeterová B (2012) Analysis of trends of low flow in river stations in eastern slovakia. Acta Univ Agric Silvic Mendelianae Brun 60:265–274
9. Kopáčik A (2006) Geodetic measurements of cross-section profiles in chosen localities and structures on the Latorica River. Final report, Bratislava
10. Pavelková D, Ivančo J, Burger F (2006) Groundwater level regime in Medzibodrožie Region and its trends during years 1963-2005. Acta Hydrol Slovaca 7:210–219
11. Kovarik K (2000) Numerical models in groundwater pollution. Springer, Berlin
12. Šoltész A, Baroková D (2008) Hydrogeology of the Medzibodrožie Region – Slovak part. RISSAC Hungarian Academy of Sciences, Budapest
13. Gomboš M, Tall A, Kandra B (2009) Creation of soil cracks as an indicator of soil drought. Cereal Res Commun 37:367–370
14. Kamenský J, Hašková L (2008) Hydrologic and hydraulic evaluation of the water level and discharge regime of the Latorica River. Budapest
15. Šlezingr M, Synkový J, Foltýnová L, Uhmanová H (2010) Possibility of utilization directing structures in river revitalization. Slovak J Civ Eng 18:33–36
16. Šoltész A, Květon R, Baroková D, Kállayová L (2005) Water management in drainage areas of the East Slovakian lowland. In: Innovation and utility in the visegrad four. Volume 1 – Environmental management and environmental protection: proceedings of the international scientific conference, Nyíregyháza, 13–15 Oct 2005
17. Šoltész A, Květon R, Baroková D, Vércseová E (2005) Hydrologic-hydraulic assessment of internal water drainage in lowland regions of Slovakia. In: Ninth international symposium on water management and hydraulic engineering, Ottenstein, 4–7 Sept 2005, pp 427–434
18. Šoltész A, Baroková D, Hašková L (2007) Optimization of water regime in the Medzibodrožie Region. Acta Hydrol Slovaca 8:173–181
19. Baroková D, Šoltész A (2008) Groundwater modelling for improving groundwater-surface water regime in Slovak part of the Medzibodrožie region. In: HydroPredict'2008. International interdisciplinary conference on predictions for hydrology, ecology and water resources management, Česká asociace hydrogeologu, Prague, pp 375–379
20. Mati R, Kotorova D, Gomboš M, Kandra B (2011) Development of evapotranspiration and water supply of clay-loamy soil on the East Slovak lowland. Agric Water Manag. https://doi.org/10.1016/j.agwat.2011.02.007
21. Gomboš M, Tall A, Pavelková D (2014) Evaluation of selected locality of East-Slovakian lowland by soil potential for volume changes. Int Multidisc Sci GeoConf Surv Geol Min Ecol Manag SGEM 2:115–122
22. Gomboš M, Štekauerová V, Pavelková D, Kandra B, Šútor J, Tall A (2011) Planar presentation of water storage change in the root zone of the soil at East-Slovakian lowland caused by the climate change. In: Halasi-kun GJ (ed) Pollution and water resources, Columbia University

seminar proceedings: environmental protection of Central Europe and USA, vol XL, 2010–2011. Institute of Hydrology SAS, Hungarian Academy of Sciences, Bratislava, Pécs, pp 335–368
23. Květon R (2009) Mathematical model of Medzibodrožie WMS. In: WMHE 2009. International symposium on water management and hydraulic engineering, University Ss. Cyril and Methodius, Ohrid, pp 315–324
24. Šulek P (2007) The project of the inflatable rubber weir on the Latorica River in profile RKM 21.6. Bratislava

Sustainable Water Management in Buildings

S. Vilčeková, E. Krídlová Burdová, and I. Selecká

Contents

Abstract A significant number of building sustainability assessment methods and tools have been developed over the past two decades. Sustainability assessment of buildings means an evaluation of environmental, social and economic aspects and indicators respecting technical and functional characteristics of buildings to design and construction of sustainable buildings. There are many tools for sustainability assessment of buildings used over the world such as LEED, BREEAM, Green Globes, SBTool, CASBEE, etc. This chapter is aimed at introducing the building environmental assessment system (BEAS) which has been developed at the Technical University of Košice. The Slovak system was developed on the base of existing systems and methods used in many countries. The BEAS includes a number of environmental, social and cultural factors. The indicators were proposed according to the analysis of building performance as well as on the base of experimental experiences. The primary fields are building site and project planning, building construction, indoor environment, energy performance, water management and waste management. Water management in buildings is presented here as a critical issue for achieving the sustainable buildings. Indicators of water management are reduction and regulation of water flow in water systems with the weight of 42.3%, surface water run-off with the weight of 12.2%,

S. Vilčeková (✉), E. Krídlová Burdová, and I. Selecká
Faculty of Civil Engineering, Institute of Environmental Engineering, Technical University of Košice, Košice, Slovakia
e-mail: silvia.vilcekova@tuke.sk

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 307–322,
DOI 10.1007/698_2017_224,
Published online: 27 April 2018

drinking water supply with the weight of 22.7% and using filtration of grey water (GW) with the weight of 22.7%.

Keywords Building, Sustainability assessment, Water management

1 Introduction

Currently, European cities and cities around the world are concerned with sustainable development, as well as its evolution. Countries seek a way to adapt to contemporary changes, to meet the required needs and ensure the population's well-being. Considering this, the new sustainability assessment tools are being developed to be used to guide and help cities and urban areas to become more sustainable. Assessment tools such as Building Research Establishment's Environmental Assessment Method (BREEAM), Sustainable Building Tool (SBTool) and Leadership in Energy and Environmental Design (LEED) constitute the basis for the other approaches used throughout the world. These and other tools are focused on rating the buildings respecting environmental, social and economic perspectives [1]. For example, sustainability assessment tool SBTool^{PT} was developed as a version for assessing the sustainability of the built environment for conditions in Portugal. This conceptual change in mentioned sustainability assessment tool boosts its application and improves the sustainability of the built environment. It leads to guide and help designers, engineers, architects, urban planners and politicians to develop urban regeneration plans as well as to define sustainability principles or indicators allowing the comparison of different measures. The scope of this assessment system methodology is to assess the sustainability of the built environment, including projects for urban planning and urban regeneration, specifically in the Portuguese context [2]. The buildings' sustainability and evaluation models, which consider the ecological, economic and social aspects of sustainability, are solved in the study [3]. This study presents the structure of the buildings' sustainability and two evaluation models, which consider all the three aspects. The first one is a global model, where a building is scored, fulfilling some requirements. The second one is a specific model, based on a simple formula, which takes into account numerical values. These evaluation models were applied on three residential buildings of different structural solutions: concrete framed structure, ceramic masonry structure and wooden structure. Each aspect has its specific requirements that characterize a building through its life cycle and contributes, in a different amount, to the overall evaluation. By applying the global and specific model to evaluate the three buildings, similar results were obtained. According to both evaluation models, the most sustainable solution was the wooden structure, followed by the concrete framed structure and at least, the less sustainable, the ceramic masonry structure. Berardi [4] shows that building energy performance is considered as the most important criterion in sustainability rating systems and the least achieved one in sustainability assessments. In contrast, other performance ratings of the building, such as water efficiency or indoor air quality, are achieved with a high rate of success in sustainability assessments. First assessment systems considered the building as a manufactured product and evaluated it almost in isolation. However, the importance given to the surrounding site is greatly increasing. Energy requirements have also become stronger in the latest versions of other assessment systems. This can certainly be motivated by the more rigid requests of energy regulations worldwide but also by the greater attention being given to energy saving in buildings. Results of certified buildings have shown that energy performances are well below the optimal ones even in sustainable buildings. Reasons for this are often the high cost of energy-saving measures and the low preparedness of construction actors. In a study [5], an approach allowing comparisons between the embodied energy and emissions of the building materials as well as the energy consumption and GHG emissions at the use stage is introduced. The results show that embodied energy can represent more than 30% of the primary energy requirement during the life cycle of a single house of 222 m^2 with a garage for one car. This study highlights that if the house does not include a parking area, the contribution of the building materials decreases. It can be explained by increasing the heated surface percentage. Further the heating and building materials in a residential building have the significant share in energy consumption. In addition the building materials represent more than 60% of the heating consumption. Citherlet and Defaux [6] compare three variants of a family house from environmental impacts for their entire life cycle. The first variant was chosen to correspond with the standard in force in Switzerland. The second alternative was selected to meet the requirements of a quality control label for houses with low energy consumption. And finally, the third variant was selected to be a very low energy consumption building. These variants have the same architectural aspect but different insulation thicknesses and types, different energy production systems and the use of different renewable energies. The environmental impacts were determined using life cycle analysis including the impact related to the energy consumption during the occupancy stage as well as the material manufacture, transport, replacement and elimination at the end of the building lifetime. Results of this study indicate that good insulation provides a significant reduction of direct environmental impacts (energy consumption during the occupancy phase). The environmental and resource impacts of wooden single-family residences designed to meet the conventional Norwegian Building Code from 2010 and the Norwegian passive house standard NS 3700 are compared using life cycle assessment which is presented in the study [7]. Four different heating systems were evaluated for the two building designs: (1) electric (resistance heating), (2) electric and wood, (3) electric and a solar heat collector and (4) electric and an air-water heat pump system. The goal of the research was to evaluate the different ways of lowering the total environmental burden of a building's life cycle. Evaluation of impacts due to implementation of renewable heating systems in comparison to standard Norwegian systems largely based on electricity was considered. According to the life cycle analysis, the wood-framed single-family residence complying the passive house standard provides a consistent and clear reduction of cumulative energy demand of 24–38% in comparison to the conventional building standard TEK10 with electric panel heating. In combination with efficient heating systems, a passive house building envelope with a heat pump system provides almost 40% savings of compared to a conventional house with electric heating. The reduction in GHG emissions of the cleanest design compared to the standard alternative is almost 30%. Solar heated water also provides substantial environmental gains for the passive house. On the other hand, a standard building envelope with a heat pump system reduces impacts to a level comparable to that of a passive house building with only electric heating. Another study [8] demonstrates the importance of criteria and sub-criteria in developing a new potential building assessment method for Saudi Arabia. The various aspects influence the criteria and sub-criteria of assessment tools such as environment, economic, social and cultural to mention. The study provides an investigation of the most popular and globally used assessment systems, BREEAM, LEED, Green Star, CASBEE and Estidama, in order to identify the effectiveness of the different aspects of the assessment criteria and the impacts of these criteria on the assessment results. These will provide a solid foundation to develop an effective sustainable assessment method for buildings in Saudi Arabia. It can be stated that all the above-mentioned tools have common issues such as energy, water and materials for increasing the knowledge about the built environment while reducing the impacts of the construction on its users and the environment. Results suggest that it is more appropriate to develop assessment method applicable in the given country and thus achieve desired results focusing on the environmental, economic, social and cultural conditions.

