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Влијанијата на климатските промени врз подземните водни ресурси - Преглед

Impacts of climate changes on groundwater resources - An overview

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ABSTRACT: Groundwater constitutes the largest reservoir of fresh water and, as such, is an important resource for societal well-being. However, it faces challenges from both anthropogenic and natural stressors, deteriorated by the expected climate change. This paper presents the impact of climate change on groundwater resources in Serbia, focusing on quantity and quality dynamics. Through legal frameworks like the Paris Agreement and the national climate and water strategies, as well as others, Serbia aims to integrate climate change considerations into water management. Climate change projections suggest changes in groundwater recharge patterns, affecting water availability and quality. Groundwater depletion and changes in hydrogeochemical conditions could cause water-supply well aging, through acceleration of the clogging process in the wells themselves as well as in the pre-filter zone. This leads to a decrease in well capacity and increased maintenance costs. Mitigation strategies are crucial, including efficient water usage, environmental preservation, and diversified water sources. Strategic planning, the construction of reservoirs for the provision of additional quantities of water and improved monitoring of the quality and quantity of underground water are advocated to ensure water security in the conditions of the expected climate change and climate uncertainty.

Keywords: *climate change, groundwater regime, impacts on quantity and quality*

1. INTRODUCTION

Groundwater resources account for approximately 99% of all liquid freshwater on Earth2, and have the potential to provide societies with social, economic, and environmental benefits and opportunities. According to UN-Water Report for 2022 [1], they supply 50% of all drinking water worldwide, about 40% of water for irrigated agriculture and 30% of water required for industry. However, these important resources are not evenly distributed and are under immense pressure from multiple stresses, anthropogenic and natural, including climate change. Different user needs for the same resource led to overexploitation, resource pollution, and changes in groundwater regimes. Climate change might add additional pressure by altering groundwater recharge rates and the availability of groundwater. Due to overexploitation, groundwater resources are depleting, leading to social, environmental and economic problems [2]. Problems are particularly pronounced in arid and semi-arid regions [3] [4]. Irrigation is the main consumer of groundwater and in many arid parts of the world, no crops can be grown without pumping groundwater [5],[6].

Groundwater is key to the UN Sustainable Development Goal 6 (SGD 6 ensures access to water and sanitation for all) but also directly contributes to poverty eradication (SGD 1), food security (SGD 2), gender equality (SGD 5), sustainability of cities and human settlement (SGD 11), combating climate change (SGD 13) and protecting terrestrial ecosystems (SGD 15).[7]

However, the impact of climate change is increasingly being felt in Southeastern Europe, with rising average temperatures and unfavorable rainfall patterns, putting an increasing pressure on groundwater resources.

A significant element that must be considered in long-term planning in the field of water usage is climate change. Groundwater resources in Serbia are relatively scarce and unevenly distributed. The complex geology of the Republic of Serbia and adjacent areas has produced hydrogeological heterogeneity and considerable variety in aquifer systems and groundwater distribution. Groundwater is primarily used for drinking water supply. For the purpose of drinking water supply to settlements, approximately 15-17 m^3/s of groundwater is abstracted, of which around 50% comes from alluvial aquifers, 22% from karst springs, approximately 16% from the main aquifer (so-called "Basic Water-Bearing Complex") in Vojvodina, while about 8% comes from Neogene formations.[8] The quantity and quality of these waters are highly heterogeneous and depend on the type of environment within which the resource is formed, as well as on the regime of surface waters and climatic conditions. The impact of groundwater use on their quantitative status depends on the aquifer and the recharge rate.

2. LEGAL FRAMEWORK

2.1 *Legal Framework*

Member states of the United Nations adopted the 2030 Agenda for Sustainable Development in 2015 (UN, 2015), which defines 17 Sustainable Development Goals (SDGs). One of the goals (SDG13) is to take urgent action to combat climate change and its impacts, which would also enhance the resilience of other goals vulnerable to the effects of climate change. In 2001, Serbia ratified the United Nations Framework Convention on Climate Change (UNFCCC). The Convention aims to prevent dangerous human interference with the climate system and stabilize greenhouse gas (GHG) concentrations. By ratifying this Convention, the Republic of Serbia committed to submitting national reports on the implementation of the Convention. As a developing country (non-Annex I state), Serbia is not obligated to reduce GHG emissions, but it is expected to integrate climate change issues into the planning processes in Serbia and provide relevant information regarding GHG emissions and removals. Serbia is also a signatory to the Kyoto Protocol and the Paris Agreement.

The National Law on Climate Change was adopted by the Government of the Republic of Serbia in 2021.

