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Bridging infrastructure gaps in water and environmental management: A case study from Kosovo and North Macedonia

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ABSTRACT

The water and environmental management systems in Kosovo and North Macedonia face persistent infrastructure challenges that hinder the progress toward sustainability, public health protection, and EU alignment. This study investigated the critical gaps in wastewater treatment, pollution control, and environmental monitoring by employing a mixed-methods approach, including spatial analysis, infrastructure performance assessment, and sustainability indicators. The findings revealed widespread disparities in service coverage, especially in rural areas, aging and underperforming facilities, weak enforcement of environmental regulations, and fragmented institutional coordination. The paper identified key pollution hotspots, highlighted the limitations of existing monitoring networks, as well as examined the socio-environmental consequences of untreated wastewater and industrial discharge. In response, it proposed a multi-pronged framework that integrates engineering and nature-based solutions, such as decentralized treatment systems, constructed wetlands, automated monitoring networks, and hydrological modeling tools. The study emphasized the need for river basin-based planning, financing strategies tailored to local contexts, and institutional capacity building. By offering practical, scalable, and context-specific recommendations, this case study contributes to addressing the infrastructure deficits that limit resilience and sustainable development in the Western Balkans.

Keywords: water resources infrastructure, environmental management, integrated management, sustainability, wastewater.

INTRODUCTION

Water resources and environmental management have been a core part of the concept of sustainability for more than 30 years. Resources can and do impact economic development, as well as public health and wellbeing, and environmental management is a tool that aids in having a more integrated approach towards solving sustainability and environmental issues (Goosen, 2012; Harmancioglu et al., 2013). Sustainability and resilience depend on effective social, economic, as well as environmental strategies, and a robust supporting infrastructure (Aho et al., 2020; Kagalou and Latinopoulos, 2020; Lundqvist et al., 1985; Maksimoví and Makropoulos, 2002).

Insufficient and outdated infrastructure for wastewater treatment, pollution control, and environmental monitoring still remains one of the greatest obstacles to achieving sustainable development, environmental protection, as well as public health security in Kosovo and North Macedonia. Although both countries have made progress toward meeting the EU integration criteria and aligning with sustainable development goals (SDGs), infrastructure gaps still exist, undermining the efforts to protect aquatic ecosystems, ensure equitable water access, and build climate resilience. Western Balkan countries in general, but also specifically the target countries of Kosovo and North Macedonia rely heavily on their water resources, not only for consumption, but also for economic development in the context of industry and agriculture (Government of the Republic of Kosovo, 2017; Novak et al., 2010; Tockner et al., 2009). Both countries use these resources for irrigation, energy production and more, while also being impacted by climate change and policies. These resources vary and fluctuate, whereas their availability is not guaranteed (OECD, 2021; Skoulikidis, 2009; Tockner et al., 2009; Vuković and Mandić, 2020; White et al., 2018). In North Macedonia, only 77% of the households are connected to the public sewer systems, and the rural population is in even worse condition, with only 11% connected to the sewer system. The existing system is old and inefficient; moreover, it does not provide sufficient coverage. Currently, North Macedonia has 26 wastewater treatment plants, with a combined total of 691'241 Population Equivalent (PE), and has gained loans and funding to build a new WWTP in Skopje with a capacity of 650'000 PE. However, according to ADKOM, 7 WWTPs are not functional, 2 only offer basic treatment and 4 are having financial difficulties (Jovanovska and Sipovikj, 2020; Novak et al., 2010). Wastewater management in Kosovo is primarily handled by Regional Water Companies (RWCs), which provide wastewater collection services to 68% of the population on average. Kosovo only has five functional wastewater treatment plants (Skenderaj, Prishtina, Harilaq, Badovc, Medvec – Vrelle, Orllan)(Deltares and Abkons, 2024c; Qevani et al., 2024b). The Lepenc River Basin lacks domestic wastewater treatment facilities, and untreated wastewater is discharged into rivers and streams. Although there is interest in developing future wastewater infrastructure, significant gaps remain across all regions (Deltares and Abkons, 2024a, 2024c, 2024b; Government of the Republic of Kosovo, 2017; Popovic et al., 2022). These deficiencies directly impact environmental quality and human health. Poorly treated or untreated wastewater leads to the degradation of rivers, lakes, and groundwater, jeopardizing biodiversity and increasing the risk of waterborne diseases. Compounding these challenges is the limited availability of real-time environmental monitoring data and the weak integration of modeling tools in infrastructure planning, which limits informed decision-making.

The purpose of this paper was to investigate the technical, operational, and institutional gaps in the water as well as environmental infrastructure in Kosovo and North Macedonia, in addition to providing a framework for addressing technical gaps in a region grappling with environmental pressures and developmental transitions. It sought to understand where, how, and why these deficits occur as well as propose actionable engineering and nature-based solutions tailored to the regional context. Specifically, the study applied a mixed-methods approach that includes spatial analysis, infrastructure performance assessment, and scenarios to identify vulnerabilities as well as develop practical recommendations for building more sustainable and resilient systems. By focusing on the intersection of infrastructure performance, environmental health, and policy alignment, this paper contributes to broader regional and global discussions on sustainable development. It aligns with several SDGs, such as SDG 6 (Clean Water and Sanitation), SDG 13 (Climate Action), and SDG 15 (Life on Land).

