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State of the art report for case study areas

Water System Solutions Study

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Executive Summary

This deliverable presents a state-of-the-art assessment of drinking water supply systems in rural and mountainous areas relevant to the WATERVILL project.

The document is based on national and partner-level inputs provided by project partners. The assessment focuses on institutional responsibilities, service provision models, ownership and management of water resources, regulatory and policy frameworks, financing conditions, and the specific challenges faced by rural and mountainous water supply systems.

The deliverable aims to provide a structured overview of the national and local framework conditions affecting the implementation and replication of WATERVILL solutions. Particular attention is given to small-scale and village water supply systems, ageing infrastructure, water losses, limited technical and financial capacity, seasonal demand pressures, climate-related water scarcity, and the role of municipalities and public utilities.

The report also identifies key preconditions for replication and transfer of WATERVILL solutions across partner countries. These include adequate institutional responsibilities, availability of financing, technical capacity of municipalities and operators, monitoring and digitalisation readiness, and regulatory compatibility.

The findings will support future project activities by helping partners understand how technical, digital and governance solutions can be adapted to different national and territorial contexts.

1. Introduction

Rural and mountainous areas across the Mediterranean face increasing challenges related to drinking water supply, water scarcity and the long-term resilience of local water services. Many of these territories rely on small, fragmented or independent water supply systems that are technically vulnerable, financially constrained and often exposed to climate-related pressures. Ageing infrastructure, high water losses, insufficient monitoring, limited technical capacity and seasonal variations in demand can significantly affect the reliability, efficiency and safety of water supply services.

The WATERVILL project addresses these challenges by focusing on innovative solutions for enhancing village water supply and addressing water scarcity in resilient rural and mountain areas. The project aims to support the modernisation of rural water management through a combination of technical, digital, governance and capacity-building measures. Particular attention is given to solutions that can reduce water losses, improve monitoring and decision-making, strengthen local management capacity and support the replication of effective practices across different territorial contexts.

The project is implemented in a transnational setting, involving partners from several Mediterranean and South-East European countries. This is important because rural and mountainous water supply systems often face similar operational problems, but they function within different institutional, legal, financial and territorial frameworks. A comparative and structured assessment is therefore needed to understand both shared challenges and country-specific conditions affecting the implementation of WATERVILL solutions.

> This State of the Art Report provides a baseline assessment of drinking water supply systems in the WATERVILL case study areas. It examines the current condition of selected rural and mountainous water supply systems and identifies the main technical, governance, financial, operational, regulatory and climate-related challenges affecting their performance.
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> The report is prepared within Activity 1.1 – State of the art analysis of the current condition of the Water Supply Systems. It supports the collection and assessment of relevant information on existing systems, including general system characteristics, institutional responsibilities, service provision models, water resources, infrastructure condition, operational performance, financial data, digital readiness and climate resilience.
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> The objective is not only to describe the current situation, but also to identify the gaps and needs that must be considered in later WATERVILL activities. These include the development of a database of solutions, the design of the Decision Support System, the preparation of pilot demonstration cases and the transfer of results to other rural and mountainous territories.

Rural and mountainous water supply systems require specific attention because their challenges differ from those of larger urban systems. They often serve dispersed settlements, operate across difficult terrain and depend on long network sections with a relatively small number of users. This can increase construction, operation and maintenance costs while reducing the financial capacity of operators and municipalities to invest in system renewal.

Small-scale and village water supply systems are particularly important in this context. In some territories, they operate outside the main public water supply network or are only partially integrated into formal public service structures. Such systems may have limited professional management, incomplete technical documentation, weak monitoring, uncertain financing and insufficient capacity for long-term maintenance. These characteristics can increase risks related to water losses, water quality, operational reliability and climate resilience.

At the same time, these systems represent an important opportunity for WATERVILL. Improving monitoring, strengthening local governance, supporting digitalisation, reducing leakages and improving decision-making can generate significant benefits for communities that are often less covered by conventional infrastructure programmes. The state-of-the-art assessment therefore focuses both on current weaknesses and on the potential for practical, transferable solutions.