Pursuant to Article 7(3) of the Law on Climate Change (Official Gazette of RS, No 26/21), Art. 38 and 50 of the Law on Planning and Building of the Republic of Serbia (Official Gazette of RS, No 30/18) and Article 4(19) of the Law on Ratification of the Paris Agreement (Official Gazette of the RS - International Agreements, No. 4/17), the Government of the Republic of Serbia adopted the Low Carbon Development Strategy of the Republic of Serbia for the period 2023-2030 with projection until 2050. Besides this Law, Serbia introduced certain sectoral policies and measures that contribute to GHG emission reduction and efficient adaptation.

The Law on Water was adopted much earlier, in 2010, while the Water Management Strategy for the territory of the Republic of Serbia until 2034 was adopted in 2017.

In the Republic of Serbia, groundwater resources fall under different jurisdictions, ministries and agencies.

3. CLIMATE CHANGE IN THE REPUBLIC OF SERBIA AND EXISTING MONITORING DATA

The effects of climate change are already a threat, while future risks could jeopardize, inter alia, the infrastructure facilities, agriculture productivity, water availability and public health.

The latest data show an average temperature increase of 0.36°C per decade between 1961 and 2017, while climate change scenarios predict an increase between 2°C and 4.3°C until 2100, compared to the period 1986-2005. Average precipitation decreased up to 10% in the period between 1961 and 2017, while according to climate change scenarios, average annual precipitation may decrease up to 4.5% by 2100 compared to the reference period 1986-2005. [9]

According to official data of the Republic Hydrometeorological Institute Serbia, between 1950 and 2017, nine out of 10 warmest years were recorded after 2000. Generally, the number of dry days in a year and dry years consistently increases.

In the near future, on the territory of the Republic of Serbia, flow changes are within several percentages and less frequently exceed 10%. But, climate scenarios indicate further decreases in flow, particularly between 2071-2100. In terms of the magnitude of changes, the Kolubara basin in central Serbia and the Toplica basin in southern Serbia will be most susceptible to changes, with up to -40% during the period 2071-2100 compared to the period 1961-1990. [10]

Dynamic information about climate and weather variabilities and trends across the Republic of Serbia is available from the Republic Hydrometeorological Service of Serbia (RHMS Serbia) as well as from the web platform Digital Climate Atlas of Serbia, which was established in 2022. In addition to climate data used for specific risk and vulnerability assessments, the Digital Climate Atlas includes:

- Sets of climate data, including historical observations, and regional climate model projections for the entire R. Serbia, as well as at subnational and local levels; and
- Online visualizations – maps and charts for various seasonal and annual analyses and data, to help screen potential hazards in a given spatial area and identify those of concern.

Observations of groundwaters are not satisfactory. The Serbian Environmental Protection Agency (SEPA) is in charge of systematic monitoring of groundwater quality in the country while monitoring the quantity of groundwater falls within the competence of the RHMS Serbia. However, RHMS monitors only shallow alluvial groundwaters with a very limited number of piezometers.

Special monitoring for observing the impacts caused by the user of the dam Iron Gate 1 and Iron Gate II on the riparian river zones of the Danube, monitoring of piezometers within groundwater sources for the water supply needs of the population or industry (such as Belgrade groundwater resources etc.) are the responsibility of these entities, and the data are not publicly available.

4. IMPACT OF CLIMATE CHANGES ON GROUNDWATER REGIME

Researching the impacts of climate change on groundwater resources is not an easy task.

The regime of groundwater encompasses both quantitative and qualitative components. The ability of groundwater to lessen the effects of climate change on communities and livelihoods depends on having dependable groundwater resources available when needed for various purposes. This can only be determined through proper monitoring.

4.1 *Impact on Groundwater Quantity*

Considering that groundwater recharge primarily occurs through rainfall infiltration and infiltration of river water, which is hydraulically connected with aquifers, while the replenishment of deep aquifers (Basic Water-Bearing Complex in Vojvodina, deep aquifers in other parts of the country) is very slow, the groundwater recharge pattern is closely linked to intra-annual distribution of precipitation for the future period. During high-water periods, river streams recharge groundwater, while during low- water periods, the situation is reversed.

As groundwater systems are affected by drought, the recharge of groundwater initially decreases, followed by a subsequent decline in groundwater levels and discharge. These periods of drought are termed groundwater droughts, which can occur over varying durations, ranging from months to years.[6]

Serbian researchers show pessimistic results especially for the end of the century. The analysis of the total amount of groundwater resources for the entire Serbia shows that there will be a decrease in groundwater storage, and the decrease compared to the period 1951-2010 increases over time from around -10% in the near future to about -50% by the end of the century. Spatial unevenness of changes is also observed, which are somewhat more pronounced in the eastern and southeastern parts of Serbia and somewhat less pronounced in the western and southwestern regions [11][12].

Climate change can cause overexploitation of groundwater resources, especially during dry periods [13]. The water needs of different users create additional pressures on groundwater resources.