2 Sustainability Assessment of Buildings

Sustainability assessment of buildings is a way on how to build high-performance green buildings. It requires the integrated design of buildings towards the reduction of resource depletion like energy, water and raw materials, prevents environmental degradation caused by facilities and infrastructure throughout their life cycle as well as creates safe and productive built environments [9]. Methods and systems for integrated evaluation of buildings are used for predesign, design, construction, operation, maintenance and end of life of buildings [10]. According to ISO 15392:2008, construction sustainability includes considering sustainable development in terms of its three primary aspects (economic, environmental and social), while meeting the requirements for technical and functional performance [11, 12]. Criteria of sustainability are included in integrated assessment methods, systems and tools for evaluating environmental, social and economic perspectives of buildings. The study [13] emphasizes that although the sustainable building is considered as multidimensional concept, it often gives an attention to the environmental indicators and ignores the substantial importance of social, economic and cultural indicators. Building sustainability involves interdependencies between natural, built and social systems and therefore comprises a complex of different priorities that require consideration at each stage of a building's life cycle. The study of Ding [14] states that the comprehensive assessment of buildings is very important in achieving sustainable development. Building environmental assessment aimed at providing a sustainable building design, construction, operation, maintenance and deconstruction thus requires cooperation between architects; structural engineers; designers of heating, ventilation and air-conditioning (HVAC) systems; environmentalists; developers; builders; and users. Sustainable buildings take into account environmental quality, functional quality, social and cultural factors, economic factors as well as future values during the entire life cycle of buildings [14]. The building construction industry consumes a lot of resources and energy, owing to current global population growth trends. Therefore the climate change became a priority issue on the agenda of the energy and environmental policy of the European Union. With regard to climate change, the energy efficiency and renewable energy are the main pillars [15]. Buildings consume approximately 40% of total global energy, during the construction phase in the form of embodied energy and during the operation phase as operating energy [16–20], and 36% of total CO_2 emissions of the EU Member States [18, 21]. In recent years worldwide commitments in reducing carbon dioxide and other greenhouse gases are recognized from the anthropogenic carbon dioxide's impact on climate change [22]. The development of assessment methods and tools is a challenge for the academic working and also practice. The primary importance is managing the flows of information and knowledge between the various experts. An important constraint to the sustainability methods is that the specific definition of "sustainable building" or "high-performance building" is complex since different actors in the building's life cycle have different interests and requirements [23]. For instance, promoters will give more attention to economic issues, whereas the end users are more interested in health and comfort issues [9]. The study [24] points out that in assessing the performance of buildings, the scope of the sustainability assessment is widening, marking an evolution from a single criterion consideration, like the social performance of buildings, towards a full integration of all aspects emerging during the lifetime of a building. Therefore we can consider the "sustainable buildings" as a broad, multi-criteria subject related to three basic interlinked aspects: environmental, economic and social. Other studies [25–27] show that modern buildings and their heating, ventilation and air-conditioning (HVAC) systems are required not only to be more energy efficient while adhering to an ever-increasing demand for better performance from comfort but equally in respect to financial and environmental issues. Many methodologies have been developed to establish the degree of accomplishment of sustainability goals, guiding the planning and design processes. In the earlier stages of the design process, planners can make decisions to improve building performance at very little cost, following the recommendations of the decision-making tool. The development of building environmental assessment is enhanced for the last 20 years worldwide. The first of such tools was in 1990, the Building Research Establishment's Environmental Assessment Method (BREEAM) [28]. After that, many methodologies have been developed and are currently widely applied such as:

- The Comprehensive Assessment System for Building Environmental Efficiency (CASBEE) from Japan

- The Building and Environmental Performance Assessment Criteria (BEPAC) from Canada
- The Building Environmental Assessment Method (BEAM) from Hong Kong
- The Green Building Rating System (SABA) from Jordan
- The Estidama from Emirate
- The Sustainable Building Assessment Tool (SBAT) from South Africa
- Deutsche the Gesellschaft für Nachhaltiges Bauen (DGNB) from Germany
- The Leadership in Energy and Environmental Design (LEED) from the United States.

Very comprehensive inventories of available tools for environmental assessment methods can be found in Ding [14], Seo et al. [29], the Whole Building Design Guide [30] and the World Green Building Council [31]. The comprehensive study of Alyami and Rezgui [32] states that the most reliable and commonly used schemes in the global context are BREEAM, LEED, SBTool and CASBEE. These tools have been highlighted in the terminal objective of implementing the principles of sustainability. There are a growing number of environmental assessment systems and tools being developed for the building sector. BREEAM and LEED are the leading systems designed for very well-known organizations (BRE and USGBC), which have made a significant contribution to sustainable development. BREEAM had a profound impact on almost all of the environmental impact assessment methods. BREEAM was also used as a design template to many other systems around the world such as Green Star, Basix Australia, BEPAC Canada, Hong Kong [14, 33]. Studies [13, 33] state that some sustainability methods were modified, for example: BREEAM for Lithuanian recreational buildings assessment and SBTool for Portuguese exist, new and renovated residential buildings. The amount of information and tools are available to assist designers and builders in incorporating sustainable technologies and design strategies in their projects. In relation to existing tools, many reports [34] present a description of the evaluation tool characteristics used for building as a whole as well as building materials and constructions, nationally and internationally. Building environmental assessment systems focus on considering the three aspects of building sustainability: environmental issues related mainly to greenhouse gas emissions and energy consumption, economic aspects such as life cycle cost and social requirements such as accessibility and quality of spaces. The most common feature of building environmental assessment systems is that they are multi-criteria systems. Multi-criteria systems are based on the evaluation of criteria measured by parameters and compare real performances with reference ones. Each criterion has a certain number of available points over total assessment. The overall evaluation of sustainability is obtained by summing the results of assessed criteria [11].

This work presents proposal of building environmental assessment system BEAS for the condition of the Slovak Republic. Percentage weight of proposed indicators' significance is determined according to methods of multi-criteria decision analysis (MCDA). The results of the presented BEAS are validated on selected residential buildings.

3 Building Environmental Assessment System in Slovakia

Slovak building environmental assessment system (BEAS) has been developed at the Technical University of Košice on the basis of existing systems used in many countries. It includes a number of environmental, social and cultural aspects and indicators. They were proposed according to the analysis of the technical, functional, environmental, social and economic performance of buildings. After the proposal of main fields and indicators, they were weighted using the AHP method. The methodology of the derivation of the field in BEAS has been performed according to study [27]. A field list has been derived by a three-step process. To establish a comprehensive set of fields of the BEAS, a review of a combination of existing environmental assessment methods used worldwide, Slovak standards and regulations and academic research papers has been conducted. A three-step process has been carried out. The first step was collecting and reviewing the existing building environmental assessment methods and tools. Sufficient information and tools are available to assist designers and builders in incorporating sustainable technologies and design strategies in their projects. In relation to existing tools, many reports [21, 28] present a description of the characteristics of a number of evaluation tools which are used for building and materials, nationally and internationally. The second step was based on a selection of a field list based on the in-depth analysis. Final main assessment fields in BEAS are the following: (A) site selection and project planning, (B) building construction, (C) indoor environment, (D) energy performance, (E) water management and (F) waste management. As a result, a final list of fields has been proposed. The multi-criteria framework incorporates the consideration of environmental and social issues in the development of BEAS. To ensure that the proposed indicators are applicable, it is necessary to validate and revise them through relevant reviews and consultation with experts and stakeholders. This series of verification processes is repeated until a refined set of indicators is obtained and sufficient to measure the sustainability performance of buildings [29].

