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Water resources usage in Kosovo and North Macedonia: Patterns, trends and socio-environmental drivers

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Highlights
- Water scarcity in both countries is driven by climate change and mismanagement.
- Study analyses water usage trends in agriculture, industry and domestic sectors.
- Climate models project temperature rise of up to 4.25°C by 2099.
- Agriculture is the largest water consumer.
- Integrated water management is essential for future climate resilience.

Abstract: Water resource management in Kosovo and North Macedonia is characterised by various challenges and complexities due to factors such as rapid urbanisation, industrial growth, agricultural activities, and changing climatic conditions. Both countries heavily rely on water resources for domestic, agricultural, and industrial purposes, making the sustainable management of water crucial for ensuring environmental sustainability and socioeconomic development. Studying water usage patterns, socio-environmental drivers, and impacts on water scarcity in the region is essential. This paper aims to determine the patterns and trends of water usage in these two countries, including predominant sectors and consumption analysis. The impact of climate change and mismanagement on water scarcity and pollution were determined. Results show that the largest water demand goes to the agriculture sector, mainly for irrigation. The second largest sectoral demand is the drinking water sector, and the last sector is the industry. Climate models project a steady increase in average annual temperatures for Kosovo and North Macedonia. By 2060, temperatures are expected to rise by 1.11°C, and by 2099, it will be a change of 4.07–4.25°C. Higher temperatures will increase water losses and uneven rainfall distribution may lead to longer drought periods and increased reliance on irrigation, exacerbating existing shortages. Without proactive and coordinated management efforts, water scarcity and competition for resources will escalate, exacerbating socio-economic vulnerabilities. Future water management strategies should integrate climate resilience measures, such as the development of drought contingency plans, flood mitigation systems, and nature-based solutions to enhance water retention and biodiversity conservation.

Keywords: climate change, social and environmental drivers, water resources management, water scarcity, water usage

INTRODUCTION

Water resources are fundamental to sustaining life, ecosystems, and economic development, forming a critical nexus between water, energy, and food. River systems have been integral to the development of human societies, providing diverse ecosystem services – supporting, provisioning, regulating, and cultural – that vary across spatial scales, from local habitats to entire drainage basins, and temporal scales, from daily cycles to decades (Lundqvist, Lohm and Falkenmark, 1985; Maksimoví and

Makropoulos, 2002; Aho *et al.*, 2020; Kagalou and Latinopoulos, 2020). In the context of Kosovo and North Macedonia, managing water resources effectively is vital due to the regions' reliance on rivers for domestic, agricultural, industrial, and energy needs. Both countries share significant hydrological systems, which are critical for their socioeconomic development and environmental health (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; Qeveria e Republikës së Kosovës, 2017). The water resources in North Macedonia serve as a lifeline for urban and rural communities, agriculture, and industries Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; White *et al.*, 2018). Similarly, the water resources in Kosovo play a vital role in providing water for irrigation, hydropower generation, and ecosystem services. The transboundary nature of these basins adds complexity to their management, necessitating cooperation between the two nations (Qeveria e Republikës së Kosovës, 2017). Water resources are indispensable for agricultural activities, which are important components of the economies of Kosovo and North Macedonia. Irrigation plays a crucial role in supporting agricultural production, enhancing crop yields, and ensuring food security for the population. Sustainable water management practices are essential for optimising water use efficiency in agriculture, mitigating the impacts of droughts and water scarcity, and promoting resilient food systems (Sveta Petka and Matka) (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; Dragovic *et al.*, 2017; White *et al.*, 2018). In 2023, as per the Kosovo Agency of Statistics, 46.47 mln m^3 of water from the irrigation systems were used for irrigation, while 56.33 mln m^3 of water used for irrigation was coming from wells (total 102.80 mln $m^3 \cdot y^{-1}$). On average, for the past 10 years, Kosovo has spent 85.9 mln m^3 of water annually for irrigation, and around 6,650 m^3 of water annually for animal consumption (Kosovo Environmental Protection Agency, 2020; ASK, 2022; ASK, 2024c). Water resources are essential for various industrial processes, including manufacturing, energy production, and mining, which are significant contributors to the economies of Kosovo and North Macedonia. Reliable access to water is crucial for industrial operations, cooling systems, and wastewater discharge. Kosovo allocates on average 16.5 mln m^3 of water annually for industrial use (two thermal power plants, SharrCem and the NewCo Ferronikeli factory), while a total of 10 hydropower plants are currently active in Kosovo (Kosovo Environmental Protection Agency, 2020; ASK, 2024c). Both countries are characterised by variability in water availability, with seasonal fluctuations and uneven spatial distribution. Climate change exacerbates these challenges by altering precipitation patterns, increasing the frequency of droughts and floods, and impacting water quality and availability. These factors underscore the need for integrated river basin management strategies to ensure sustainable water use and equitable distribution (Skoulikidis, 2009; Tockner, Uehlinger and Robinson, 2009; Vuković and Mandić, 2018; White *et al.*, 2018; OECD, 2021a; OECD, 2021b). The increasing demand for water across sectors places significant pressure on existing resources. Efficient management ensures a reliable supply for drinking, agriculture, and industry while safeguarding environmental needs. The purpose of this paper is to establish water usage trends and patterns for both countries, including a water consumption analysis, predominant sectors and usage types. Additionally, the impact of different drivers such as climate change, mismanagement of resources and others on water scarcity and pollution was determined. This will serve as a basis for future recommendations on water resources management for both countries.