> The report combines two levels of analysis.
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> The first level is the national and partner-level overview, which describes the broader institutional, legal, financial and regulatory context in which municipalities and water operators function. This level is important for understanding responsibilities, tariff rules, financing mechanisms, water resource governance, public service models and the status of small-scale systems in each partner context
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> The second level is the pilot municipality assessment, which focuses on the actual condition and operation of water supply systems in the selected case study areas. This includes municipal governance arrangements, service coverage, water sources, infrastructure characteristics, maintenance practices, water quality monitoring, water losses, financial performance, climate risks, digital tools, data availability and local innovation needs.

By combining these two levels, the report connects national framework conditions with local implementation realities. This approach makes it possible to distinguish between challenges that are primarily technical, such as ageing pipes or high leakage, and challenges that are institutional, financial or regulatory, such as unclear responsibilities, insufficient tariff revenues or weak integration of village systems.

2. Methodology

2.1 Purpose of the methodology

The methodology for this State of the Art Report is based on the systematic collection, structuring and assessment of information related to drinking water supply systems in the WATERVILL case study areas. The aim is to establish a clear and comparable baseline of the current condition of rural and mountainous water supply systems and to identify the main technical, governance, financial, operational and climate-related challenges affecting their performance.

The assessment follows the logic of Activity 1.1 – State of the art analysis of the current condition of the Water Supply Systems. This activity focuses on collecting and analysing key information on existing water supply systems, including general system characteristics, time-series data, spatial data and financial data. The collected information provides the basis for understanding the starting point of each pilot area, identifying critical gaps and supporting the design of later WATERVILL activities.

The methodology combines two analytical levels:

- The first level is the national and institutional context, which explains the governance, legal, financial and regulatory framework within which municipalities and water operators function
- The second level is the pilot municipality assessment, which focuses on the actual condition, operation and challenges of water supply systems in the selected case study areas.

This two-level approach is necessary because the performance of rural and mountainous water supply systems depends not only on infrastructure and technical conditions, but also on the institutional setting, financing mechanisms, tariff rules, ownership models, operator capacity and regulatory requirements that shape local implementation

2.2 Data collection instruments

Two main data collection instruments were used for the preparation of this report.

The first instrument is the Partner-level national overview. This document provides a high-level description of the national and institutional context relevant to drinking water supply systems in rural and mountainous areas. It covers the distribution of responsibilities between national, regional, municipal and utility levels, service provision models, ownership and management of water resources, tariff setting, financing mechanisms, small-scale and village water supply systems, regulatory challenges and conditions for replication of WATERVILL solutions.

The purpose of the partner-level overview is to support comparability between partner countries and to explain the institutional context in which pilot municipalities operate. This is important because similar technical problems, such as ageing infrastructure, water losses or insufficient monitoring, may be influenced by different national governance models, financing arrangements, legal frameworks and institutional capacities.

The second instrument is the pilot municipality questionnaire. This questionnaire collects more detailed information on the current condition and operation of water supply systems in the pilot municipalities. It covers governance and institutional arrangements, ownership and management models, service provision and coverage, water resource governance, tariff setting, financial governance, regulatory barriers, water quality management, maintenance practices, operational challenges, technical and financial system data, climate risks, digitalisation needs and transferable solutions.

The pilot municipality questionnaire was designed to capture local conditions and operational realities that cannot be fully understood from national-level information alone. It therefore provides the core evidence base for the case study profiles and for the comparative analysis of pilot areas.