METHODOLOGY

Study area

The study focused on Kosovo and North Macedonia – both of which face growing water stress due to climate change, population growth, urbanization, and industrial expansion. The Republic of North Macedonia's territory includes 477 km^2 of surface waters such as 35 rivers, lakes (3 natural tectonic lakes, 25 natural glacial lakes, 14 artificial lakes), wetlands and other larger sources of water. The rivers of North Macedonia belong to three different river basins: the Aegean, the Black Sea and the Mediterranean, with the Aegean being the largest, covering 87% of the territory. Lake Ohrid is the largest lake at 359 km^2 and a depth of 286 m, out of which, 230 km^2 are in North Macedonia, while the smallest is Dojran with only 43 km^2 and a depth of 10 m, out of which, 27 km^2 are located in North Macedonia. The Mavrovo lake is located at the altitude of 1197 m. Additional lakes include Prespa, Tikvesh, and Debar – Globochica (Global Water Partnership, 2022; Novak et al., 2010; Stefanovska et al., 2023). This country's rivers are divided into 4 river basins (Figure 1), including Crn Drim, Vardar, Binachka Morava and Strumica River Basins. The largest is Vardar, including its tributaries Treska, Lepenec, Pcinja, Bregalnica, Crna Reka, Bosava and Dosnica. It also includes the smallest natural lake in North Macedonia, Dojran Lake, which is a transboundary lake of North Macedonia and Greece. Additionally, the Aegean Basin also includes River Strumica, Cironska and Lebnica, with tributaries Vodoca, Turija, Radoviska and Podareska. Crn Drim River Basin is the second largest. In addition to the river Crn Drim (44.5 km long), it receives water from the Prespa and Ohrid lakes as well, two of the largest natural lakes in the country (Gjorgjievska et al., 2024; Micevska et al., 2018; Novak et al., 2010; Stefanovska et al., 2023).

Kosovo is also divided into 4 river basins, including Ibër, Drini I Bardhë, Morava e Binçës and Lepenc river basins (Figure 1). The Morava e Binçës basin originates from the Black Mountains in North Macedonia and flows north-east in Kosovo, through the Anamorava plain, Velekinca and up to the strait of Konçuli. It includes the river Morava e Binçës with its tributaries Kriva Reka (Lumi i Shtrembër) as well as Desivojca, Perlepnica, Gjilani, Livoçi, Cernica, Smira, Pogragja, Llashticë, Ribniku, Svintulbkes, Llapushnica, Pasjani, Zhegra, Letnica, and Pakita (Beranica). The Ibër River originates from six springs in mountains in Montenegro, flows into Kosovo at the Banja settlement, and eventually merges with the Morava River in Serbia, with a length of 90 km (in Kosovo), and approximately 270 km in total. The basin includes its tributaries: Sitnica (Gracanica, Prishtevka (Prishtina River), Sllakovaqa, Studime, Sazlia, Caraleva, Llapi, Drenica, Trepça, Smrekovnica, Gojbule, Dumnica), and Lushta, Kozareva, Bajska, Kamenica, Vuça, Gërkaja, Jashanica, Borogllava, Vraqeva, Trebiçka, Bistrica, Ceraja, Mushnica, Dubrava, Jagnjeniqa, Brusovaqa, Bernjaka, Çeçeva, Zubodolli (Albaniku), Zubqana, Drena, Tverdan, Leposavic and Sllatina, while also including the Gazivoda Reservoir, the largest water storage facility and drinking resource in Kosovo, out of 6 other surface water accumulations that Kosovo has (Batllava, Badovci, Livoçi, Radoniqi and Prilepnica). This basin holds the largest population share, including the capital city as well as industrial and mining cities. The Lepenc River Basin includes river Lepenc and its 30 tributaries. Tributaries include Nerodime river (the biggest and most significant) as well as Ortica, Kavaqeva, Dubrava, Biqeva, Verbeshtica, Suva Reka, Sushica, Ropoti, Prroi i Thatë, Murzhica, Kotlina, Koshtanjeva and Kerveniku rivers. The Drini I Bardhë River Basin originates in the Zhleb mountain in Peja, and includes tributaries such as Lumbardhi i Pejës, Lumbardhi i Deçanit, Lumbardhi i Prizrenit, Prue potok, Erenik, Istogu, Klina, Mirusha, Rimniku, Topluha and Lumbardhi i Prizrenit (Deltares and Abkons, 2024c; Government of the Republic of Kosovo, 2017; Hana et al., 2023; Popovic et al., 2022; Veselaj et al., 2020).

North Macedonia climate is variable across its territory with 8 different types such as sub-Mediterranean climate, temperate-continental, warm continental, cold continental, Podgrosko alpine climate, forest-continental alpine, subalpine, and alpine mountain (>2250 m). The Vardar basin is predominantly in the warm continental zone, with

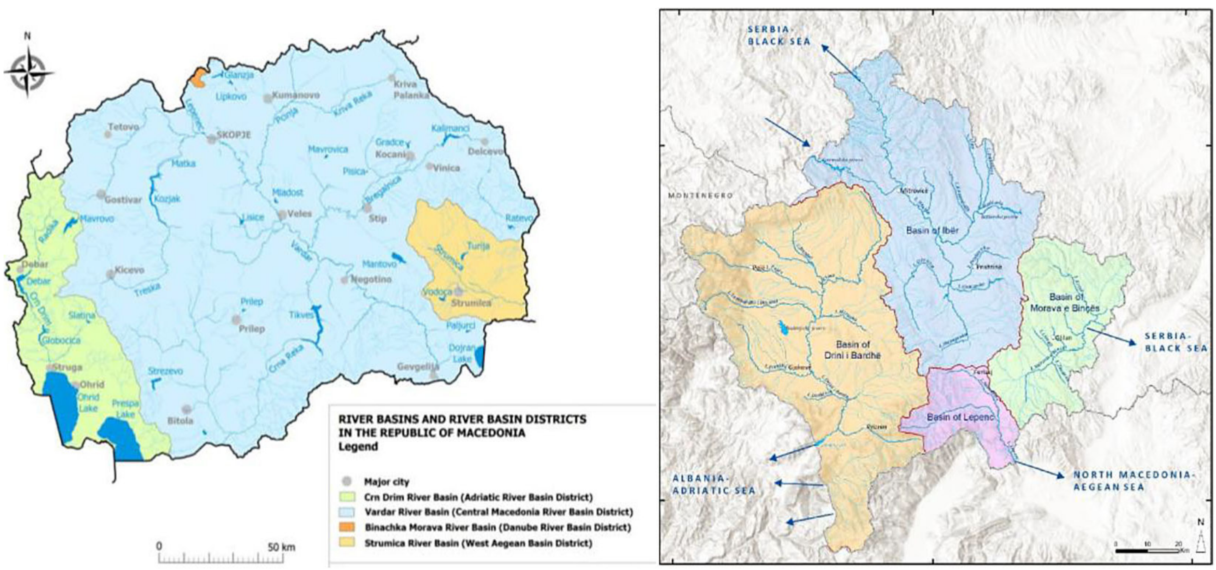

Figure 1. North Macedonia River Basins (left) (Novak et al., 2010), and Kosovo River Basins (right) (Deltares and Abkons, 2024b)