MATERIALS AND METHODS

STUDY AREA

The Republic of North Macedonia has an area of 25,436 km^2, of which 477 km^2 are surface waters (1.88% of the territory). The water resources in North Macedonia include 42 lakes (3 natural tectonic, 25 natural glacial, and 14 artificial lakes), 35 rivers, and 1,100 larger sources of water. Likewise, North Macedonia has 44 wetlands, which include marshes, ponds, and aquatic beds. North Macedonia seems to have sufficient water resources; however, the distribution is not equal (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; GWP, 2022; MoEPP, 2023). North Macedonia has four river basin districts (Fig. 1): Vardar River basin, Crn Drim River basin, Strumica River basin and Binachka Morava River basin. The Vardar River basin is the largest in the Aegean basin. The Strumica River basin has the least amount of water resources in the country. The Crn Drim River basin belongs to the Adriatic basin, which is the second largest and covers 13% of the territory. The Morava River basin includes the river Binachka Morava, which flows into the Morava and further into the Danube and the Black Sea basin. It is the smallest basin and very insignificant in terms of water resources availability in the country (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; Center for Ecological Democracy Florozon, 2018; MoEPP, 2023; Gjorgjievska, 2024). In addition to its national river basins, North Macedonia also participates in four international river basin districts (RBD) as per the European Union Water Framework Directive (EU WFD), such as the Danube RBD, the Central Macedonia RBD, the West Aegean RBD, and the Adriatic RBD (GWP, 2022). Total yearly available surface water resources in North Macedonia are 6,372 bn m^3, the majority from the Vardar River basin. Groundwater is a significant water supply source in the country, with a 70% participation rate in the total water supply. Regarding protected areas in North Macedonia, Lake Ohrid is a UNESCO World Heritage Site as well as on the RAMSAR list and a categorised Nature Monument; Lake Prespa and Dojran are also on the RAMSAR list and a categorised Nature Monument (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; Jovanov, 2015; GWP, 2022).

The Republic of Kosovo has an area of 10,887 km^2. Kosovo has four river basins (Fig. 1), such as the Ibër River basin, the Drini I Bardhë River basin, the Morava e Binçës River basin and the Lepenc River basin, totalling 10,601.35 km^2. The Morava e Binçës basin covers an area of 1,564 km^2, serving 421,765 inhabitants. The Ibër River basin covers approximately 4,044 km^2 within Kosovo (Drenica region and Kosova Valley) and is critical for water supply, agriculture, and hydropower, serving 1,053,000 inhabitants. The Gazivoda Reservoir on the Ibër is one of the largest water storage facilities in Kosovo, with a capacity of 370 mln m^3, supplying water to industrial and municipal users. The Lepenc River basin has an area of 653 km^2,