2.3 Types of data collected

The collected data can be grouped into several categories:

General system data include information such as the number of inhabitants, number of connected users, service coverage, system length, number of supply units, water sources and basic characteristics of the water supply network

Operational and time-series data include hourly or daily water supply flow curves, load curves, water production, water consumption, peak demand, leakage rates and water losses. These data are important for understanding system performance, identifying periods of operational stress and assessing the scale of non-revenue water

Spatial data include GIS or AutoCAD network data, locations of water sources, supply units, wells, reservoirs, pumping stations and end users. Spatial data are important for understanding the physical structure of the systems and for supporting future modelling, asset management and decision-support activities

Financial data include water tariffs, water supply costs per unit, revenues, expenses, maintenance costs, costs associated with water losses and investment financing sources. These data are used to assess the financial sustainability of the systems and the ability of municipalities and operators to finance maintenance, rehabilitation and future upgrades

Governance and regulatory data include information on ownership, operation, maintenance responsibilities, tariff approval, water abstraction permits, quality monitoring responsibilities, institutional barriers and the role of municipalities, public utilities and national authorities

Climate resilience and innovation data include information on water scarcity, seasonal variations in demand, droughts, floods, heatwaves, hydrogeological conditions, nature-based solutions, digital monitoring, SCADA systems, smart metering, GIS availability and other tools relevant for improving system resilience

2.4 Assessment approach

After collection, the data were structured and assessed in order to identify the main characteristics, similarities and differences between the case study areas. The assessment focuses not only on the technical condition of the water supply systems, but also on the governance, financial, regulatory and organisational factors that influence their long-term sustainability.

The assessment is based on a common set of thematic dimensions applied across all pilot municipalities. These include governance and institutional arrangements, service provision models, water resources, infrastructure condition, operational performance, water quality management, financial sustainability, climate resilience, digital readiness and transferability potential. This common structure enables comparison between case study areas while still allowing each local context to be described in sufficient detail.

Particular attention is given to small-scale and village water supply systems, because these systems are often more vulnerable to water quality risks, limited financing, weak monitoring, fragmented management and climate-related pressures. Their status and level of integration into formal public water supply systems are therefore important for understanding both current challenges and future replication potential.

2.5 Data limitations and use of findings

The methodology recognises that data availability differs between municipalities and countries. Some pilot areas may have detailed technical, spatial or financial data, while others may rely on partial records, descriptive information or estimates. For this reason, the report does not only present available data, but also identifies data gaps that may affect future modelling, pilot design and the development of WATERVILL tools.

The information presented in this report is based on partner-level inputs, pilot municipality questionnaires, existing documentation and available institutional knowledge. Where quantitative data were not available, qualitative descriptions provided by partners and municipalities were used to identify key challenges and contextual factors. A consistent notation is used in the comparative matrix to distinguish between data that were not provided, indicators that are not applicable to a given system, values that are not measured because no metering is in place and confirmed zero values. Where the assessment of a specific system relies primarily on qualitative rather than measured information, this is indicated in the relevant case study section, so that descriptive findings are not read as quantified results. Such limitations are explicitly considered in the assessment and are treated as relevant findings, particularly in relation to digitalisation readiness, monitoring capacity and decision-support needs.

The findings of this report will be used as a basis for later project activities. The national and partner-level inputs support the understanding of institutional and regulatory conditions. The pilot municipality inputs provide the basis for assessing the current state of water supply systems in the case study areas. The combined findings will inform the development of the database of solutions, the Decision Support System, pilot demonstration cases, capacity-building activities and transferability measures.

Overall, this methodological approach enables the report to connect the current condition of water supply systems with the future implementation of WATERVILL solutions. It provides a structured basis for identifying where technical, digital, governance and capacity-building measures are most needed and where they may be most effectively replicated.

3. National and partner-level overview of drinking water supply systems

This chapter provides a national and partner-level overview of drinking water supply systems relevant to the WATERVILL project. Its purpose is to explain the broader institutional, legal, financial and operational framework within which rural and mountainous water supply systems operate in the partner countries.

The analysis is based on partner inputs and focuses on the distribution of responsibilities between national, regional, municipal and utility levels; service provision models; ownership and management of water resources; tariff setting and financing mechanisms; regulatory and policy frameworks; and the specific challenges faced by small-scale, rural and mountainous water supply systems.