western parts of the basin being influenced also by Podgorsko climate and the forest – continental climate. The center of the basin is predominately temperate continental climate. The average temperature is 11.5 °C, and ranges from 22.2 °C during summer, to 0.3 °C during winter. The lowest temperature recorded was -32 °C in Berovo, and the highest was 48 °C in Demir Kapija. On average, North Macedonia receives 680 mm of rainfall annually, however the rainfall is very variable due to the terrain (more rainfall in the west, and less in the east) (Gjorgjievska et al., 2024; Стефановска et al., 2023). Kosovo is divided into three climatic areas, that of Kosovo, that of Dukagjini and that of mountains and forests. Winters can go on average down to -10 °C, and summers are on average 20 °C. However, more extreme temperatures have been observed, down to -26 °C and up to 37 °C. Rainfall is of the orographic and convective types. Annual precipitation varies between 400 and 1200 mm, with higher rainfall in the mountainous areas, however, amounts as high as 1265 mm have been recorded (Deltares and Abkons, 2024c; Veselaj et al., 2020).

Data sources

The data for this research were drawn from a combination of primary field-based assessments, government and institutional datasets, as well as geospatial and remote sensing tools:

- Institutional and statistical data: Kosovo Environmental Protection Agency, Kosovo Agency of Statistics, Ministry of Environment and Physical Planning of North Macedonia, and regional water utilities.
- Infrastructure datasets: coverage, type, treatment levels, discharge points, operational status, and compliance with EU Water Framework Directive (WFD) standards.
- Water quality data: parameters such as BOD, COD, nitrates, phosphates, heavy metals.
- GIS layers and spatial datasets: Land use/land cover (LULC), basin boundaries, population density, and urban growth.

DATA ANALYSIS

A structured framework was used to evaluate the coverage, capacity, as well as condition of wastewater treatment infrastructure and environmental monitoring systems.

- Coverage: proportion of population served by wastewater collection and treatment systems.
- Capacity: design vs. actual treatment volumes; peak load handling; operational efficiency.
- Compliance: whether effluent meets national and EU discharge standards.
- Technology and Age: type of treatment (primary, secondary, tertiary), system age, and maintenance needs.
- Decentralization: presence of small-scale or nature-based solutions in peri-urban/rural areas.
- Using GIS, spatial analysis was performed to identify the areas with:
- Low wastewater treatment coverage
- High population density and discharge proximity
- Known pollution hotspots (e.g., industrial discharge zones)
- Downstream vulnerability (e.g., wetland areas, drinking water sources)

These analyses supported the prioritization of regions needing infrastructure upgrades or targeted interventions. To evaluate future needs and potential solutions, the study used the DPSIR Framework (Drivers–Pressures–State–Impact–Response) for scenario planning. The study used technical and sustainability-oriented indicators to assess infrastructure gaps and performance (Table 1).

STATUS OF WATER AND ENVIRONMENTAL INFRASTRUCTURE AND IDENTIFIED GAPS

Wastewater treatment infrastructure

In North Macedonia, only 77% of the households are connected to the public sewer systems, and the rural population is in even worse condition with only 11% connected to the sewer system. The public water supply and wastewater treatment services are offered by public utility enterprises. These public utility enterprises are overseen by the Municipality, with the council being the authority that appoints the enterprise manager. These enterprises are responsible for the management and protection of water resources, including tanks, distribution network, operations, maintenance and protected zones. The existing system is old and inefficient; moreover, it does not provide sufficient coverage. Furthermore, 59.88% of households are connected

Table 1. Selected indicators for assessment of infrastructure

Category	Indicator	Source/Benchmark
Wastewater	% population connected to WWTP	SDG 6.3.1, EU WFD
Treatment quality	% compliance with discharge limits	EU Urban Wastewater Directive
Monitoring	Frequency of water quality testing	National standards
Resilience	System redundancy and modularity	IPCC/UN-Habitat
Investment	Per capita infrastructure investment	OECD average benchmarks

to the public sewer system, 20.55% of households have a septic tank, 12.19% are connected to the free wastewater pipeline and 7.39% have no connections at all. Currently, North Macedonia has 26 wastewater treatment plants, with a combined total of 691,241 Population equivalent (PE) or approximately 37% of the population and has gained loans and funding to build a new WWTP in Skopje with a capacity of 625,000 PE from the European Investment Bank, which is expected to be finished at the end of 2027. However, according to ADKOM, 7 WWTPs are not functional, 2 only offer basic treatment and 4 are having financial difficulties. The Kočani WWTP has a capacity of 65’000 PE and 55% of its power consumption is covered by solar and biogas from the anaerobic digestion of the sludge. Currently, WWTPs Volkovo, Ilinden, Kočani, Radovish, Berovo, Strumica, Dojran, Gevgelija, Vranishta and Prilep are operational, WWTPs Rankovce, Sveti Nikole, Lozovo, Jasenovo, Dolneni, Saraj and Debarca are not operational, WWTPs Chucher Sandevo, Kumanovo, Makedonski Brod, Resen, Kichevo and Krivogashtani are operational but with difficulties, whereas WWTPs Tetovo, Gostivar, Debar, Vevchani, Delchevo, Shtip, Kavadarci, Bitola and the new one in Skopje are planned but not yet built (Jovanovska and Sipovikj, 2020; Novak et al., 2010).