In other words, when planning and constructing hydro-technical systems (both for drainage and irrigation), as well as for supplying water to the population and industry, power production or flood protection, it is necessary to consider projections of climate change and the sector's vulnerability to altered climatic conditions.

4.2 *Impact on Groundwater Quality*

When discussing the impact of climate change on water resources, the focus is mostly on changes in the quantitative component, while the quality of resources is often overlooked.

The quality of groundwater is directly related to the hydrogeochemical conditions prevailing in the underground environment.

Redox conditions in the underground environment are important regulators of biogeochemical processes occurring during groundwater filtration. The oxidation state in which chemical elements occur affects their solubility, adsorption affinity, toxicity, and distribution between solid, liquid, and gaseous phases.

If the concentration of CO_2 is not a limiting factor, and according to the energy released, the processes will proceed according to the following scheme:

$$O_2 \rightarrow NO_3^- \rightarrow Mn^{4+} \rightarrow Fe^{3+} \rightarrow SO_4^{2-} \rightarrow CO_2$$

Redox processes are divided into oxygen reduction, nitrate reduction, manganese reduction, iron reduction, iron and/or sulfate reduction (depending on the mass ratio of iron and sulfide H_2S), sulfate reduction, and methanogenesis. But there is also a possibility that some other process occurs depending on trace metals, pesticides, etc. The microbiological factor plays a significant role in the rate of occurrence of individual processes.[14]

The rate of water exchange within the geological matrix and the origin of the water feeding the aquifer (rivers, infiltration of precipitation, hydraulic connection with other deeper aquifers or different types of aquifers) affects changes in geochemical conditions both seasonally, as a result of changes in recharge patterns, and also depending on the exploitation of the groundwater resources.

The amount and rate of incrustation depends on several factors: chemical composition of the groundwater (concentrations of bivalent iron, dissolved oxygen, manganese, sulfates, nitrates, CO_2), redox conditions (especially if there is mixing of water from different redox zones), change in chemical balance as groundwater enters the near-well region, operating mode of the well, and the presence of microorganisms that accelerate incrustation.

In many alluvial aquifers in Serbia, there is an increased concentration of iron and manganese. [14][15] Infiltration of oxygen-rich river water influences the formation of deposits that coat particles of the geological matrix, reducing its porosity. This process is significantly more pronounced in the presence of groundwater exploitation due to fluctuations in groundwater levels near the water wells, leading to the formation of iron and manganese oxide deposits within the wells themselves and in the pre-filtration zone. The formation of carbonate deposits can occur not only in limestone environments but also in wells that capture gravelly-sandy sediments with carbonate content above several mass percentages. Borehole clogging can occur through mechanical, chemical, and biochemical processes. Mechanical clogging is independent of the chemical and microbiological characteristics of groundwater, while the other two types of clogging rarely occur as separate processes.

The processes of clogging can be particularly pronounced, especially under conditions of overexploitation. [13][14][15]. It is known that deposits form in wells that capture different vertical geochemical zones, but it should be noted that drastic examples of clogging occur when well filters are located in different geochemical zones, which is most often the result of overexploitation.

On the other hand, the resilience of an aquifer to pumping, which may create unstable hydrogeochemical conditions, can be improved by human intervention, provided that a precise understanding of the system is accessible. [6]

Changes in hydrogeochemical conditions of aquifers currently used for water supply or irrigation can be expected under climate change and may alter the type of water sources from oxic to anoxic due to reduced recharge from rivers. The changes in oxic conditions have already been recorded in the riparian river zones of the Danube, Tisa, and Velika Morava rivers

because of alterations in the hydraulic connection between the river and the alluvial aquifer.[16]

The deterioration of water quality can be an additional factor exacerbating the pressure of climate change on public health and healthcare system costs, as well as operational costs of groundwater exploration infrastructure.

4.3 *Other Impacts*

The consequences of climate change impacts on groundwater resources are reflected through the reduction in quality and availability of water for water supply, agricultural production, and industry. These consequences can lead to a decrease in GDP through water purchasing, as well as an increase in the prices of water, food, and energy.

The development of agriculture (crop and fruit production) under climate change has brought about the need to restore irrigation systems and build new ones. The Serbian Government is investing efforts, not only financial but also technical, to expand irrigation systems to the extent possible.

According to the current Serbian Water Law, Article 72 stipulates that groundwater suitable for drinking and water from public sources should only be used for supplying water to the population, sanitary-hygienic needs, livestock watering, for industries requiring high-quality water (such as food, pharmaceuticals, etc.), and the needs of small consumers (below 1 l/s). Waters designated for drinking purposes in water management plans cannot be used for other purposes, except for fire extinguishing, nor in a way that would adversely affect the quantity and quality of water. However, in practice, the use of shallow aquifers for irrigation purposes on smaller plots or for watering green areas is often encountered without any permits or control. This leads to a local decline in groundwater levels, the attraction of water from unregulated septic tanks, and the presence of herbicides, pesticides, and fertilizers in the first aquifers. During pronounced drought periods, this phenomenon becomes more pronounced.