The chapter does not assess individual pilot municipalities in detail. Instead, it provides the national and institutional context needed to understand the conditions under which WATERVILL solutions may be implemented, replicated and transferred.

This distinction is important because similar technical challenges, such as ageing infrastructure, high water losses, insufficient monitoring or seasonal water scarcity, may be shaped by different governance models, financing arrangements and regulatory requirements in each country.

The partner contributions cover several complementary perspectives:

- Local public authorities provide direct insight into pilot areas, local infrastructure conditions and implementation needs
- Local government associations contribute knowledge on municipal responsibilities, governance models, institutional capacities and transferability across municipalities
- The water sector association provides professional and technical knowledge on utilities, regulation and operational challenges
- Academic partners contribute research-based perspectives related to climate resilience, digitalisation, water management, hydrology and decision-support tools.

Together, these contributions create a comparative basis for identifying common challenges, country-specific barriers and transferable WATERVILL solutions.

3.1 Republic of Srpska, Bosnia and Herzegovina – Association of Municipalities and Cities of the Republic of Srpska (AMCRS)

This section presents the assessment provided by the Association of Municipalities and Cities of the Republic of Srpska (AMCRS). Water governance and communal service frameworks in Bosnia and Herzegovina are organised through different jurisdictional levels. The legal, institutional and policy analysis presented below therefore describes the framework applicable in the Republic of Srpska, one of the two entities of Bosnia and Herzegovina, and does not describe a single country-wide system.

3.1.1 Governance, service provision and water resource management

In the Republic of Srpska, drinking water supply is primarily organised through local self-government units and public water utility companies. Municipalities and cities are responsible for ensuring the provision of water supply services, usually as founders of public water utility companies. The public water utility company is responsible for operational service delivery, including the supply of drinking water to end users, daily system operation, maintenance and technical management.

Ownership and management responsibilities are divided between municipalities or cities and public utility companies. Municipalities and cities generally own water supply infrastructure, while public water utility companies are entrusted with its management, operation and use. This creates a decentralised public service model in which local governments retain a strong role as owners, organisers, financiers and partial regulators, while utilities act as operational service providers.

Planning and financing of infrastructure investments are mainly carried out at the level of the municipality or city, through local assemblies and municipal or city budgets. Investment financing may combine several sources, including local budgets, loans, grants from the Government of the Republic of Srpska, international donor support, revenues from water bills and water-related fees. This makes the investment capacity of water supply systems strongly dependent on the financial capacity and priorities of individual local self-government units.

The main model of drinking water service provision is a decentralised public model based on local public water utility companies. Participation of the private sector is very limited. In larger urban areas, services are generally provided through more developed public utility systems with professional management, more extensive networks and more systematic water quality control. In rural and mountainous areas, local or village water supply systems are more common, infrastructure coverage is weaker, and technical and management capacities are often limited.

Small-scale and village water supply systems are present in many rural, mountainous and less densely populated areas. These systems are typically found in settlements that are not connected to the central municipal network. They often use local springs, wells or captured sources and are managed by local communities, user committees or local associations. Their networks are usually small, the number of users is limited, and financing is commonly based on user contributions or local fees.

The legal and institutional status of small-scale and village systems is mixed and only partially regulated. Some systems are formally registered as local associations, water supply organisations or entities recorded by municipalities, while others operate on the basis of local community arrangements without full formal registration.

> *Small-scale and village systems are subject to basic sanitary and public health requirements, particularly regarding drinking water safety, but they are not supervised in the same systematic way as public water utilities. Oversight is often occasional and depends on municipal capacities, inspection activities or donor-supported projects.*

Water resources in the Republic of Srpska have the status of a public good and cannot be privately owned. Surface water and groundwater are managed at the entity level. The Republic of Srpska defines the legal and strategic framework for water management, water protection and water use. The main authority responsible for water abstraction and use permits is the Ministry of Agriculture, Forestry and Water Management of the Republic of Srpska, with operational and technical support from the Public Institution "Vode Srpske".