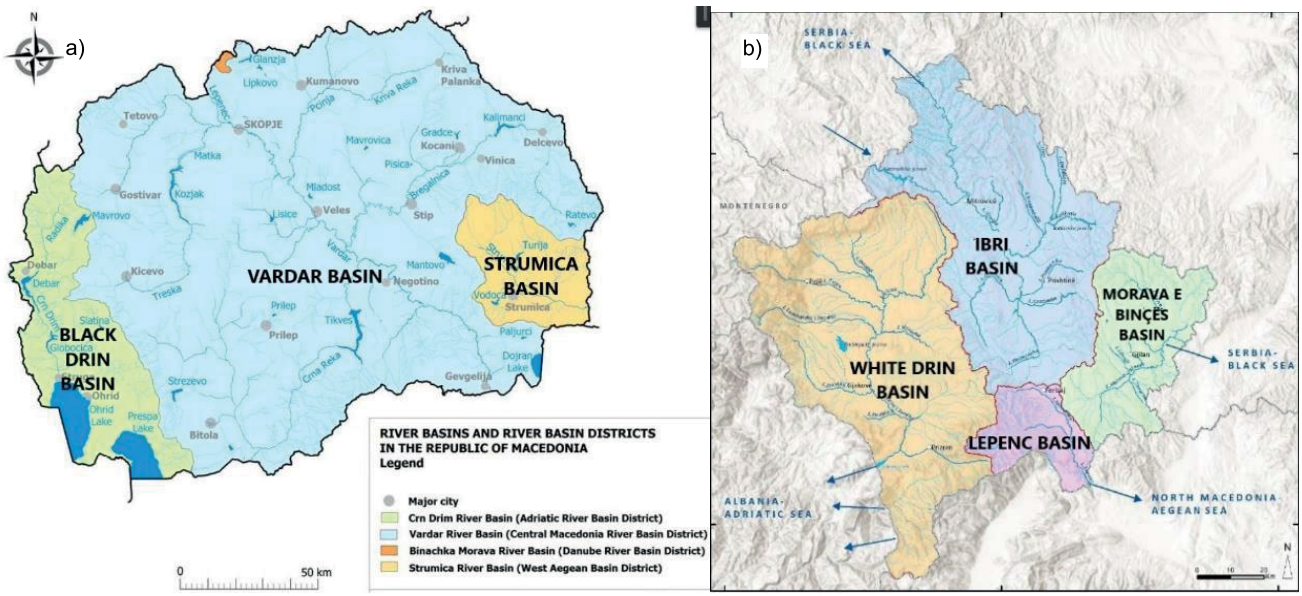

Fig 1. Division into river basins of: a) North Macedonia, b) Kosovo; source: Government of the Republic of Slovenia, Government of the Republic of Macedonia (2010) and Deltares and Abkons (2024c)

serving 157,669 inhabitants. The Drini I Bardhë River basin covers an area of 4,644 km^2 and the river itself is 122 km long (Qeveria e Republikës së Kosovës, 2017; Ministry of Environment, Spatial Planning and Infrastructure, 2020; Republika së Kosovës, Ministria e Mjedisit, Planifikimit Hapësinor dhe Infrastrukturës, 2022; Republic of Kosovo, 2023; Deltares and Abkons, 2024c, 2024b, 2024a). Kosovo has six accumulations of surface waters: Ujmani, Batllava, Badovci, Livoç, Radoniq and Prilepnica. They cover a total of 1,634.6 km^2 area and a volume of 563 mln m^3. Groundwater is mainly found in the western part of the country (Ministry of Environment, Spatial Planning and Infrastructure, 2020).

DATA COLLECTION

This study relies on a comprehensive dataset to analyse the hydrological, environmental, and socio-economic dynamics of the study area. Kosovo Agency of Statistics, Ministry of Environment, Spatial Planning and Infrastructure, and other agencies such as River Basin District Authority, Hydrometeorological Institute, Regional Water Companies and more have been utilised for data collection on water usage and quantities. Data collection focuses on three primary categories listed below.

a) Climate data: precipitation, temperature, and evapotranspiration. These data were obtained from meteorological stations, national meteorological agencies, and global datasets (Agri4-Cast).
b) Hydrological data: river flow measurements and historical water use data. These data were obtained from hydrological monitoring stations, national water agencies, and river basin management authorities.
c) Land use and land cover (LULC): spatial data on agricultural, urban, and forest areas. These data were obtained from remote sensing datasets (CORINE land cover), national land use databases and reports, and geographic information system (GIS) platforms. The LULC data provides insights into the human–environment interaction, land management practices, and their impact on water resources.