The wastewater management in Kosovo is primarily handled by Regional Water Companies (RWCs), which provide wastewater collection services to 68% of the population on average. Kosovo only has five functional wastewater treatment plants (Skenderaj, Prishtina, Harilaq, Badovc, Medvec – Vrelle, Orllan)(Deltares and Abkons, 2024c; Qevani et al., 2024b). Coverage varies by region, with RWC “Prishtina” serving 78% of its population and RWC “Mitrovica” covering 60%. In the Ibër River Basin, 72% of the population has access to sewer systems, but wastewater treatment is limited. Five functional treatment plants exist, with RWC “Mitrovica” managing one and RWC “Prishtina” operating four small facilities. Collectively, they treat a minimal portion of wastewater – RWC “Mitrovica” serves only 14% of households, while RWC “Prishtina” treats less than 1%. The situation is similarly poor in other basins. Currently, the KfW is in the process of preparation for the plans of two additional WWTPs, one in Prishtina (400’000 people) and one in Ferizaj (65’000 people). The Lepenc River Basin lacks domestic wastewater treatment facilities, whereas untreated wastewater is discharged into rivers and streams. Industrial facilities like Sharrcem operate private treatment plants for their processes, with Sharrcem recycling all water used. Settlements outside formal systems often rely on direct discharge or septic tanks. The Morava e Binçës River Basin has the lowest wastewater service coverage at 40% and lacks operational treatment plants. Although there is interest in developing future wastewater infrastructure, significant gaps remain across all regions. The Gjakova WWTPs is the newest facility that has been built and began operating in 2023, offering services to 213,000 people, while EBRD is currently supporting the construction of a new WWTP for the municipality of Gjilan which will be completed in 2026 (capacity of 76,000 PE) and has approved funding for a new WWTP in the municipality of Podujeva (capacity of 50,000 PE)(Deltares and Abkons, 2024a, 2024c, 2024b; Government of the Republic of Kosovo, 2017; Popovic et al., 2022).

Pollution control systems

Pollution control infrastructure remains rudimentary in Kosovo. Few industries operate with dedicated pre-treatment units, and stormwater management is largely unregulated (Bajra-Brahimaj et al., 2024; Gashi et al., 2023). When it comes to industrial discharge, major polluters include the thermal power plants (Kosova A and B), mining facilities (e.g., Trepça), and heavy industry (e.g., NewCo Ferronikeli), with dairy and food processing industries following closely behind. Only a handful of these facilities comply with discharge permits. There is widespread nutrient loading from fertilizers and livestock waste, especially in the Drini i Bardhë and Morava e Binçës basins. Likewise, urban areas lack separate sewer systems for stormwater, resulting in combined overflows and direct pollution of surface waters during rainfall (Deltares and Abkons, 2024c, 2024b; Government of the Republic of Kosovo, 2017; Popovic et al., 2022; Veselaj et al., 2020; World Bank Group, 2018).

North Macedonia has taken more systematic steps toward pollution control, particularly in terms of permit-based regulation and industrial monitoring, though enforcement remains inconsistent. Larger industries have some form of wastewater pre-treatment, especially in energy and food processing sectors, but small and medium enterprises often discharge untreated effluents. Like Kosovo, many cities in North Macedonia operate combined sewer systems prone to overflow. Agricultural runoff is a serious concern in regions such as the Vardar Valley, where irrigation-intensive farming coincides with high nutrient levels in nearby water bodies (Bakllamaja and Hristov, 2013; Dimitrovska et al., 2012; Global Water Partnership, 2022; Mirta, 2024; Novak et al., 2010).

Environmental monitoring infrastructure

Despite the existing legislative framework and policies, these countries face challenges when it comes to their capacity to enforce and implement them. This is mainly due to insufficient funding, lack of technical expertise, as well as limited coordination between agencies and institutions. As a result, the quality of surface and groundwater is lowered by industrial pollution, agricultural runoff, as well as untreated wastewater due to lacking enforcement and monitoring mechanisms (Alibašić, 2024; Begolli and Lajçi, 2016; Lecollinet, 2022; World Bank Group, 2018).

Kosovo's water management and environmental protection involve multiple institutions with distinct roles and responsibilities. Kosovo Environmental Protection Agency (KEPA) develops a unified environmental information system, monitors environmental quality, in addition to providing guidance for environmental assessments and policy implementation. Similarly, the Kosovo Hydrometeorological Institute (KHMI) oversees the monitoring of surface water, groundwater, and reservoirs, representing Kosovo internationally in meteorology and hydrology while managing long-term monitoring programs under the Law on Waters of Kosovo (Development, 2015; Government of the Republic of Kosovo, 2017; Kosovo Environmental Protection Agency, 2020; Qevani et al., 2024a).

The surface water quality monitoring in Kosovo is not as extensive as it ought to be, with 54 monitoring stations that measure 39 chemical parameters, 8 heavy metals and 10 physical parameters (Figure 2), while groundwater quality monitoring was practically non-existent or limited to small areas on a project basis. In 2022, the first groundwater level monitoring system was established. The existing monitoring system is mostly manual and sporadic, with delays in laboratory analysis, and Regular measurement of pollutants such as heavy metals, pharmaceuticals, and pesticides is rare (Deltares and Abkons, 2024c, 2024b, 2024a; Kosovo Environmental Protection Agency, 2020; Popovic et al., 2022). It is only recently that updates to the system have been planned and begun implementation as part of Swiss Government funding.

In North Macedonia, environmental monitoring systems are somewhat more developed, especially through partnerships with international agencies. Six ministries have responsibilities and competencies when it comes to water and resource management. North Macedonia also has the River Monitoring System Project (RIMSYS) (Figure 3), which takes samples monthly for approximately 100 parameters, including hydrological, physical, chemical, biological and harmful substances such as heavy metals and organic micropollutants (Dragovic et al., 2017; Micevska et al., 2018; Negm et al., 2020; Novak et al., 2010). The country's national hydrological institute published water quality data online on their website. Laboratory capacity has improved in recent years, though gaps remain in sediment and biota sampling, and automation is more prevalent for larger rivers like Vardar. North Macedonia has also developed the National Environmental Information System (NEIS) which collects data on air, water, and soil quality, but real-time updates are limited.