> Water resources in the Republic of Srpska have the status of a public good and cannot be privately owned

Municipalities and cities do not own raw water resources and do not have primary authority over natural water resource management. However, they play an important operational and organisational role at the local level. Their responsibilities include planning and developing local water supply infrastructure, providing spatial and urban planning documentation, organising public utility services, supervising local public utility companies and participating in water source protection and local infrastructure projects. Strategic water resource management, abstraction permits and broader regulatory powers remain centralised at the entity level.

Water quality monitoring and enforcement are based on a combination of utility-level obligations, public health institutions and inspection control. Public water utility companies are responsible for internal monitoring of physical, chemical and microbiological parameters, residual chlorine, turbidity, network pressure and the condition of sources and reservoirs. Larger utilities may use internal laboratories, while authorised accredited laboratories and public health institutes also perform analyses. External supervision is carried out through health and water inspections, and unsafe drinking water may lead to measures such as disinfection, restrictions on use, mandatory boiling notices, penalties or emergency remediation.

3.1.2 Financing, tariffs and regulatory framework

The financing of drinking water supply services in the Republic of Srpska is based on a combination of local budgets, user payments, loans, government grants and international donor support. Municipal and city budgets play an important role in financing emergency rehabilitation, network expansion, subsidies to public utility companies and co-financing of international projects. Since municipalities and cities are usually the founders of public utilities, they may also cover part of utility losses or provide guarantees for loans.

Revenue from water service tariffs is the primary regular source of financing for public water utility companies. User bills finance drinking water supply, sewerage services, wastewater treatment where applicable, connection fees, operational costs, salaries, energy expenses, maintenance activities and smaller investments.

However, in many municipalities, tariff revenues are not sufficient to ensure full cost recovery.

Tariff setting is decentralised. Water service tariffs are formally approved by municipal or city assemblies as founders of public utility companies. Although tariffs are generally expected to follow the principle of cost recovery, there is no single central regulatory authority for water services in the Republic of Srpska. In practice, tariff determination is based on communal service legislation, local government decisions and methodologies developed through sector guidelines and donor-supported programmes.

This creates significant differences between municipalities. Each municipality may have a different water tariff, depending on local decisions, political conditions, economic capacity and the financial position of the utility.

Political and social pressure often leads municipalities to keep tariffs below the economically justified level. As a result, public water utility companies may be unable to fully cover maintenance costs, depreciation, network investments and wastewater treatment costs.

The regulatory framework for water supply and water services includes the Water Law of the Republic of Srpska, the Law on Communal Activities of the Republic of Srpska, the Integrated Water Management Strategy of the Republic of Srpska and River Basin

A major development in the regulatory framework is the ongoing preparation of the Law on Water Services of the Republic of Srpska.

Management Plans. These documents regulate water resource management, the use and protection of water resources, the organisation of water services as municipal utility activities, coordinated water management and the achievement of good water status at river basin level.

AMCRS has been involved in the water sector reform process and participated in the working group for the development of this draft law. The proposed law aims to regulate the provision of water services, the construction, management and maintenance of public infrastructure, the methodology for determining water service prices, the analysis of service providers' operations and other issues relevant to sustainable water service provision.

The planned reform is important because the current system is characterised by fragmented regulation, uneven tariff policy, limited regulation of small-scale systems and weak institutional capacities. A more comprehensive legal framework could support improved financial sustainability, clearer responsibilities, better service standards and further integration of water protection and sustainable water management.

3.1.3 Rural and mountainous area challenges

Rural and mountainous areas in the Republic of Srpska face a combination of technical, financial and institutional challenges in drinking water supply. The main problems include ageing infrastructure, high water losses, seasonal water shortages, limited financial capacity, weak technical capacity and fragmented management arrangements.