RESULTS AND DISCUSSION

WATER USAGE PATTERNS AND TRENDS

A significant 88.9% of North Macedonian households are covered with drinking water supply services from the public pipeline, with the majority of uncovered households being located in rural settlements. This coverage goes up to 100% for Skopje. Drinking water supply accounts for 11% of the total water demand MoEPP, 2023). Water supply consists of a combination of surface and groundwater. Spring water supplies Skopje, Prilep, Kicevo, Makedonski Brod, Krusevo, Struga, Debar, Gostivar, Tetovo and Kriva Planka. Groundwater supplies Skopje, Stip, Veles, Kocani, Probistip, Gevgelija, Ohrid, Demir Hisar, Delcevo and Radovis. Treated surface water supplies Bitola, Kumanovo, Strumica, Veles, Berovo, Vinica, Sv. Nikole, and Kratovo. Areas Ohrid, Kavadarci, Negotino, Delcevo and Vinica have combined water supplies (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; MoEPP, 2023). As statistics show, the trendline for water consumption supply is showing a decrease since 2021. There are seven regional water companies providing 99.83% of the Kosovo population with water. In 2023, that amount was 67.35 mln m^3, while on average for a 10-year period, these companies provide approximately 62.23 mln m^3 annually (Ministry of Environment, Spatial Planning and Infrastructure, 2020; ASK, 2024a). These regional water companies (RWC) are not only water suppliers, but also wastewater managing units, including the operating of the sewer system and wastewater treatment plants. Only 68% of the population has wastewater collection services, and Kosovo only has five functional wastewater treatment plants (Deltares and Abkons, 2024c; ASK, 2024c; ASK, 2025). Water supply in Kosovo consists of a combination of surface and groundwater, and consumption trends show a slight increase since 2010 (Fig. 2).

The Republic of North Macedonia possesses favourable climatic and pedological conditions that support intensive agricultural production. However, the uneven distribution of precipitation across time and space makes irrigation a critical

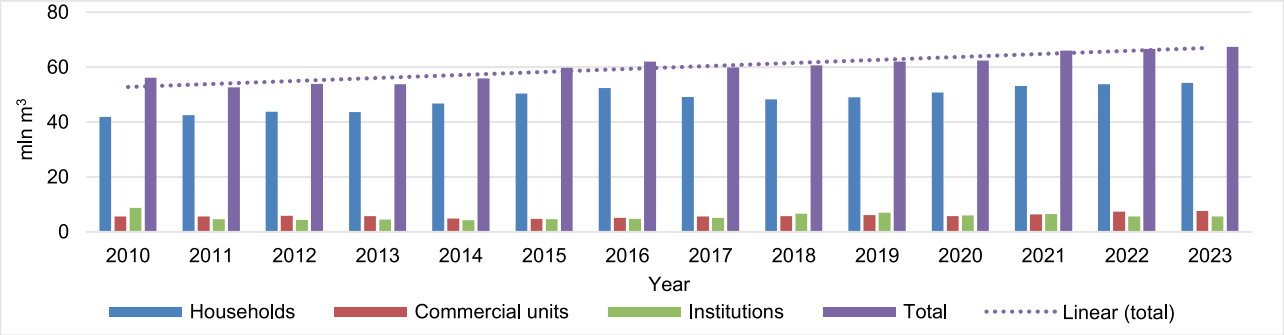

Fig. 2. Drinking water consumption trends for Kosovo; source: own study

component for successful agriculture. The country's arable land spans approximately 667,000 ha, with an estimated 400,000 ha (60% of the total) potentially irrigable through fully constructed irrigation schemes. To date, 106 irrigation schemes have been developed, covering 163,693 ha or nearly 49.9% of the potential irrigable area. Yet, only about 126,600 ha are currently irrigated, with most systems constructed between 1958 and 1980, rendering them operational for over 40 years. These schemes predominantly use sprinkling methods (61%), while the remaining 39% rely on surface irrigation. However, according to statistics, as much as 44% of the total water demand is used for irrigation, and another 11% – for fishponds (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; Dragovic *et al.*, 2017; Gjorgjievska, 2024). The total irrigation water demand would be approximately 1,798,670,000 m^3 annually for the total arable agricultural area. Of the 23 accumulations in North Macedonia, only two are not used for irrigation (Sveta Petka and Matka) (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; Dragovic *et al.*, 2017; White *et al.*, 2018).