A final list of proposed indicators for building environmental assessment system for conditions of Slovak Republic is as follows:

- *A – Site Selection and Project Planning*

  A1 Site selection: Use of land with previously high ecological sensitivity or value, land vulnerable to flooding, land close to water endangered contamination, distance to commercial and cultural facilities, distance to public green space and distance to road-traffic infrastructure

  A2 Site development: Development of density, possibility of change of building purpose, impact of the design on existing streetscapes, compatibility of urban design with local cultural values, policies governing use of private vehicles, guarantee of sufficient public green space and provision of trees with shading potential

- *B – Building Construction*

B1 Materials: Degree of reuse of suitable existing structures where available, use of materials that are locally produced, material efficiency of structural and building envelope components, radioactivity of building materials, ease of disassembly, reuse or recycling
B2 LCA: Primary energy embodied in building materials, GWP and AP

- *C – Indoor Environment*

C1 Thermal comfort
C2 Humidity
C3 Acoustic
C4 Daylighting
C5 Total volatile organic compounds (TVOC)
C6 Indoor air quality
C7 Radon
C8 Nitrogen oxides (NOx)
C9 Particulate matters for fraction of 10 micrometres (PM10)
C10 Microbe

- *D – Energy Performance*

D1 Operational energy: Energy consumption for heating, energy consumption for domestic hot water, energy consumption for mechanical ventilation, energy consumption for cooling, energy consumption for lighting and energy consumption for appliances
D2 Active systems using renewable energy sources: Solar system, heat pump, photovoltaic technology and heat recuperation
D3 Energy management: Energy management system, operation and maintenance, degree of local control of lighting systems and degree of personal control of technical systems by occupants

- *E – Water Management*

E1 Reduction and regulation of water flow
E2 Surface water run-off
E3 Drinking water supply
E4 Using filtration of grey water

- *F – Waste Management*

F1 Measures to minimize waste resulting from building operation
F2 Measures to minimize emission resulting from building construction, operations and demolition
F3 Risk of hazardous waste resulting from facility operations

In step 3, a questionnaire survey has been conducted to get the suggestions from the group of participating experts to refine the draft fields. A questionnaire survey aimed at weighing the final fields in BEAS. The task of experts was the determination of significance intensity of main fields according to nine-point scale of relative importance [30]. For the determination of criterion significance, weighting the median absolute deviation (MAD) method was used. MAD is a well-known statistical method that is mostly used in the problem of decision between many independent opinions. According to Lee et al. [31], credit-weighting is the heart of all assessment schemes. It can be said that this way dominates the overall performance score of the assessed building. This system has 52 indicators in six main fields. Each field has several indicators which have the intent of assessment and the scale of assessment. This scale is from negative (−1 point), acceptable practice (0 points), good practice (3 points) and best practice (5 points). The result of each indicator is obtained by multiplying the point with a weight of indicator.

4 Water Management

Sustainable water management can contribute to the preservation and protection of wetlands because it maintains high water quality and quantity conditions, fulfils the present and future water demands and minimizes potential environmental impacts. Applications of water management plans in Europe have a history of approximately 50 years, and this has played a significant role in the improved water conditions encountered in most European countries nowadays [35]. The study [36] mentions that controlling the environmental problems with technical solutions is considered to be the strong engineering tradition in water resource management. The management of risks relied on the ability to predict extremes and limit their impact with technical means such as dikes, dams and reservoirs [36]. Grey water (GW) is the water collected separately from sewage flow that originates from clothe washers, bathtubs, showers and sinks but does not include wastewater from kitchen sinks, dishwashers or toilets. Dish, shower, sink and laundry water comprise 40–50% of residential wastewater. GW is used in groundwater recharge, landscaping and plant growth [37].

Reducing building water consumption and rethinking the wastewater strategy employed for the built environment can dramatically extend the available supply of water, improve human health and reduce threats to ecological systems. In addition to these benefits, the Rocky Mountain Institute (RMI) suggests that water efficiency can have these other tangible and calculable benefits [38]:

- Energy savings
- Reduced wastewater production
- Lower facility service investments
- Industrial processes
- Higher worker productivity
- Reduced financial risk
- Environmental benefits
- Public relations value

The water management field aimed at reducing drinking water consumption, reusing grey water for irrigation or flushing toilets, preserving site watersheds and groundwater aquifers and reducing off-site treatment of wastewater. It is known that two of the more significant problems of the modern society are the water shortage and the degradation of the environment [39]. The increasing demand for sustainable development has a serious impact on urban infrastructures. Even today, there is a lack of knowledge of how sustainable development should be achieved. Next we often do not know how sustainability of various technical systems should be assessed. So a set of sustainability criteria covering health and hygiene, social and cultural aspects, environmental aspects, economy and technical considerations are defined. To promote the practical use of a set of sustainability criteria, it must be related to quantifiable indicators that are easily measured [40].

Water management in Slovak system BEAS has a percentage weight of 8.88%. Water management field includes four indicators: reduction and regulation of water flow in water systems with the weight of 42.3%, surface water run-off with the weight of 12.2%, drinking water supply with the weight of 22.7% and an indicator that addresses using filtration of grey water with the weight of 22.7%.

The indicators related to the field of water management and method for determining the significance weight of this field in BEAS are presented. In water management field of significant environmental assessment systems, the percentage weights vary from 2 to 27.7%. The lowest significant weight of 2% is in Japanese system CASBEE. Significant weights of 6%, 6.67%, 7%, 8.5% and the highest of 27.7% are in BREEAM (UK method), NABERS (Australian system), LEED (US system), Green Globes (Canadian system) and SABA (Jordan system), respectively. All those weights of significance reflect national specificities.

5 Family House Assessment from Water Management

Five family houses were chosen for their evaluation from water management point of view. Family houses are located in the northwest part of the town of Kosice in the Slovak Republic. According to urban zoning plan of Kosice, the built-up areas are localities intended to low-rise residential areas. The location of the houses is not in the floodplain town of Kosice [41]. According to environmental regionalization of Slovakia, the territory where family houses are situated is soft disturbed environment [42].

Family house 1 is situated in a slightly sloping terrain. Family house 2 is located in an area which was initially used for gardening purposes, near the forest in a slightly sloping terrain. Family house 3 is located in a slightly sloping terrain in a dense built-up area with cramped conditions for further construction, and family houses 4 and 5 are located in a sloping terrain in the slightly built-up area.

Table 1 Way of the assessment of water management

E	Water management	8.88%	
E1	Reduction and regulation of water flow in water systems	42.3%	
Purpose	To reduce water consumption using equipment for reduction and regulation water flow in plumbing fixtures and WC stop in the toilet	Point	Weight
Indicator	Consumption of potable water		2.115
Negative practice	According to drawing documentation, there are no facilities designed to reduce and control the flow of water fittings and toilet flushing		−1
Acceptable practice	According to drawing documentation, there are facilities designed to reduce and control the flow of water fittings		0
Good practice	According to drawing documentation, there are facilities designed to reduce and control the flow of water fittings and toilet flushing		3
Good practice Best practice	According to drawing documentation, there are high-quality facilities designed to reduce and control the flow of water fittings and toilet flushing		5
E2	Surface water run-off	12.2%	
Purpose	To ensure that surface water is managed within site boundaries and is reinjected into the aquifer	Point	Weight
Indicator	The quality of a surface water management plan		0.61
Negative practice	A general plan has not been developed for the management of surface water		1
Acceptable practice	A general plan has been developed for the main agreement of surface water and its percolation into the ground within site boundaries, including at least 80% of natural surface water courses, paved and landscaped areas		0
Good practice	A detailed plan has been developed for the management of surface water and its percolation into the ground within site boundaries, including at least 90% of natural surface water courses, paved and landscaped areas		3
Best practice	A detailed plan has been developed for the management of surface water and its percolation into the ground within site boundaries, covering 100% of areas		5
E3	Drinking water supply	22.7%	
Purpose	To ensure the quality of drinking water in buildings which are not supplied by water with water supply	Point	Weight
		5	1.135
Indicator	The quality of drinking water		
Negative practice	The building is supplied with not enough drinking water		−1
Acceptable practice	The building is supplied with enough drinking water		0
Good practice	The building is supplied with enough drinking water of good quality		3
Best practice	The building is supplied with enough drinking water of high quality		5
E4	Using filtration of grey water	22.7%	
Purpose	To ensure using “grey water” for flushing of the toilet	Point	Weight
			1.135

(continued)

Table 1 (continued)

E	Water management	8.88%
Indicator	Design of "grey water" system in drawing documentation	
Negative practice	According to drawing documentation, the building has not designed a "grey water" system	−1
Acceptable practice	According to drawing documentation, the building has designed a "grey water" system for irrigation	0
Good practice	According to drawing documentation, the building has designed a "grey water" system for irrigation and flushing of the toilet	3
Best practice	According to drawing documentation, the building has designed a "grey water" system for irrigation and flushing of the toilet, and the building has separate metering of water consumption	5

Table 2 Characteristics of the groundwater aquifers in the Nile Delta and its fringes [12]

Photo	Subfield: score – evaluation
	**E1: 0** – Equipment designed to reduce and control the water flow in the armature **E2: −1** – Surface water is not stored and used for irrigation **E3: 5** – Sufficient amount of fresh water with high quality **E4: −1** – Split potable and grey water systems are not used
	**E1: 0 –** Equipment designed to reduce and control the water flow in the armature **E2: 5** – Collected in storage tank and is used for irrigation **E3: 3** – Sufficient amount of fresh water with high quality **E4: −1** – Split potable and grey water systems are not used
	**E1: 3 –** Equipment designed to reduce and control the water flow in the armature and flush toilet **E2: 5** – Water of surface run-off is collected in vegetation roof **E3: 5** – Sufficient amount of fresh water with high quality **E4: −1** – Split potable and grey water systems are not used
	**E1: 3 –** Equipment designed to reduce and control the water flow in the armature and flush toilet **E2: 5** – Water of surface run-off is collected in storage tank and is used for irrigation **E3: 5** – Sufficient amount of fresh water with high quality **E4: −1** – Split potable and grey water systems are not used
	**E1: 3 –** Equipment designed to reduce and control the water flow in the armature and flush toilet **E2: 5** – Water of surface run-off is collected in vegetation roof **E3: 5** – Sufficient amount of fresh water with high quality **E4: −1** – Split potable and grey water systems are not used

The highest score of 5 was assigned to the indicator drinking water supply for all family houses and water management of surface run-off for four family houses. All buildings are supplied with sufficient amount of fresh water with high quality. Only family house 1 did not collect the water from surface run-off in the storage tank and used for irrigation. Score 3 was assigned to the indicator reduction and regulation of water flow in water systems for family houses 3, 4 and 5. Family houses have designed equipment to reduce and control the water flow in the armature and flush toilet. Score 0 was assigned to the indicators reduction and regulation of water flow in water systems for family houses 1 and 2. Score -1 was assigned for the indicator system of grey water for all family houses. Buildings do not use split potable and grey water system.