Identified gaps and implications

In both countries, infrastructure development has disproportionately favored urban centers and

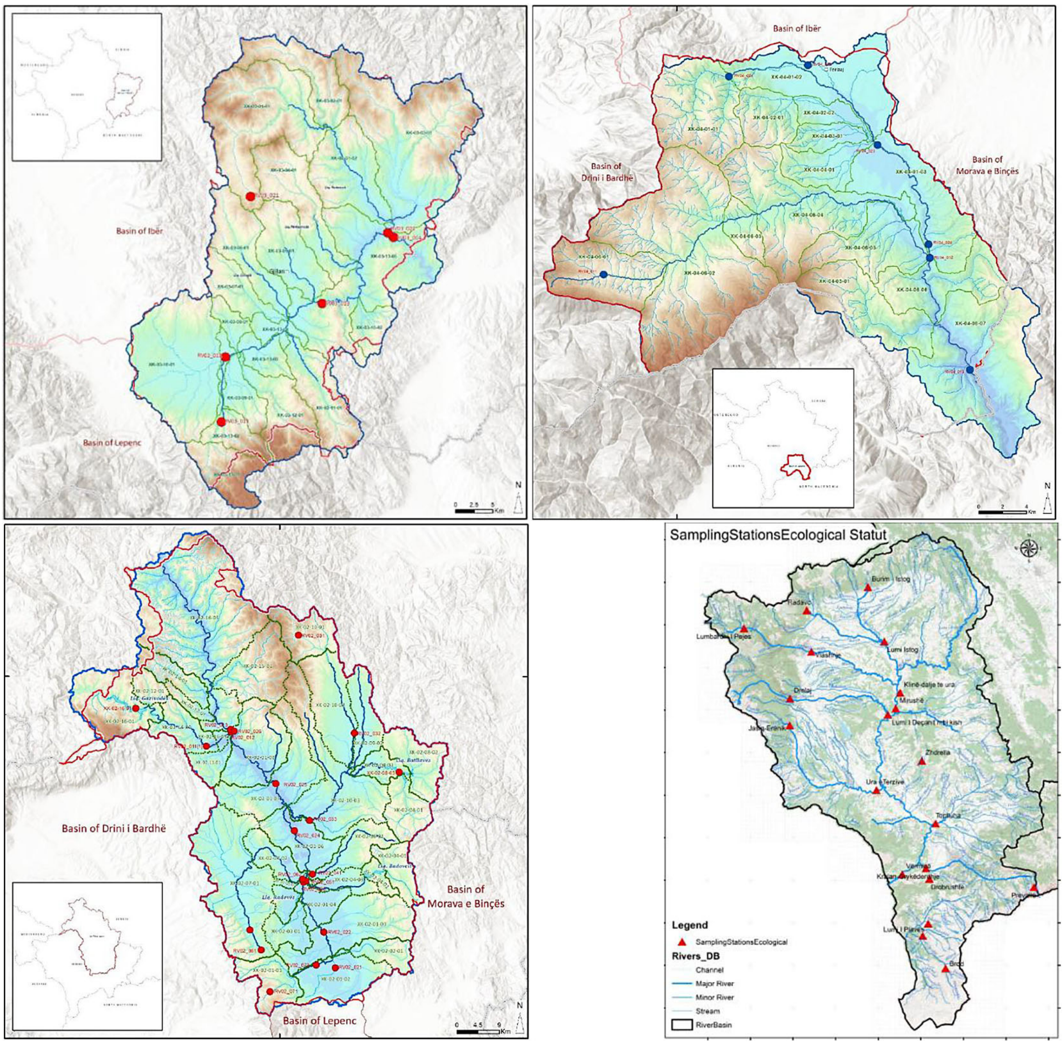

Figure 2. Water quality monitoring network in Kosovo's four basins (Deltares and Abkons, 2024c, 2024b, 2024a; Popovic et al., 2022)

EU-funded flagship projects. This has resulted in significant disparities. These gaps not only threaten environmental integrity but also widen the social equity gap, exposing poorer, rural, and marginalized communities to higher risks of pollution and health-related hazards. The urban wastewater treatment plant coverage is low in Kosovo and moderate in North Macedonia, with improvements having begun in major cities for both countries. On the other hand, the access to treatment in rural areas is very limited and fragmented, often even absent for both countries. When it comes to industrial regulation, Kosovo still has insufficient monitoring and weak permitting, while in North Macedonia, the issue is with uneven enforcement of regulations. Monitoring networks are incomplete in both countries and require updating. Nature based solutions are very rare in Kosovo and quite limited in North Macedonia, mostly pilot scale.

The core technical limitations in both countries pertain to insufficient infrastructure coverage, outdated technologies, and low operational efficiency. Kosovo has inadequate wastewater treatment coverage, with less than 20% of the population served by functional WWTPs and an overreliance on centralized systems, even in areas better served by decentralized or modular approaches. Likewise, the lack of redundancy leaves systems vulnerable to overloads and failure during peak flows or storm events. North Macedonia on the other hand, has ageing infrastructure, much of which was built decades ago with insufficient upgrades, and underperforming treatment plants due to outdated or missing tertiary treatment stages. Similarly to Kosovo, there