For Kosovo, in contrast, out of a total of six accumulations, only two (Ujmani and Radoniqi) are used for irrigation of on average, 30,000 ha of land (52.5% of the total irrigable surface). In 2023, as per the Kosovo Agency of Statistics, 46.47 mln m^3 of water from the irrigation systems were used for irrigation, while 56.33 mln m^3 of water used for irrigation came from wells (total 102.80 mln $m^3 \cdot y^{-1}$). On average, for the past 10 years, Kosovo has spent 85.9 mln m^3 of water annually for irrigation, and around 6,650 m^3 of water annually for animal consumption (Kosovo Environmental Protection Agency, 2020; ASK, 2022; ASK, 2024c). There is an increasing trend when it comes to irrigation. Said trend is also observed when comparing the quantities of water that have been used for irrigation in the period 2010–2023. Irrigation via wells only began in 2013 and became a significant contributor in 2022 and 2023. Overall, the irrigation supply that comes from the system has decreased over the years.

Water resources are essential for various industrial processes, including manufacturing, energy production, and mining, which are significant contributors to the economies of Kosovo and North Macedonia. In North Macedonia, approximately 1.9 mln m^3 of water were used annually for industry and mining. The projected industrial demand for water in 2020 was approximately 3 mln m^3 (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010). Water utilised in production processes, such as manufacturing and cooling, represents the majority of industrial water use. Between 2000 and 2023, fresh water accounted for more than 99% of the water used for technical purposes in production, with the exception of 2012, where it was only 88.8% (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; Gjorgjievska, 2024). Kosovo allocates on average 16.5 mln m^3 of water annually for industrial use (two thermal power plants – Kosova B and A, SharrCem, and the NewCo Ferronikeli factory), which is more than 30% of the total amount of water consumption in Kosovo. The trendline shows a decrease in water usage from the thermal power plants (TPP) in the last 13 years. The TPP Kosova B is supplied with raw water from the Ibër-Lepenc canal, while TPP Kosova A is supplied with river water (Llap River), lake water (Batllava) and the Ibër-Lepenc canal (Kosovo Environmental Protection Agency, 2020; ASK, 2024b; Ministry of Environment, Spatial Planning and Infrastructure, 2020). In addition to the Kosovo Energy Corporation that used water for its thermal power plants, there are two large industry shareholders in Kosovo, SharrCem, which is a cement-producing factory and NewCo Ferronikeli, which is the heavy metal industry. Trepça Mining Co. is also a large industrial component in Kosovo. NewCo Ferronikeli is also supplied with the water from the Ibër-Lepenc Canal (Bivolak River), while SharrCem is supplied from the Lepenc River and the Dimca stream. On average (for a 10-year period), NewCo Ferronikeli spends approximately 1.68 mln m^3 of water annually, while SharrCem only spends 162,300 mln m^3, considering that SharrCem utilises a closed-water system, meaning the water is recycled. Overall, there is a decreasing trend in water usage by NewCo Ferronikel, while SharrCem does not present any significant trends, it remains as always (Ministry of Environment, Spatial Planning and Infrastructure, 2020; ASK, 2024a; ASK, 2024b).

SOCIO-ENVIRONMENTAL DRIVERS OF SCARCITY AND IMPACTS

Reduced and erratic rainfall, rising temperatures, and earlier snowmelt in basins like Ibër and Lepenc have led to prolonged droughts and lower water availability. Increased water demand from agriculture, industry, and urbanisation further depletes both surface and groundwater. Inefficient irrigation, municipal water losses, and untreated wastewater contamination worsen scarcity, with rivers like Morava e Binçës and Lepenc showing high levels of pollutants. Sectoral conflicts over limited resources, particularly in Ibër and Morava e Binçës, may escalate as climate change intensifies water stress (Republika së Kosovës, Ministria e Mjedisit, Planifikimit Hapësinor dhe Infrastrukturës, 2022; Deltares and Abkons, 2024a; Deltares and Abkons, 2024b; Deltares and Abkons, 2024c). By 2050, effective rainfall in North Macedonia is

projected to decline by up to 40%, and by 2100, by as much as 70% in certain regions. Water availability in the Vardar River basin may shrink by 18%, with groundwater recharge declining to 57.6% of current levels. Rising temperatures will intensify dry spells and flash floods, exacerbating water shortages, particularly in the eastern part of the country (Ministry of Environment and Physical Planning, 2003; UNECE, 2019; GWP, 2022; Mirta, 2024).