Based on the evaluation, it can be said that family house 1 obtained a rating of 1.0, family house 2 obtained 1.906 points, and the best rating of 3.106 was assigned to family houses 3, 4 and 5.

6 Conclusion and Recommendations

The integrated assessment of buildings is critical in achieving sustainable development. The aim of sustainability assessment of buildings is to provide a sustainable building design, construction, operation, maintenance and renovation. Sustainable buildings involve taking the entire life cycle of buildings, environmental quality, technical and functional quality, social and cultural factors, economic factors as well as future values all into account.

The developed building environmental assessment system applicable in Slovak conditions consists of 6 primary fields and 52 relevant indicators. The basis of assessment development consists of systems and methods used in many countries. The main fields are building site and project planning, building constructions, indoor environment, energy performance, water management and waste management.

Main features of the system include the following:

- BEAS as the multi-criteria system includes environmental, social and cultural aspects.
- Indicators respect European and Slovak standards, rules, studies and experiments.
- This system allows to establish indicator weights that reflect their varying importance in the region.
- Designers can specify targets of building performance in terms of various aspects.
- Assessors can accept the assessment made by designers.

The theoretical level of the present knowledge of building environmental assessment is wholly analysed and applied making it necessary to implement this knowledge in construction practice. For the purpose of system verification, a statistically significant set of buildings needs to be evaluated, the outcome of which will be a modification of the fields and indicators weighting.

Future research work will be aimed at evaluation of a statistically significant set of buildings in the field of water management. According to the results, it will be necessary to perform the modification of indicators and their significant weight.

References

1. Kibert CJ (2013) Sustainable construction, green building design and delivery.3rd edn. Wiley, Hoboken
2. Castanheira G, Bragança L (2014) The evolution of the sustainability assessment tool SBToolPT: from buildings to the built environment. Sci World J 2014:1–10. https://doi.org/10.1155/2014/491791
3. Bob C, Dencsak T, Bob L (2010) Sustainability of buildings. In: 4th WSEAS international conference on advances in energy planning, environmental education and renewable energy sources, Kantaoui, Sousse, 3–6 May 2010
4. Berardi U (2012) Sustainability assessment in the construction sector: rating systems and rated buildings. Sustain Dev 20(6):411–424. https://doi.org/10.1002/sd.532
5. Zabalza IB, Aranda-Usón A, Scarpellini S (2009) Life cycle assessment in buildings: state-of-the-art and simplified LCA methodology as a complement for building certification. Build Environ 44(12):2510–2520. https://doi.org/10.1016/j.buildenv.2009.05.001
6. Citherlet S, Defaux T (2007) Energy and environmental comparison of three variants of a family house during its whole life span. Build Environ 42(2):591–598. https://doi.org/10.1016/j.buildenv.2005.09.025
7. Dahlstrøm O, Sørnes K, Eriksen ST, Hertwich EG (2012) Life cycle assessment of a single-family residence built to either conventional or passive house standard. Energ Buildings 54:470–479. https://doi.org/10.1016/j.enbuild.2012.07.029
8. Banani R, Vahdati M, Elmualim A (2013) Demonstrating the importance of criteria and sub-criteria in building assessment methods. WIT Trans Ecol Environ 173:443–454. https://doi.org/10.2495/SDP130371
9. Sustainable by the WBDG Sustainable Committee. http://www.wbdg.org/design/sustainable.php. Cited 3 Sept 2017
10. Vierra S (2011) Green building standards and certification systems. [online]. Whole Building Design Guide. http://www.wbdg.org/resources/gbs.php. Cited 3 Sept 2017
11. Berardi U (2012) Sustainability assessment in the construction sector: rating system and rated buildings. Sust Dev 20:411–424. https://doi.org/10.1002/sd.532
12. ISO 15392:2008 sustainability in buildings – general principles
13. Mateus R, Braganca L (2011) Sustainability assessment and rating of buildings: developing the methodology SBTool$^{PT–H}$. Build Environ 46(10):1962–1971
14. Ding GKC (2008) Sustainable construction – the role of environmental assessment tools. J Environ Manag 86(3):451–464
15. Užšilaityte L, Martinaitis V (2010) Search for optimal solution of public building renovation in terms of life cycle. J Environ Eng Landsc Manage 18(2):102–110
16. Moldovan MC, Visa I, Neagoe M, Burduhos BG (2014) Solar heating and cooling energy mixes to transport low energy buildings in nearly zero energy buildings. Energy Procedia 48:924–937
17. Bonakdar F, Dodoo A, Gustavsson L (2014) Cost-optimum analysis of building fabric renovation in a Swedish multi-story residential building. Energ Buildings 84:662–673. https://doi.org/10.1016/j.enbuild.2014.09.003
18. Burman E, Mumovic D, Kimpian J (2014) Toward measurement and verification of energy performance under the framework of the European directive for energy performance of buildings. Energy 77:153–163. https://doi.org/10.1016/j.energy.2014.05.102
19. Dixit MK, Culp CH, Fernández-Solís JL (2013) System boundary for embodied energy in buildings: a conceptual model for definition. Renew Sust Energ Rev 21:153–164. https://doi.org/10.1016/j.rser.2012.12.037
20. Dodoo A, Gustavsoson L, Sathre R (2011) Building energy-efficiency standard in a life cycle primary energy perspective. Energ Buildings 43:1589–1597. https://doi.org/10.1016/j.enbuild.2011.03.002

21. European Commission (2008) Energy efficiency: delivering the 20% target. European Commission, Brussels
22. Iddon CR, Firth SK (2013) Embodied and operational energy for new-build housing: a case study of construction method in the UK. Energ Buildings 67:479–488. https://doi.org/10.1016/j.enbuild.2013.08.041
23. Cole RJ (1998) Emerging trends in building environmental assessment methods. Build Res Inf 26(1):3–16. https://doi.org/10.1080/096132198370065
24. Dimitris A, Giama E, Papadopoulos A (2009) An assessment tool for the energy, economic and environmental evaluation of thermal insulation solutions. Energ Buildings 41:1165–1171. https://doi.org/10.1016/j.enbuild.2009.06.003
25. Korolijaa I, Marjanovic-Halburdb L, Zhanga Y, Hanbya I (2011) Influence of building parameters and HVAC systems coupling on building energy performance. Energ Buildings 43: 1247–1253
26. Neto AH, Fiorelli FAS (2008) Comparison between detailed model simulation and artificial neural network for forecasting building energy consumption. Energ Buildings 40(12): 2169–2176. https://doi.org/10.1016/j.enbuild.2008.06.013
27. Mwasha A, Williams RG, Iwaro J (2011) Modeling the performance of residential building envelope: the role of sustainable energy performance indicators. Energ Buildings 43(9): 2108–2117. https://doi.org/10.1016/j.enbuild.2011.04.013
28. Kridlova Burdova E, Vilcekova S (2012) Energy performance indicators developing. Energy Procedia 14:1175–1180. https://doi.org/10.1016/j.egypro.2011.12.1072
29. Seo S, Tucker S, Ambrose M, Mitchel P, Wang CH (2006) Technical evaluation of environmental assessment rating tool. Research and Development Corporation, Project No. PN05 1019(6)
30. Whole Building Design Guide (WBDG). [online]. http://www.wbdg.org/. Cited 3 Sept 2017
31. World Green Building Council (WGBC). [online]. http://www.worldgbc.org/. Cited 3 Sept 2017
32. Alyami SH, Rezgui Y (2012) Sustainable building assessment tool development approach. Sustain Cities Soc 5:52–62. https://doi.org/10.1016/j.scs.2012.05.004
33. Raslanas S, Stasiukynas A, Jurgelaitytė E (2013) Sustainability assessment studies of recreational buildings. Procedia Eng 57:929–937. https://doi.org/10.1016/j.proeng.2013.04.118
34. Trusty WB, Horst SW (2002) Integrating LCA tools in green building rating systems. The Austin papers: best of the 2002 international green building conference. Building Green, Inc., Brattleboro
35. Zacharias I, Dimitriou E, Koussouris T (2003) Developing sustainable water management scenarios by using thorough hydrologic analysis and environmental criteria. J Environ Manag 69:401–412. https://doi.org/10.1016/j.jenvman.2003.09.017
36. Pahl-Wostl C, Tabara D, Bouwen R, Craps M, Dewulf A, Mosters E, Ridder D, Taillieu T (2008) The importance of social learning and culture for sustainable water management. Ecol Econ 64:484–495. https://doi.org/10.1016/j.ecolecon.2007.08.007
37. Al-Jayyousi OR (2003) Greywater reuse: towards sustainable water management. Desalination 156:181–192. https://doi.org/10.1016/S0011-9164(03)00340-0
38. Kibert CJ (2003) Sustainable construction: green building design and delivery.3rd edn. Wiley, Hoboken, p 521
39. Mariolakos I (2007) Water resources management in the framework of sustainable development. Desalination 213:147–151. https://doi.org/10.1016/j.desal.2006.05.062
40. Hellstroma D, Jeppssonb U, Karrmanc E (2000) A framework for systems analysis of sustainable urban water management. Environ Impact Assess 20:311–321. https://doi.org/10.1016/S0195-9255(00)00043-3
41. Urban zoning plan city of Kosice. http://www.kosice.sk/static/up_2013_V-3.htm
42. Environmental regionalization of Slovakia. http://www.enviroportal.sk/uploads/spravy/2013-03-regionalizacia.pdf