Hydrological extreme events, such as the flood of 2014, can threaten existing water supply infrastructure (intakes and treatment facilities) and necessitate additional measures to ensure the provision of safe drinking water.[15]

Unreasonable water consumption during prolonged drought periods can affect the stability of population's water supply and the provision of industrial needs, potentially leading to conflicts between different consumers and water demands.

5. MITIGATION OF THE IMPACT OF CLIMATE CHANGE ON GROUNDWATER RESOURCES

Some of the necessary steps to mitigate the impact of climate change on groundwater resources include:

- Water consumption management: Promoting more efficient water use in households, industry, and agriculture can reduce pressure on groundwater resources.
- Preservation of natural habitats: Protecting natural habitats, such as wetlands and forests, can help preserve the quality of groundwater.
- Diversification of water sources: Considering alternative water sources such as rainwater harvesting and water recycling can reduce pressure on groundwater and increase resilience to climate change.
- Monitoring and managing groundwater: Monitoring the quantity and quality of groundwater, as well as managing water flows in line with changes in climate conditions, can help maintain the balance of groundwater systems.
- Education and awareness: Raising awareness about the importance of preserving groundwater and its responsible use can contribute to long-term sustainable management of this resource.
- It is essential to build the capacity of relevant institutions and involve all stakeholders (scientific institutions, water users, authorities, and decision-makers) in the development of strategies for water resource management in the context of climate change.

These steps can help mitigate the negative effects of climate change on groundwater resources and ensure their long-term sustainability.

6. CONCLUSION

Climate change is impacting the hydrological cycle through unpredictable precipitation patterns, causing unreliable water sources and/or water quality degradation.

Cities that rely solely on a single groundwater source, especially if it is formed in shallow alluvial deposits, may increasingly struggle to meet the required quantities of water of a certain quality, even with an increasing number of wells, due to decreased recharge from the river during low-flow periods expected as a result of climate change. This will require strategic planning and finding more reliable solutions, also relying on surface water sources. Since water intake directly from natural watercourses is quite vulnerable (turbidity during periods of high water, the possibility of direct surface water pollution without the self-purifying effects of groundwater, necessary quantities of water for dependent ecosystems, and others), a more likely solution is the establishment of new reservoirs and the improvement of the management of existing ones.

For that reason, it is necessary to reserve space for the construction of reservoirs and protect certain alluvial areas, which can serve as potential sources for future water supply.

Although Serbia has made significant progress in recent years regarding legislation on climate change, it is essential to harmonize existing regulations and sectoral policies especially regarding water resources.

Monitoring of groundwater resources (qualitative and quantitative) must include parameters that will timely indicate potential climate influences, in order to apply adaptation measures appropriately and promptly.

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Brankica Majkić-Dursun

From: Markovski Goran Prof. D-r. <markovski@gf.ukim.edu.mk>
Sent: 28 May, 2024 12:40
To: Brankica Majkić-Dursun
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Dear Mrs. Brankica Majkić - Dursun

This year, the Faculty of Civil Engineering Skopje as a constituent part of the Ss. Cyril and Methodius University in Skopje marks 75 years since its foundation. On the occasion of this important jubilee, there will be published, inter alia, a special issue of Monograph that, in addition to basic data on the development and current conditions of the Faculty, will also contain presentation of the most characteristic scientific-research achievements of its departments.

To give an impetus and highlight the importance of intensive international cooperation for the achievement of scientific-research goals, the Editorial Board has made a decision to ask each department to invite one of its renowned collaborators from abroad to present his/her current research, part of his/her own research or provide an overview of current world achievements in the field and thus contribute to raising the quality of the Monograph.

The Department of hydraulics, hydrology and arrangement of watercourses has nominated you as a distinguished expert and researcher to be our guest at the celebration and an invited lecturer at the conference named "75 years of Faculty of Civil Engineering – From Slide Rule to Artificial Intelligence".

Emphasizing the inseparable mutual connection of education and science with economy, in the chapter entitled "Friends of the Civil Engineering Faculty", to our respected business partners from the country and abroad will also be given the opportunity to present their achievements or to advertise themselves.

Thanking you for the accepted invitation, allow me, on behalf of the Faculty of Civil Engineering, to invite you, with a great pleasure, to the Official Ceremony and the Scientific Conference to be held in Skopje on the 3rd, i.e., the 4th October 2024.

Sincerely yours,

Faculty of Civil Engineering Skopje
Dean

Prof. Goran Markovski PhD

***
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