Climate change and socio-economic factors will drive a 30% increase in Skopje's drinking water demand, while agricultural water use, already the largest consumer at 40%, will grow further. Precipitation is expected to decrease by 10% by mid-century and 14% by 2100, with demographic shifts playing a significant role in water demand (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; Gjorgjievska, 2024; State Statistical Office of the Republic of North Macedonia, 2024). Water shortages reduce agricultural yields, increasing food insecurity and rural poverty. Limited access to clean water heightens health risks, while industrial disruptions and economic losses strain national budgets. Inequalities in water access and transboundary conflicts threaten regional stability. Both countries face worsening environmental degradation as climate change and poor management deplete biodiversity, water resources, and socio-economic resilience (Dinar and Mendelsohn, 2011; Mosello, 2015; Vuković and Mandić, 2018). Climate models project a steady increase in average annual temperatures for Kosovo and North Macedonia. By 2060, temperatures are expected to rise by 1.11°C, and by 2099, it will be a change of 4.07°C in the Ibër basin in Kosovo. In the Vardar basin in North Macedonia, temperatures are expected to rise by 1.1°C until 2060, and by 2099, it will be a change of 4.25°C according to the CMIP6, scenario SSP5-8.5 modelling (Fig. 3). Higher summer temperatures will lead to increased evaporation, reducing surface water availability in rivers and reservoirs. The warm spell duration index indicates a rise from 32–37 days for the period of 2020–2039, to 159–185 days for the period of 2080–2099.

Droughts and floods pose increasing risks, impacting agriculture, forests, and wetlands. Over 102,000 ha in North Macedonia are flood-prone, with flash floods damaging infrastructure and farmlands. Climate-sensitive areas such as Taor Gorge and Mavrovo-Radika face biodiversity threats as species migrate due to shifting precipitation patterns (Ministry of Environment and Physical Planning, 2003; Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010). Water extraction for drinking and irrigation often disregards ecological needs, depleting rivers like Petruska and Sermeninska. Industrial pollution has severely degraded surface waters, particularly Dojran Lake, while hydropower and river sediment extraction disrupt ecosystems. Agricultural expansion and urbanisation reduce wetlands and forests in key basins like Ibër and Lepenc (Republika së Kosovës, Ministria e Mjedisit, Planifikimit Hapësinor dhe Infrastrukturës, 2022; Deltares and Abkons, 2024a; Deltares and Abkons, 2024b).

Ageing irrigation infrastructure in North Macedonia could consume 25% of river water in dry years, while Kosovo's reliance on wells risks long-term groundwater depletion. Hydropower plants and heavy industry may face reduced production due to low river flows. Climate change will intensify these challenges, making effective water management essential to avoid severe socio-economic and environmental consequences (Government of the Republic of Slovenia, Government of the Republic of Macedonia, 2010; Qeveria e Republikës së Kosovës, 2017; Deltares and Abkons, 2024a; Deltares and Abkons, 2024c).