Update, Conclusions and Recommendations for Water Resources in Slovakia: Climate Change, Drought and Floods

Martina Zeleňáková and Abdelazim M. Negm

Contents

Abstract This chapter highlights the update of the topic, main conclusions and recommendations of the chapters presented in the book. Therefore, this chapter contains information on water resources in Slovakia in the period of climate change. It focuses on hydrological extremes and Slovakia – droughts and floods – risk assessment and protection; it is devoted to sustain their management. Also, it covers the main issues of the indoor environment – water management in the buildings (construction) level. Also, a set of recommendations for future research is pointed out to direct the future research towards sustainability of water resource management which is one of the strategic themes of the Slovak Republic.

Keywords Climate change, Droughts, Floods, Indoor environment, Management, Protection, Risk assessment, Slovakia, Sustainability, Water resources

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

A. M. Negm (✉)
Water and Water Structures Engineering Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt
e-mail: Amnegm@zu.edu.eg; Amnegm85@yahoo.com

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 325–338,
DOI 10.1007/698_2018_327,
Published online: 20 June 2018

1 Introduction

Sustainable development of water management is based on the principle that water as a natural resource may be utilized only to that extent which ensures future generations sufficient usable supplies of water in the seas, rivers, lakes and reservoirs and that reserves contained in porous environments below the surface of the land remain preserved in the same quantity and quality. It is evident that surface waters are more vulnerable than groundwater in terms not only of their hygienic quality and safety but also of their protection as a natural ecosystem and maintenance of their amounts. For this reason, it is necessary to devote all the more attention to the protection of water sources. The first step towards effective protection of water resources is to know their size and distribution and manage the extreme events in the period of climate variability.

The chapter presents a summary of the essential findings and conclusions of the studies on the climate change, droughts and floods and their management for better use in the indoor and outdoor environments. Also, a set of recommendations extracted from all contributions are presented to help researchers and decision makers to go forward towards sustainable use of water resources in Slovakia.

2 Update

In the following the national studies regarding the water resources in Slovakia concerned with climate change and extreme hydrological phenomena – droughts and floods – are presented. Also, some studies regarding the water management in buildings are mentioned. The brief results of the studies are introduced.

The 20-year extraordinary warm period from 1988 to 2007 in Slovakia and also the reliability of climate change scenarios issued in 1991–2000 were evaluated by Faško et al. [1]. In Slovakia, as in many other European countries, the freshwater-related risk and specifically the floods and droughts are expected to become more frequent, intense and prolonged due to climate change [2, 3]. Most of the studies about the issue in Slovakia are focused on specific regions or aspects rather than aiming at a comprehensive characterization of the phenomenon for the whole country, based on extensive hydrological ground data [4–10] and others relating droughts [11–28] and others relating to floods. “The analysis of time series of daily precipitation and runoff at selected places in the highest part of the Western Carpathian was done by Bičárová and Holko” [29]. It was focused on both wet and dry periods in precipitation and runoff data series. They revealed a significant increase in the number of days with daily precipitation 40–60 mm. The occurrence of dry and wet periods in altitudinal vegetation stages of West Carpathians in Slovakia: Time-Series Analysis 1951–2005 was studied by Škvarenina et al. [30]. Drought variability and its characteristics across the Tatra National Park as an integral part of Tatra Mountains in the period 1961–2010 were studied by Vido et al. [10] by

Standard Precipitation Index (SPI). The results showed that frequency of drought occurrence has a cyclic pattern with an approximately 30-year period. The spatial analyses showed that precipitation shadow of the mountains influences the risk of drought occurrence. Portela et al. [31, 32] present a comprehensive characterization of the droughts for entire Slovakia by using the Standardized Precipitation Index, SPI, computed based on a monthly precipitation dataset over a time span of 33 years (from January 1981 to December 2013) at 491 rain gauges covering the entire country. Taking into account the relevance of agriculture in Slovakia, the time scale of 3 months, SPI3, was adopted to exemplify the results. Gregor [9] evaluated changes in the surface water and groundwater quality during periods of hydrological drought in the upper Nitra River catchment. The water quality within periods of water scarcity was also assessed in his work. Fendeková and Fendek [33] evaluated the drought on a yearly scale. The standardized base flow drought severity index was proposed for base flow drought characterization. It was documented that years with the extremely low base flow occur much often in the mountainous part of the Nitra River Basin than in the lowland part.

The occurrence of meteorological, surface water and groundwater droughts for the upper part of the Torysa river catchment and the influence of water abstraction were analysed by Fendekova et al. [34]. The most extended period of drought with the discharge below the minimum flow occurred during the multiyear drought 1986–1987. Habitat suitability curves were constructed for *Barbus carpathicus*, and minimum flow for life conditions for barbel was estimated. “The problem of minimum flow preservation should be solved in the upstream part of the catchment, where natural streamflows are strongly influenced by water abstraction”. Zeleňáková et al. [35] analysed trends of low flows at streams in eastern Slovakia, namely, Poprad, Hornád, Bodva and Bodrog river basins. The availability of using hypothesis test techniques to identify the long-term trends of hydrological time series was investigated in this study. Statistically significant trends have been determined from the trend lines for the whole territory of eastern Slovakia. The results indicate that the observed changes in Slovakian river basins do not have a clearly defined trend. A brief review on the availability of general circulation models (GCMs) and regional circulation models (RCMs) outputs for regional downscaling is presented in [36]. The additional one – a combined method, usually based on GCMs (mean annual/monthly warming and mean annual/monthly change in precipitation totals) and on historical analogue (statistical structure of daily/monthly data series, including physical plausibility among phenomena) – was utilized in Slovakia [37]. Some results of different climate change scenarios for Hurbanovo and possible user problems are discussed. Special scenarios of exceptional weather events are also demanded by users, mainly from the hydrology, agriculture and forestry sectors, and very concise overview of such scenario design is presented in [37].

The analysis of the long-term average monthly Danube discharges was done by Pekárová et al. [38]. “It revealed, that in the last 25 years the discharge rates increased in the winter half-year, while a decline was observed between June and August. From the long-term trend analysis, it follows, that the mean annual Danube discharge at Bratislava, in any case, did not rise in the 1876–2005 period” [38]. This study [38] was also devoted to the long-term prediction of monthly discharge of the Danube by applying stochastic methods. The applicability of medium-range quantitative precipitation forecasts was explored in a flood forecasting system for a medium-size mountainous basin – Hron river basin in [39]. Gaňová et al. [40] aimed to geographically assess the flood occurrence in eastern Slovakia by using one of the methods of multi-criteria analysis – rank sum method. Flood risk assessment is conducted in three specific cases: the long-term period 1989–2009, the extremely wet 2010 year, and the extremely dry 2011 year. Solín [41] assessed the flood vulnerability of basic urban units located in the headwater basins of Slovakia. The overall vulnerability of urban units was calculated via a summation of the specific vulnerability indices. Using visualization in GIS, the urban units were grouped into three classes, of low, medium and high vulnerability.

3 Conclusions

In the next sections, some of the conclusions and recommendations of the chapters[1] in this volume (no. 70) of the Handbook of Environmental Chemistry Series are presented. Surface water and groundwater resources of Slovakia are rich enough to ensure current and prospective water needs. Water plays a vital role in both the environment and human life. Assessment of the impact of climate variability on water resources is an essential activity because we consider water as a strategic raw material. The quantitative characteristics of renewable water resources of a region or river basin can be determined by two approaches: by using meteorological data or by using river runoff observations. The chapter titled "Climate Change Impacts on Water Resources" evaluates climatic and hydrological variables in selected river basins in eastern Slovakia. The comparison of the time series of observed variables over a period of about 60 years is included. The results of the work are the plots of observed variables, which have been evaluated. We have also been working on the using of water in selected Slovak river basins, namely, by water abstraction and water discharge. The impact of climate variability on water resources in eastern Slovakia is minimal.

In the chapter "Climate Changes in Slovakia: Analysis of Past and Present Observations and Scenarios of Future Developments", the scenarios of climate change were calculated up to the time horizon of the year 2100 based on the modified model outputs and the measured data from meteorological stations for the period 1951–2016. The alternative IPCC emission scenarios, the SRES A2, A1B and B1, were applied. Scenarios for the variables the daily means, the maxima and minima of the air temperature, the daily means of the relative air humidity, the daily precipitation totals, the daily means of wind speed, the daily totals of the global radiation

[1]The word "chapter" followed by titled and a title of a chapter implies that the chapter in contained in this volume.

and also the water balance elements and the snow cover characteristics have been prepared. On the basis of the statistics obtained from the measured and modelled data, the modelled in the future were adjusted in such a way as to best capture the predicted climatic characteristics of the region. The results show that an increase in the 30-year averages by about 2–4°C up to the end of the twenty-first century. Precipitation totals will also change in a relatively wide range, but generally, an increase of about 10% in annual totals is expected, more in the north and less in the south part of Slovakia. These scenarios can be successfully used to prepare studies on the impacts of and the vulnerability to climate change in different economic sectors.