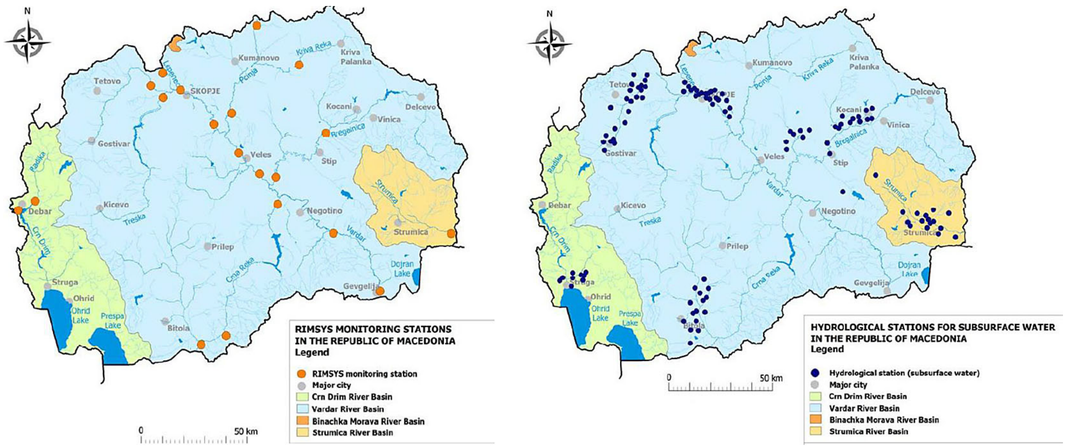

Figure 3. North Macedonia RIMSYS monitoring points (left) and groundwater monitoring points (right) (Novak et al., 2010)

is low adoption of nature-based solutions, despite their potential in small towns and rural settings.

Technical issues are compounded by institutional fragmentation and planning deficiencies, which limit strategic coordination and long-term investment. There is insufficient cross-sectoral coordination, especially between water, agriculture, environment, and health sectors. The lack of integrated planning tools, such as watershed-based investment frameworks or adaptive infrastructure strategies and weak data systems as well as monitoring that hinder evidence-based planning and compliance tracking, have added to the problem and a lack of sustainable solutions even more. This is all made worse by financial constraints, with insufficient public investment, limited access to climate financing, and weak incentives for private sector participation.

Infrastructure gaps translate directly into ecological degradation as well as increased risks to human health and livelihoods (Harmancioglu et al., 2013; Sun and Fei, 2019). Nutrient and pathogen pollution in surface waters leads to eutrophication, biodiversity loss, and degraded ecosystem services. Pollution hotspots in rivers such as the Lepenc, Ibër, and Vardar threaten aquatic life and downstream users (Deltares and Abkons, 2024c, 2024a). Cumulative impacts of untreated industrial discharge, agricultural runoff, and domestic wastewater erode the resilience of hydrological systems. The exposure to untreated wastewater increases the prevalence of gastrointestinal and waterborne diseases, particularly in vulnerable rural populations. Polluted surface waters affect drinking water sources, irrigation quality, and recreational use. Lack of resilient sanitation in flood-prone or drought-sensitive areas exacerbates health risks under climate stress (Clini et al., 2008; Novotny, 2020; Shahzad, 2023).

The failure to modernize water and environmental infrastructure imposes significant costs on the economy and society, bringing issues such as loss of agricultural productivity due to degraded water quality and limited irrigation safety, industrial inefficiencies, particularly for the sectors relying on high-quality process water or regulated discharge permits, reduced competitiveness in attracting investment, especially in tourism and sustainable agriculture sectors, as well as increased public expenditures for health care, environmental remediation, and emergency response to floods or contamination events (Jensen, 2009; Krakowiak-Bal and Vaverkova, 2019; OECD, 2006; Pandey et al., 2021).

ENGINEERING AND NATURE-BASED SOLUTIONS, AND RECOMMENDATIONS

Addressing the infrastructure deficits in Kosovo and North Macedonia requires a dual-track approach: upgrading and expanding conventional engineering systems while simultaneously introducing nature-based and decentralized solutions. Lack of reliable, real-time data continues to hinder planning, enforcement, and infrastructure performance evaluation. The first step that must be undertaken is to modernize the water quality monitoring networks with automatic sensors and digital reporting platforms which would also require all wastewater treatment facilities to install SCADA or equivalent monitoring systems. Likewise, the national portals for infrastructure performance must be updated and dashboards must be accessible to the public and decision-makers.

In urban and peri-urban areas where centralized infrastructure already exists or is under development, technical upgrades and process optimization can significantly improve performance and compliance with the EU standards. Therefore, in such cases, secondary treatment systems should be retrofitted with tertiary modules to remove nutrients and micropollutants. Automation and real-time monitoring should be added to improve operational efficiency, especially in large WWTPs. For developing countries like Kosovo and North Macedonia, it is very important to valorize such infrastructure; therefore, energy recovery and resource reuse (e.g., anaerobic digestion for biogas, treated effluent for irrigation) are very important strategies that should be implemented.

For small towns, rural settlements, and remote areas not served by centralized systems, decentralized or modular treatment options provide cost-effective and environmentally friendly alternatives. This would include technologies like constructed wetlands, anaerobic baffled reactors, sequencing batch reactors, mobile WWTP in containers, and/or bio-digesters. These technologies are optimal in such cases due to their higher adaptability to terrain and settlement patterns, which is very important, especially for Kosovo and its hilly terrain. Likewise, these technologies have lower capital and operating costs, reduced land and energy use, in addition to being easier to operate and maintain. In Kosovo, constructed wetlands have been piloted in Rahovec, Kramovik village and studies have been conducted on the potential for implementation of constructed wetlands all over Kosovo (Lavdim Osmanaj et al., 2015; Sanchez and Krasniqi, 2024). In North Macedonia, decentralized systems are being explored for national parks and touristic zones where seasonal loads require flexible solutions.

This concept would also support the implementation of Nature-based solutions (NbS). The first step is to adopt a national NbS policy framework, including technical standards, design templates, and eligibility criteria for public funding. Countries must also offer fiscal incentives for municipalities or industries that implement NbS for wastewater or runoff management and encourage pilot-to-scale programs in areas with high ecological or tourism value (e.g., wetlands near protected areas, rural eco-villages). This would include the creation of riparian buffer zones for nutrient filtration, floodplain restoration to increase retention and reduce sediment loads, implementation of green infrastructure in urban areas and implementing agro-environmental practices such as contour planting and reduced fertilizer applications near water bodies. This would ensure biodiversity conservation, groundwater recharge, and carbon sequestration in addition to the aesthetic and recreational value.