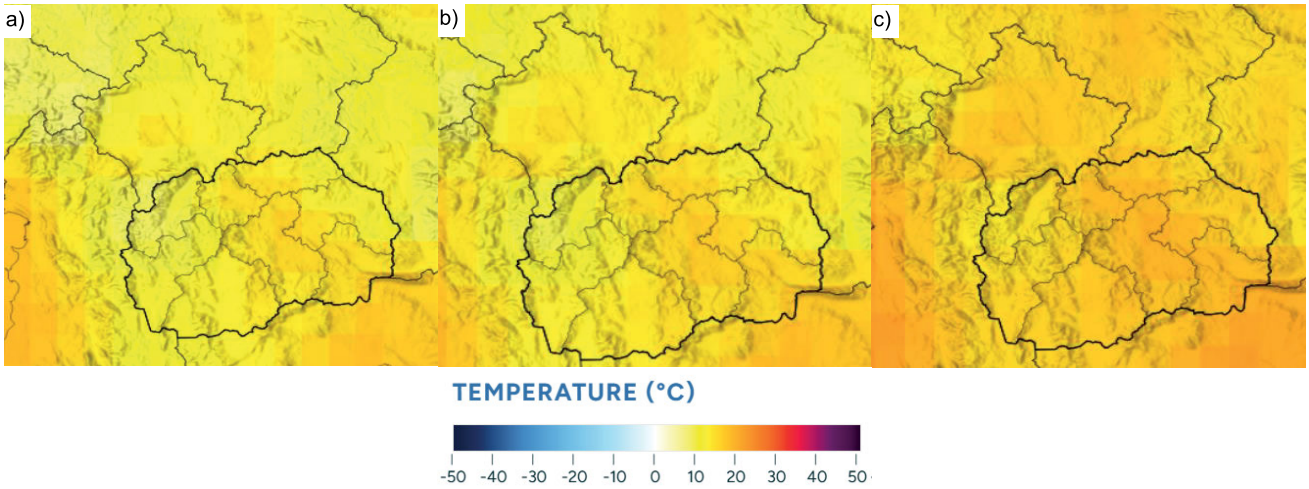

Fig 3. Annual surface temperature changes (°C) for the periods with respect to the baseline period (1995–2014) according to the SSP5-8.5 scenario for both countries (multi-model ensemble): a) current scenario 2020–2039, b) near future 2040–2059, c) end of the century 2080–2099; source: World Bank (2025)

CONCLUSIONS

Water scarcity is a critical issue affecting Kosovo and North Macedonia, driven by a combination of environmental, social, and economic factors. With increasing demands for water across domestic, agricultural, and industrial sectors, coupled with inefficient management practices, both countries face significant challenges in ensuring the sustainable use and availability of water resources. Water scarcity in Kosovo and North Macedonia is a multifaceted challenge driven by climate variability, overconsumption, pollution, and inefficient use practices. Its socioeconomic impacts ripple through agriculture, public health, and economic development, underscoring the need for urgent

action. Water demand in North Macedonia by the end of the century will be influenced not only by climate change but also by socio-economic developments. While no long-term national studies on socio-economic changes are available, climate change, particularly extreme events such as high temperatures and droughts, is expected to increase drinking water demand, with an estimated 30% rise in Skopje's needs. Irrigation water demand is also anticipated to grow, particularly in areas that previously did not require irrigation. Agriculture currently accounts for approximately 40% of the country's water demand and is the largest consumer. Climate change is expected to exacerbate pressure on water resources, particularly in the eastern Mediterranean and Middle East regions, which include North Macedonia. Kosovo's water management is also under strain, with water shortages reported in 80% of municipalities due to hydrological droughts and water misuse. The increasing temperature, uncertain rainfall, and reduced runoff, coupled with socio-economic developments, exacerbate the risk of droughts. Reduced snow cover and earlier snowmelt in the upstream areas of river basins, such as the Ibër River, lead to seasonal water shortages downstream. Increased variability in precipitation results in both droughts and floods, posing challenges for water resource planning and ecosystem stability. Higher temperatures will increase water losses from reservoirs, irrigation canals, and agricultural fields, raising the overall demand for water, especially in agriculture. Uneven rainfall distribution may lead to longer drought periods and increased reliance on irrigation, exacerbating existing shortages. In drier years, available river water may not be sufficient to meet irrigation needs, impacting food security. These river basins rely on snowmelt for water supply, and climate change will and has reduced snow accumulation in winter, leading to decreased river flows in summer when demand is highest. The conclusion from this research is that without proactive and coordinated management efforts, water scarcity and competition for resources will escalate, exacerbating socio-economic vulnerabilities. Addressing these issues requires a multi-pronged approach that includes investing in modernised water infrastructure, promoting efficient irrigation techniques, enhancing wastewater treatment, and implementing policy frameworks that encourage sustainable water use. Strengthening transboundary cooperation is particularly critical, as shared water resources necessitate harmonised governance mechanisms, data sharing, and collaborative decision-making to ensure equitable water distribution and ecosystem protection. Future water management strategies should integrate climate resilience measures, such as the development of drought contingency plans, flood mitigation systems, and nature-based solutions to enhance water retention and biodiversity conservation.

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CONFLICT OF INTERESTS

The author declares no conflict of interest.

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