Slovakia is located in Central Europe, and its complex surface consists of mountains, valleys, but also lowlands, which are crucial for agricultural production. In the neighbouring countries, especially in Hungary and Czech Republic, there has been paid great attention to drought occurrence for a longer time. In Slovakia, hydrological drought assessment was more often under investigation than the meteorological aspect of the drought in the past. The regionally developed methods were primarily used for its estimation, while the internationally established indicators were rarely applied. In the last years, the drought became to be discussed more frequently in the Slovak climatology, which led to the start of operational drought monitoring in Slovakia in 2015. Drought periods, which occurred in the last years and caused also yield losses in agriculture, raised the interest of public and experts from different economic sectors in this phenomenon. The intersectoral approach seems to be the crucial way of further drought research. The chapter "Meteorological Drought Occurrence in Slovakia" aims to present two case studies, which could be the example of the linkage between climatological and hydrological approach in drought assessment on an operational level. The first case study describes the operational meteorological drought monitoring, which has run since 2015. The slightly modified methodology of widely known indices (SPI and SPEI) shows promising results, which can be obtained on a daily basis. It enables them to be used in intersectoral drought analysis. The example of such analyses is presented in the second case study, in which the linkage between meteorological and hydrological drought was examined. The knowledge about the causalities between these two drought types brings higher assumption for the successful design of effective integrated drought monitoring. The chapter "Hydrological Drought Occurrence in Slovakia" presents the problem of drought and describes its classification and methods of assessing this risk. This chapter aims to identify statistically significant trends in streamflow characteristics of low water content in Eastern Slovakia, which are used in the evaluation of hydrological drought. In this chapter is presented a new methodology for evaluating hydrological drought based on statistical analysis of observed minimal flows at selected 63 gauging stations in Eastern Slovakia for a 32-year period. Mann-Kendall statistical test identifies the frequency of minimal flow trends, in individual gauging stations, in river basins – Poprad, Hornád, Bodva and Bodrog – throughout eastern Slovakia, and also in groups of gauging stations with the same physico-geographical parameters. Size of the flow trends is identified by directives of the trend lines. The procedure is also applied in assessing the impact of human activities and the impact of physico-geographical factors for the emergence of hydrological drought. Obtained results from the statistically significant trends in the flows are established a prediction of hydrological drought risk in each month of the hydrological year in eastern Slovakia. Groundwater regime and drought occurrence studies are significant for Slovakia, where groundwater is preferentially used for drinking water supply. It was shown by several studies that the groundwater drought occurs in Slovakia more often since the 1980s, causing problems in various sectors of the Slovak economy. Groundwater drought can be described either through groundwater heads, base flow and groundwater storage or by the spring yield change. As the main reasons for groundwater drought occurrence, the natural factors and human activities can be mentioned. The amount of groundwater stored in the rock environment primarily depends on the water availability in the area and on the storage capacity of the rock environment itself. The lack of precipitation, high air temperature and the unfavourable storage properties of the rock environment belong to the main natural factors conditioning the groundwater drought occurrence. The groundwater over-abstraction also could increase the sensitivity of the local hydrological system to drought development. The groundwater drought studies for the Slovak territory were first published in the 1990s as a result of drought which hit the territory in the period of 1982–1984. After that several important scientific works were performed to analyse factors of drought development, occurrence and impacts on nature and social sphere. Base flow drought, groundwater head drought and spring yield decrease were studied as presented in the chapter titled “Groundwater Drought Occurrence in Slovakia”.

Drought by itself cannot be considered a disaster. However, if its impacts on local people, economies and the environment are severe and their ability to cope with and recover from it is difficult, it should be considered as a disaster. Droughts and floods are a recognizable category of natural risk. Hydrological assessments of drought impacts require detailed characteristics. In the chapter “Drought as Stress for Plants, Irrigation and Climatic Changes” is proposed a new conceptual framework for drought identification in landscape with agricultural use. Hydrological drought characteristics are described with impacts at the agricultural landscape as well as food security and the issues related to drought water management. In the past, the Slovak Republic was not considered a country immediately threatened with drought. The situation had changed at the turn of the millennium, especially after the extreme weather conditions in 2014 and also in 2015, when, for example, the historical minima were recorded. It is supposed that because of the climate change, the extreme hydrological events are going to be more pronounced and more frequent in the future also on the territory of Slovakia. The occurrence, duration and severity of hydrological droughts in Slovakia were studied during 3 years of the twenty-first century – 2003, 2012 and 2015 in the chapter “Major Droughts in Slovakia in the 21st Century”. Mainly 2003 and 2015 belong to the warmest years of the twenty-first century with the occurrence of hydrological drought on the Pan-European scale. Data on average daily discharges at 12 discharge gauging stations across Slovakia were used for evaluation. The data covered the period 1981–2016. Hydrological drought in discharges was evaluated using the sequent peak algorithm method

(SPA); the fixed threshold value of the 80th percentile was applied. The threshold value was estimated for the reference period of 1981–2010. The theoretical Weibull and GEV frequency distributions were used for drought characteristic calculation, their evaluation and comparison of the 2003, 2012 and 2015 droughts. Data calculated for the evaluated years were compared with the reference period of 1981–2010. Spatial distribution of hydrological drought occurrence was discussed in connection to meteorological drought occurrence analysis.

Slovakia is a mountainous country, and the occurrence of floods in headwater areas is thus a remarkable phenomenon. The chapter "Flood Hazard in Mountainous Region of Slovakia" concerns the identification of regional types of flood hazards in a mountainous region resulting from the physical geographic characteristics of the upper basins. The regional type is the unit of regional taxonomy, which is not contiguous in geographical space and is referred to as the flood hazard potential or disposition of the basins to floods. A brief overview of flood events in Slovakia is provided. Then, the rest of the chapter presents the assessment of the flood hazard itself. The evaluation process consists of four steps. The first step of the regional taxonomic process is the creation of a basic set of upper basins and a database of their physico-geographic attributes. The second step is the identification of the physical geographic attributes that significantly influence the essential features of the drainage process and the spatial variability of the flood hazard. The delineation of flood hazard classes based on a combination of physical basin attributes and classification of upper basins into flood hazard classes is the third one. Testing the significance of differences between the assigned flood hazard classes in terms of the frequency of flood situations is the last and fourth step. The aim of the chapter "Flood Risk of Municipalities in Upstream Basins of Slovakia" is to present a comprehensive, integrated flood risk assessment for municipalities located in the upper basins. An integrated approach perceives the flood risk as the combination of flood hazard and vulnerability. The flood hazard is expressed as the potential of the basin to the floods due to basin attributes. The vulnerability is understood as inherent characteristics of municipalities that create the potential of municipalities for the susceptibility of houses to damage and of people to suffer physical and mental harm and the ability of people to cope with negative consequences of floods. A spatial multi-criteria decision analysis was applied to express the flood risk relatively on an ordinal scale. Municipalities were classified into the five classes of flood risk by an aggregation of subindices reflecting flood hazard and vulnerability. An integrated approach addresses the assessment and management of the flood risk more complexly and eliminates the adverse effects of more traditional engineering approaches.

The Slovak Republic with an area of 49,035.81 km^2 is in most of its territory a mountain landscape and has watercourses with a total length of 61,147 km. From this length, approximately 24,000 km (39.25%) have the character of torrents. The chapter titled "Mountain Watersheds, Torrents and Torrent Control in Slovakia" deals with the issues of mountain watersheds, torrent control and torrents which are in Slovakia in the length of 19,408 km managed by forestry organizations. The chapter provides basic information about Slovakia's mountain watersheds and torrents and about the methods to the determination of watercourse type (river, brook and torrent) through technical standards or calculation. Also, the chapter includes the history of torrent control and torrent flash floods in mountain watersheds of Slovakia. Also, it deals with lessons from the history of flash floods. In this chapter is analysed discharge capacity of natural torrent beds in various geomorphologic units of Slovakia. A part of this chapter deals with forests in mountain watersheds and their impact on runoff formation and water balance of individual forest altitudinal vegetation zones of Slovakia. In a separate part, an example of water balance in mountain watersheds of the highest mountain of Slovakia (the High Tatras) is explained. Finally, it presents the calculation procedure to the determination of T-yearly discharges in forestry practice in Slovakia. The chapter "Hydrological and Hydraulic Aspects of the Revitalization of Wetlands: A Case Study in Slovakia" was developed based on the results of a research project within the frame of the INTERREG initiative between the Hungarian and Slovak Republics. It was concentrated on the Medzibodrožie region located in the south-eastern part of the Slovak Republic. This project, initiated by water board companies in Hungary and Slovakia, was focused on a creation of a possibility for the design of technical measures for the revitalization of the rivers in the area of interest, which dried out. The first step consisted of an analysis of the recent hydrological state of the surface water, groundwater and soil water in the area of interest and finding of a water source for the revitalization of the old river bed and branches. The next phase concentrated on modelling the hydrological and hydraulic processes of the surface (using HEC-RAS and MIKE-11) and subsurface flows (using TRIWACO software for groundwater modelling). At the end of the project solution, two technical alternatives were proposed. The recommended variant considers the construction of a bag weir in the Latorica River, which enables the revitalization of the Tice River and its dead branches and the creation of conditions for a better quality of life of the inhabitants in the villages affected.