To be able to design and implement these technical and natural solutions, the access to planning and optimization tools must first be ensured. Advanced modeling tools enable infrastructure managers and planners to assess trade-offs, optimize system performance, and plan adaptively under uncertainty. Infrastructure development should be planned at the river basin scale to ensure hydrological coherence and avoid fragmented investments. Tools such as GIS, SWAT and WEAP can aid in identifying hotspots of pollution and prioritizing investment, simulating the cost-benefit scenarios for centralized vs. decentralized systems, and evaluate the climate resilience of infrastructure options.

However, sustainable infrastructure solutions require not only technical designs but also enabling financial and policy environments. Addressing the infrastructure gap requires long-term, diversified, and climate-sensitive financing strategies. The recommendation is to develop the project pipelines that meet eligibility for international climate and development finance (e.g., GCF, IPA III, EIB), enable public-private partnerships (PPPs) for decentralized infrastructure and service delivery, introduce performance-based funding mechanisms, especially in rural areas (e.g., outcome-linked grants), and explore co-financing models with community contributions, diaspora investments, and environmental funds.

Sustainable infrastructure cannot be achieved without trained personnel, knowledge transfer, and professional development. Therefore, countries must create regional training centers for plant operators, environmental inspectors, and municipal engineers. Additionally, industry must partner with universities and technical institutes to offer certification programs in water and wastewater engineering as well as establish peer learning platforms between municipalities and cross-border cooperation units to exchange best practices.

CONCLUSIONS

This study provided a comprehensive assessment of the infrastructure challenges in water and environmental management across Kosovo and North Macedonia. The analysis highlighted persistent deficits in wastewater treatment coverage, pollution control systems, and environmental monitoring capacity, particularly in rural and underserved regions. These gaps threaten both ecological integrity and public health, while also impeding the progress toward EU Water Framework Directive compliance and key Sustainable Development Goals.

The research identified a range of interlinked challenges – technical limitations, institutional fragmentation, outdated infrastructure, and weak data systems – that must be addressed through integrated and strategic interventions. The paper presented a portfolio of actionable recommendations, combining engineering upgrades with decentralized and nature-based solutions, supported by digital monitoring tools and basin-scale planning frameworks. Moreover, it emphasized the necessity of enabling policy and financing environments, cross-sectoral coordination, and capacity-building efforts to ensure long-term infrastructure sustainability.

Ultimately, bridging these infrastructure gaps is not only a technical imperative but a governance challenge that demands systemic reform and regional collaboration. The insights and solutions proposed herein can serve as a roadmap for the Western Balkans and similar regions navigating the intersection of environmental degradation, climate pressures, and development needs.

REFERENCES

1. Aho, K. B., Flotemersch, J. E., Leibowitz, S. G., Johnson, Z. C., Weber, M. H., Hill, R. A. (2020). Adapting the index of watershed integrity for watershed managers in the Western Balkans Region. *Environmental Management*, *65*(5), 602–617. https://doi.org/10.1007/s00267-020-01280-x
2. Bajra-Brahimaj, T., Sahiti, H., Dalo, E., Zogaj, M., Muriqi, S., Ibrahimi, A. C. (2024). Assessing environmental pollution in Kosovo's industrial areas using plant bioindicators. *Journal of Ecological Engineering*, *25*(3), 155–162. https://doi.org/10.12911/22998993/178488
3. Bakllamaja, A., Hristov, G. (2013). *Macedonia Water and Wastewater Sector Challenges*. Lap Lambert Academic Publishing GmbH KG. https://books.google.com/books?id=uoVpngEACAAJ
4. Clini, C., Musu, I., Lodovica Gullino, M. (2008). *Sustainable Development and Environmental Management: Experiences and Case Studies*. Springer.
5. Deltares, Abkons. (2024a). *River Basin Management Plan for Lepenc River Basin, Kosovo*.
6. Deltares, Abkons. (2024b). *River Basin Management Plan for Morava e Binçës River Basin, Kosovo*.
7. Deltares, Abkons. (2024c). *River Basin Management Plan of the Ibër River Basin, Kosovo*.
8. Development, O. E. C. O. (2015). *The Governance of Water Regulators*. IWA Publishing. https://books.google.com/books?id=WIMbCgAAQBAJ
9. Dimitrovska, O., Markoski, B., Toshevska, B. A., Milevski, I., Gorin, S. (2012). Surface water pollution of major rivers in the Republic of Macedonia. *Procedia Environmental Sciences*, *14*, 32–40. https://doi.org/10.1016/j.proenv.2012.03.004
10. Dragovic, N., Ristic, R., Pülzl, H., Wolfslehner, B. (2017). *Natural Resource Management in Southeast Europe: Forest, Soil and Water*.
11. Gashi, S., Sofiu, V., Balaj, N. (2023). Surface water pollution from urban and industrial waste – A case study of the Lumbardhi River flow, Prizren (Kosovo). *Ecological Engineering and Environmental Technology*, *24*(7), 30–37. https://doi.org/10.12912/27197050/169385
12. Gjorgjievska, T., Stankov, D., Angelov, K., Zekjirovikj, E. (2024). *Statistical Yearbook of the Republic of North Macedonia*.
13. Global Water Partnership. (2022). *Country Brief: North Macedonia*.
14. Goosen, M. F. A. (2012). Environmental management and sustainable development. *Procedia Engineering*, *33*, 6–13. https://doi.org/10.1016/j.proeng.2012.01.1171
15. Government of the Republic of Kosovo. (2017). *Kosovo National Water Strategy Document 2017–2036*.
16. Hana, D., Xhaferi, H., Maksuti, A., Duraku, S., Dabiqaj, B., Bajrami, S. (2023). *Kosovo Green Report 2023*.
17. Harmancioglu, N. B., Barbaros, F., Cetinkaya, C. P. (2013). Sustainability issues in water management. *Water Resources Management*, *27*(6), 1867–1891. https://doi.org/10.1007/s11269-012-0172-4
18. Jensen, J. N. (2009). *Public Health and Environmental Infrastructure Implications of Hurricanes Katrina and Rita*. DIANE Publishing Company. https://books.google.al/books?id=XultiNgf0cIC
19. Jovanovska, A., Sipovikj, S. (2020). *SDG: Voluntary National Review - North Macedonia*.
20. Kagalou, I., Latinopoulos, D. (2020). Filling the gap between ecosystem services concept and river basin

management plans: The case of Greece in WFD 20+. *Sustainability (Switzerland)*, *12*(18). https://doi.org/10.3390/su12187710

21. Kosovo Environmental Protection Agency. (2020). *Raport: Gjendja e Ujërave në Kosovë 2020*.
22. Krakowiak-Bal, A., Vaverkova, M. (2019). *Infrastructure and Environment*. Springer International Publishing. https://books.google.al/books?id=nsSuwgEACAAJ
23. Osmanaj, L., Haxhikadrija, A., Dodane, P.-H., Vokshi, A. (2015). Potential of constructed wetland for wastewater treatment in rural areas in Kosovo. *J. of Hydraulic Engineering*, *1*(1). https://doi.org/10.17265/2332-8215/2015.01.003
24. Lundqvist, J., Lohm, U., Falkenmark, M. (1985). *Strategies for River Basin Management : Environmental Integration of Land and Water in a River Basin*. Springer Netherlands.
25. Maksimoví, C., Makropoulos, C. K. (2002). Integrating river basin management and the coastal zone: the (blue) Danube and the (black) Sea. *Water Science & Technology*, *46*(8), 187–149. https://doi.org/https://doi.org/10.2166/wst.2002.0177
26. Micevska, O., Kukulovski, I., Petkovski, L. (2018). *Analysis of situation with water management in the Republic of Macedonia and consumers rights protection*.
27. Mirta, Y. (2024, June 4). North Macedonia' priorities as new Party to The Protocol on Water and Health in the area of WASH and climate. *EUGreenWeek*.
28. Negm, A., Romanescu, G., Zelenakova, M. (2020). *Water Resources Management in Balkan Countries*. https://doi.org/10.1007/978-3-030-22468-4
29. Novak, J., Kodre, N., Terpin Savnik, S., Repnik Mah, P., Šiško Novak, S., Dolinar, D., Pipus, G., Kegl Pivec, N., Ivanc, A., Dodic, J., Erzen, P., Panovski, Z., Popovska, C., Dodeva, S., Boev, B., Ilijovski, Z., Stojanova, E. (2010). *Water Strategy for the Republic of Macedonia*.
30. Novotny, V. (2020). *Integrated sustainable urban water, energy, and solids management*. John Wiley & Sons Inc.
31. OECD. (2006). *Environmental Finance Financing Water and Environment Infrastructure The Case of Eastern Europe, the Caucasus and Central Asia: The Case of Eastern Europe, the Caucasus and Central Asia*. OECD Publishing. https://books.google.al/books?id=UhyBlkvgL3cC
32. OECD. (2021). *Multi-dimensional Review of the Western Balkans*. OECD. https://doi.org/10.1787/4d5cbc2a-en
33. Pandey, V. P., Shrestha, S., Wiberg, D. (2021). *Water, Climate Change, and Sustainability*. Wiley. https://books.google.al/books?id=AVQmEAAAQBAJ
34. Popovic, M., Mulla, F., Maluenda, J., Krasniqi, E., Dana, H., Ibrahimi, H., Kamberi, F., Kasapolli, A., Morina, R., Qela, T., Sahiti, F., Bojkovska, R., Sutovic, A., Shala, A., Hasani, H., Kastrati, B., Bublaku, S., Azizi, A. (2022). *Plani i Menaxhimit të Pellgut të Lumit Drini i Bardhë*.
35. Qevani, B., Kurti, H., Ahmeti, I., Shosholli, F. (2024a). *Statistikat e Bujqësisë dhe Mjedisit*.
36. Qevani, B., Kurti, H., Ahmeti, I., Shosholli, F. (2024b). *Statistikat e Ujërave në Kosovë 2022–2023*.
37. Sanchez, D. P., Krasniqi, V. (2024). Engineered wetlands use case for climate change adaptation of vineyards in the Rahovec wine region of Kosovo. *Nature-Based Solutions*, *6*. https://doi.org/10.1016/j.nbsj.2024.100158
38. Shahzad, N. (2023). *Water and Environment for Sustainability: Case Studies from Developing Countries*. Springer Nature Switzerland.
39. Skoulikidis, N. T. (2009). The environmental state of rivers in the Balkans – A review within the DPSIR framework. In *Science of the Total Environment* 407(8), 2501–2516. https://doi.org/10.1016/j.scitotenv.2009.01.026
40. Sun, R., Fei, L. (2019). Environmental Science Sustainable Development of Water and Environment. In *Proceedings of the ICSDWE*. http://www.springer.com/series/3234
41. Tockner, K., Uehlinger, U., Robinson, C. T. (2009). *Rivers of Europe*. Academic Press.
42. Veselaj, T., Mehmeti, M., Shala, A., Gashi, P., Buza, F., Fetoshi, O., Bilalli, F., Raci, S., Hasani, H., Berisha, A., & Berisha, F. (2020). *Report the State of Water in Kosovo 2020*.
43. Vuković, A., Mandić, M. V. (2020). *Study on climate change in the Western Balkans*. www.rcc.int
44. White, O., Sadauskis, R., Sheate, W., Papadopoulou, L. (2018). *Water Use in the Western Balkans: regional outlooks and global megatrends*.
45. World Bank Group. (2018). *Water Security Outlook for Kosovo*. www.worldbank.org
46. Stefanovska, A., Shaqiri, A., Nestorovska - Krsteska, A., Malkov, P., Golubov, N., Tasic, I., Cvetkovska, M., Rushiti, A., Nikolovska, K., Dimiskova, A., Obradovic Grncharovska, T., Trpeski, V., Jordanov, S., Kamcheva, D., Zeqirovic, E. (2023). *Environmental Quality in the Republic of North Macedonia:* Annual Report 2022.