New reports of water scarcity and record droughts due to climate changes are becoming increasingly common as reported in the chapter "Water Demand Management and Its Impact on Water Resources at the Building Level". The costs of water infrastructure have risen dramatically. Discussing the water used in a good or bad (waste) way led us to think if we are using water in a sustainable way. A common characteristic of water demand in buildings means its relentless rise over many years and conception of continuous growth over coming decades. The main influencing factors of water demand patterns are population growth, lifestyle change depending on the region, demographic structure and the possible effects of upcoming changes in climate and other health risk factors. In the European Union, it is common to use well and rainwater source for no potable purposes (as irrigation, toilet flushing, etc.). Grey water reuse is in Slovakia still rare. Common household usage consumes much water. There is a need to manage its end use as sustainable as our conditions allow us. Potable water consumption of the Slovak households is not above average at all, but its use is inappropriate. Questionnaire on water, as one of data collection methods, gives a closer look at water habits of households. The results show that most of Slovakia citizens are pro water saving oriented and open to new water ideas – as in the building water cycle. The primary goal of this chapter is to present the background for the water use, regulations and legislative framework in the context of a water conservation strategy and discuss water types in building water cycle connected to a water-energy nexus on the broader environment. There is a gap for water regulation and water supply of grey- and rainwater systems. This chapter pointed out the challenges and recommendations to strengthen and enhance future of alternative water sources based on the scientific findings, policy, economic and social impacts.

A significant number of building sustainability assessment methods and tools have been developed over the past two decades. Sustainability assessment of buildings means an evaluation of environmental, social and economic aspects and indicators respecting technical and functional characteristics of buildings to design and construction of sustainable buildings. There are many tools for sustainability assessment of buildings used over the world such as LEED, BREEAM, Green Globes, SBTool, CASBEE, etc. This chapter is aimed at introducing the building environmental assessment system (BEAS) which has been developed at the Technical University of Košice. The Slovak system was developed on the base of existing systems and methods used in many countries. The BEAS includes a number of environmental, social and cultural factors. The indicators were proposed according to the analysis of building performance as well as on the base of experimental experiences. The primary fields are building site and project planning, building construction, indoor environment, energy performance, water management and waste management. Water management in buildings is presented here as a critical issue for achieving the sustainable buildings. Indicators of water management are reduction and regulation of water flow in water systems with the weight of 42.3%, surface water runoff with the weight of 12.2%, drinking water supply with the weight of 22.7% and using filtration of grey water with the weight of 22.7%. More details could be found in the chapter titled “Sustainable Water Management in Buildings”.

To attain sustainability of water resources involves taking economic, environmental and socially feasible measures without detrimental consequences for the time to come. Providing adequate water supply and sanitation is a challenging task in the world. The country is facing the need to ensure water quality by using technical systems, and thus one of the requirements of life for today’s civilization is becoming water saving, treatment, and its management. Lots of aspects may contribute to the solution on how to collect, produce and finally use alternative water sources. Massive use of reused water for non-potable purposes in buildings promotes the conservation of natural water resources. While respecting the necessary parameters of alternative water sources, it is required for the end user or building manager to ensure the prescribed quality of water depending on the purpose. The chapter “Decision Analysis Tool for Appropriate Water Source at the Building Level” presents a decision analysis tool on alternative water use at the building level. Water management strategies and presented 11 portfolios should provide general guidance on the issues and information to support decisions on alternative water use and make it more attractive to the public. The evaluation of the two main criteria as economic and environmental could be used to change the water habits or help the investor to make the right decision for the best water management portfolio. Presented costs and benefits of the portfolios are scored and compared to screening criteria calculated by analytical hierarchy process. The decision analysis tool could fill the information gap on sustainable water strategies in Slovakia by a better understanding of the building water cycle and help to change the thinking of the society to be in the balance with nature.

Today we are facing the need to ensure water quality, so the primary requirement of today's civilization is to assess the water quality and perform the necessary treatment, adapt, transport and heat it. The water pipes as a significant part of the entire water distribution system have undergone considerable technical and technological development. Today we know that the various piping materials that have been used to transport water throughout historical development had an enormous impact on water quality. Drinking water must not cause any health problems to users. Microbiological contamination of drinking water and the health risk caused by pathogens that colonize the technical systems, however, occasionally cause serious problems. These include, for example, some cases of epidemic outbreaks of deaths that have occurred in the past 10 years in various parts of the world (e.g. cholera, typhus). Legionnaires' disease *Legionellosis* also belongs to such newer diseases. The first case of *Legionella* infection from water distribution system was recorded in a patient's kidney transplantation. Since then, *Legionella* has begun to be tracked in water systems in different types of buildings, including hotels, homes, factories and ships. This bacterium was found throughout the water system, from the water source to the outflow fittings. The goal of the chapter titled "Water Distribution System in Building and Its Microbiological Contamination Minimization" is to present hot water tank – a mathematical model which simulates temperature profile of hot water tank and works on obtained approximated function. Temperature and water stagnation are one of the factors that caused microbiological contamination of water, and by knowing the temperature profile, we can reduce the possible risks. While respecting the basic parameters of hot water, it is required for a water supplier and operator of a building to ensure the prescribed quality and water temperature at each sampling site and avoid the *Legionella* growth.

Human generally during his operating in the landscape and at the same time in the river basin affects not only on its state and appearance. Our activity in the landscape has a significant influence mainly on the hydrologic processes, e.g. evapotranspiration, interception, soil moisture and groundwater recharge. Essential activities influence also the precipitation distribution on the surface water and groundwater discharge. Therefore it is necessary, during the landscape influence exploitation evaluation on the hydrologic regime of the territory, to compare the actual balance with the long-term balances and to look for changes in the landscape, those could they caused. In the small river basins with different landscape exploitation (agriculture, forest, high mountain, urbanized) are changes and landscape exploitation better analysed, but also for the balances in the range of essential river basins, it is necessary, during the analyses of the hydrologic regime changes, to begin from the most elementary elements. Only an integrated approach to evaluation and water resource management is possible for the water sustainability in the landscape.

4 Recommendations

Assessing the impact of climate variability on water resources has an impact on the practice of sustainable development. During the last 10 years, we have experienced several extreme hydrological but also climatic situations. Often we meet with so-called storm water floods which in the past were a rare phenomenon. In this work, we focused on water sources in eastern Slovakia.

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 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.

An approach is the assessment of data and information needs of potential users and their comparison with the services provided by information centres and prognosticating systems. This includes the strengthening of existing global databases and countries which provide data to such databases. For this reason, the use of geographic information systems and similar computer technologies is increased. One specific application of hydrological data is the installation and operation of hydrological prognosticating systems and associated activities, which are vitally necessary for the protection of lives and property against massive natural catastrophes.

The 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 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.

Recommended activities for water resource sustainable management in Slovakia include:

1. Identification of the need for data on water and analysis and presentation of such data in forms suitable for planning and managing the development of water resources. Also for other purposes, such as the study of the environmental impact of water management projects.
2. The collecting and distributing of datasets associated with water on the regional and worldwide levels and information and use, among others, with the managing of resources in international basins and in climate change studies.
3. The assessment of surface water and groundwater resources and the interactions of surface water and groundwater.
4. The assessment of risks of flooding from the runoff of rainwater and snow and storm water and the installation of hydrological prognosticating and warning systems for such risks.

5. The assessment of risks of drought and the installation of drought warning systems for the support of schemes for ameliorating the consequences of drought, distributing these values to all who request information and ensuring the incorporation of information on water resources into decision-making processes.
6. The creation and strengthening of research and development programmes which correspond to the needs of countries, so that the following are increased: the understanding of basic processes associated with the water cycle, including interactions between water, soil and the atmosphere. Supporting the assessment of water resources and activities of hydrological prediction.
7. Support for the development of new technologies for assessing water resources and hydrological prognostication, full use of the knowledge of local experts in this regard.
8. The transfer of appropriate technologies to users.
9. Strengthening the relevant international and regional programmes on the national and global levels.
10. Applying the sustainability principle to maintain the water resources for sustainable use.

References

1. Faško P, Lapin M, Pecho J (2008) 20-year extraordinary climatic period in Slovakia. Meteorol J 11:99–105
2. OECD Organisation for Economic Co-operation and Development (2013) Water and climate change adaptation: policies to navigate uncharted waters. OECD studies on water. OECD Publishing. https://doi.org/10.1787/9789264200449-36-en
3. Kovats RS, Valentini R, Bouwer LM, Georgopoulou E, Jacob D, Martin E, Rounsevell M, Soussana JF (2014) Europe. In: Barros VR, Field CB, Dokken DJ, Mastrandrea MD, Mach KJ, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds) Climate change 2014: impacts, adaptation, and vulnerability. Part B: Regional aspects. Contribution of Working Group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 1267–1326
4. Machlica A, Stojkovova M, Fendekova M (2008) Assessment of hydrological drought occurrence in Nitra River catchment (Slovakia) in the period 1976-2005. In: EGU General Assembly 2008, geophysical research abstracts, vol 10, EGU2008-A-09329. SRef-ID: 1607-7962/gra/EGU2008-A-09329
5. Oosterwijk J, van Loon AF, Machlica A, Horvát O, van Lanen HAJ, Fendeková M (2009) Hydrological drought characteristics of the Nedozery sub catchment, upper Nitra, Slovakia, based on HBY modelling. Technical report n. 20. WATCH – Water and Global Change
6. Šiška B, Takáč J (2009) Drought analysis of agricultural regions as influenced by climatic conditions in the Slovak Republic. Időjárás: Q J Hungarian Meteorol Serv 113(1–2):135–143
7. Faško P, Pecho J, Mikulová K, Nejedlik P (2009) Trends of selected characteristics of precipitation in the northern Carpathians in the light of water supply for agriculture. In: Eitzinger J, Kubu GH (eds) Impact of climate change and adaptation in agriculture. Extended abstracts of the international symposium, Vienne, Austria. BOKU-Met report 17, pp 106–109. ISSN 1994-4179 (print), ISSN 1994-4187 (online). http://www.boku.ac.at/met/report

8. Büngten U, Brázdil R, Frank D, Esper J (2010) Three centuries of Slovakian drought dynamics. Clim Dyn 35:315–329. https://doi.org/10.1007/s00382-009-0563-2
9. Gregor M (2012) Analysis of hydrological drought. In: Surface and groundwater quality changes in periods of water scarcity. Springer theses. Springer, Berlin, Heidelberg, pp 77–139. https://doi.org/10.1007/978-3-642-32244-0_5
10. Vido J, Tadesse T, Šustek Z, Kandrík R, Hanzelová M, Škvarenina J, Škvareninová J, Hayes M (2015) Drought occurrence in Central European mountainous region (Tatra National Park – Slovakia) within the period 1961–2010. Advances in meteorology. Hindawi Publishing, Cairo
11. Bačová-Mitková V, Kohnová S, Pekárová P (2004) Comparison of estimates of seasonal floods for the Danube in Bratislava. Acta Hydrol Slovaca 5:34–41
12. Hlavčová K, Kohnová S, Szolgay J (2004) Estimation of rainfall flood risk on the Torysa River. J Hydrol Hydromech 52:141–155
13. Kohnová S, Szolgay J, Hlavčová K, Parajka J (2004) Mapping of design maximum daily precipitation depths in the Hron River basin. In: Geophysical research abstracts, vol 6/2004: EGU 1st General Assembly 2004, Nice, Francúzsko, 25–30 Apr 2004
14. Pekárová P, Kohnová S, Matúšová E, Miklánek P, Szolgay J, Hlavčová K, Pauerová I (2006) On the determination of the 100-year specific peak flows in small catchments for flood risk mapping. Meteorol J 9:157–164
15. Szolgay J, Kohnová S, Blaškovičová L, Benko M (2007) Flood warning and forecasting system of the Slovak Republic. In: Geophysical research abstracts, vol 9/2007: abstracts of the contributions of the EGU General Assembly, Vienna, Austria, 15–20 Apr 2007
16. Solín Ľ (2008) Analysis of floods occurrence in Slovakia in the period 1996–2006. J Hydrol Hydromech 56:95–115
17. Zeleňáková M (2009) Preliminary flood risk assessment in the Hornád watershed. In: River basin management 5: 5th international conference on river basin management including all aspects of hydrology, ecology, environmental management, flood plains and wetlands, Ramla Bay Resort, Malta. Wessex Institute of Technology, Southampton, pp 15–24
18. Zeleňáková M (2011) Flood risk assessment and management in Slovakia. In: River basin management 6: 6th international conference on river basin management including all aspects of hydrology, ecology, environmental management, flood plains and wetlands, 25–27 May 2011, Riverside, California, USA. Wessex Institute of Technology, Southampton, pp 61–69
19. Solín Ľ, Feranec J, Nováček J (2011) Land cover changes in small catchments in Slovakia during 1990–2006 and their effects on frequency of flood events. Nat Hazards 56:195. https://doi.org/10.1007/s11069-010-9562-1
20. Blaškovičová L, Horvát O, Hlavčová K, Kohnová S (2011) Methodology for post-event analysis of flash floods – Svacenický Creek case study. Contrib Geophys Geodesy 41:235–250
21. Macurová Z, Výleta R, Hlavčová K, Szolgay J, Kohnová S (2012) An analysis of the impact of climate change on the Laborec River basin using two different hydrological models. Acta Hydrol Slovaca 13:242–253
22. Gaál L, Szolgay J, Kohnová S, Hlavčová K, Parajka J, Viglione A, Merz R, Bloschl G (2015) Dependence between flood peaks and volumes: a case study on climate and hydrological controls. Hydrol Sci J 60:968–984
23. Hlavčová K, Lapin M, Valent P, Szolgay J, Kohnová S, Rončák P (2015) Estimation of the impact of climate change-induced extreme precipitation events on floods. Contrib Geophys Geodesy 45:173–192
24. Blöschl G, Szolgay J, Parajka J, Kohnová S, Miklánek P (2016) Thematic issue on floods in the Danube basin – processes, patterns, predictions. J Hydrol Hydromech 64:301–303
25. Jeneiová K, Kohnová S, Hall J, Parajka J (2016) Variability of seasonal floods in the Upper Danube River basin. J Hydrol Hydromech 64:357–366
26. Zeleňáková M, Gaňová L, Purcz P, Satrapa L (2015) Methodology of flood risk assessment from flash floods based on hazard and vulnerability of the river basin. Nat Hazards 79:2055. https://doi.org/10.1007/s11069-015-1945-x

27. Gaňová L, Zeleňáková M, Purcz P, Diaconu DC, Orfánus T (2017) Identification of urban flood vulnerability in eastern Slovakia by mapping the potential natural sources of flooding – implications for territorial planning. Urbanism Arhitectura Constructii 8(4):366–377
28. Šoltész A, Červeňanská M, Baroková D (2016) History of flood protection structures in Slovakia. Ovidius Univ Ann Constanta Ser Civil Eng 18(18):9–16
29. Bičárová S, Holko L (2013) Changes of characteristics of daily precipitation and runoff in the High Tatra Mountains, Slovakia over the last fifty years. Contrib Geophys Geodesy 43(2):57–177
30. Škvarenina J, Tomlain J, Hrvol' J, Škvareninová J (2009) Occurrence of dry and wet periods in altitudinal vegetation stages of west Carpathians in Slovakia: time-series analysis. In: Střelcová K et al (eds) Bioclimatology and natural hazards. Springer, Dordrecht, pp 1951–2005
31. Portela MM, Zelenáková M, Santos JF, Purcz P, Silva AT, Hlavatá H (2015) Drought analysis in Slovakia: regionalization, frequency analysis and precipitation thresholds. In: 8th international conference on river basin management including all aspects of hydrology, ecology, environmental management, flood plains and wetlands, RBM15, Wessex Institute, New Forest
32. Portela MM, Zelenáková M, Santos JF, Purcz P, Silva AT, Hlavatá H (2017) Comprehensive characterization of droughts in Slovakia. Int J Environ Sci Dev 8(1):25–29
33. Fendeková M, Fendek M (2012) Groundwater drought in the Nitra River Basin – identification and classification. Hydrol Hydromech 60(3):185–193. https://doi.org/10.2478/v10098-012-0016-1
34. Fendekova M, Demeterova B, Slivova V, Macura V, Fendek M, Machlica A, Gregor M, Jalcovikova M (2011) Surface and groundwater drought evaluation with respect to aquatic habitat quality applied in Torysa River Catchment, Slovakia. Ecohydrol Hydrobiol 11 (1–2):49–61
35. Zeleňáková M, Purcz P, Soľáková T, Demeterová B (2012) Analysis of trends of low flow in river stations in eastern Slovakia. Acta Univ Agric Silvic Mendelianae Brun 60:265–274. https://doi.org/10.11118/actaun201260050265
36. Melo M (2003) Climatic models and their utilization for assessment of climatic changes in Slovakia. PhD thesis, GFÚ SAV, Bratislava, 155 pp (in Slovak)
37. Lapin M, Melo M (2004) Methods of climate change scenarios projection in Slovakia and selected results. J Hydrol Hydromech 52(4):224–238
38. Pekárová P, Miklánek P, Pekár J (2007) Long-term Danube monthly discharge prognosis for the Bratislava station using stochastic models. Meteorologický časopis 10:211–218
39. Hlavčová K, Szolgay J, Kubeš R, Kohnová S, Zvolenský M (2006) Routing of numerical weather predictions through a rainfall-runoff model. In: Marsalek J, Stancalie G, Balint G (eds) Transboundary floods: reducing risks through flood management. Nato science series: IV: earth and environmental sciences, vol 72. Springer, Dordrecht
40. Gaňová L, Zeleňáková M, Purcz P, Kuzevičová Ž, Hlavatá H (2013) A rainfall distribution and their influence on flood generation in the eastern Slovakia. Acta Universitatis Agriculturae Et Silviculturae Mendelianae Brunensis 61(182):1645–1652. https://doi.org/10.11118/actaun201361061645
41. Solín Ľ (2012) Spatial variability in the flood vulnerability of urban areas in the headwater basins of Slovakia. J Flood Risk Manage 5:303–320

Index

A. M. Negm and M. Zeleňáková (eds.), *Water Resources in Slovakia: Part II - Climate Change, Drought and Floods*, Hdb Env Chem (2019) 70: 339–344,
https://doi.org/10.1007/978-3-319-92865-4,