Small-scale and village water supply systems are especially vulnerable. Many of these systems serve a small number of users over dispersed settlements, rely on local springs or wells, and operate without permanent professional staff. Their financial base is often weak because they depend on user contributions or local fees, which may be irregular or insufficient for proper maintenance, water quality testing, rehabilitation or system expansion.

> *Infrastructure condition is a major challenge in rural and mountainous territories. Ageing pipelines, limited maintenance, weak monitoring and difficult terrain contribute to water losses, operational inefficiency and reduced reliability. In remote areas, long distances between settlements and low population density make it economically difficult to expand or integrate central water supply networks. This increases dependence on independent or community-managed systems.*

Water quality management is also more difficult in small-scale systems. Although such systems may be subject to sanitary and public health requirements, monitoring is often less systematic than in formal public utility systems. Laboratory testing and inspection control may be occasional, and oversight depends on the capacity of municipalities, local communities or specific project-based support. This creates risks for public health, especially in systems without professional management or regular monitoring.

Financial sustainability is another critical issue. Many local utilities and rural systems have limited ability to finance infrastructure renewal from their own revenues. Tariffs are often influenced by local political considerations and may not cover depreciation, long-term maintenance or investment needs. Smaller municipalities and utilities are therefore highly dependent on external financing, grants, loans or support from higher levels of government and international donors.

Institutional fragmentation further complicates rural water supply management. Public utility companies manage formal public systems, while many village systems remain outside or only partially connected to the formal public service framework. The absence of a fully harmonised regulatory system for all small-scale systems makes it difficult to establish uniform service standards, systematic monitoring, long-term investment planning and effective integration into municipal water management structures.

Institutional capacity at the municipal level is itself a limiting factor. Smaller local self-government units often have a very small number of staff covering utility services, spatial planning and investment preparation at the same time, and rarely employ specialised engineering, GIS or project preparation profiles. This limits their ability to prepare investment documentation, apply for and manage external financing, supervise utility performance and meet the reporting obligations attached to donor and EU-funded projects, even where the technical need and the political commitment are present.

Climate-related pressures may further increase the vulnerability of these systems. Rural and mountainous areas can be exposed to seasonal shortages, droughts, floods and changes in source yield or water quality. Where monitoring and technical capacity are weak, it becomes more difficult to detect operational stress, manage water losses or respond quickly to water quality problems. These conditions make rural and village water systems highly relevant for WATERVILL interventions.

3.1.4 Relevance for WATERVILL replication and transfer

In the Republic of Srpska, the replication of WATERVILL solutions is particularly relevant in the context of small, rural and village water supply systems that are not fully integrated into the formal public water service system. The main preconditions for successful implementation include legal and institutional reform, stronger coordination between municipalities, public utility companies and entity-level institutions, financial sustainability, digital readiness and capacity building of local water operators.

An important framework for future implementation is the ongoing water sector reform process and the preparation of the Law on Water Services of the Republic of Srpska. This law is expected to contribute to clearer regulation of water service provision, management of public infrastructure, determination of water service prices and analysis

> *The most easily transferable WATERVILL solutions in the Republic of Srpska are technical and basic digital solutions, as they can be introduced gradually and without major institutional changes.*

of service providers’ performance. Its implementation could create more favourable conditions for long-term sustainability, improved regulation and better integration of smaller systems.

The most transferable WATERVILL solutions in the Republic of Srpska are technical and digital solutions that can be introduced gradually and without major changes to the legal framework. These include leakage detection, basic monitoring equipment, pressure and flow measurement, GIS mapping, digital asset registers, smart metering in selected areas and tools for improved operational decision-making.

Governance solutions are also relevant, but they require stronger institutional support. They may include clearer allocation of responsibilities, improved cooperation between municipalities and public utility companies, gradual integration of village systems into the formal public system, capacity building for local operators, and improved maintenance planning, water quality control and financial management.

As the association of local self-government units in the Republic of Srpska, AMCRS represents cities and municipalities in the water sector reform process and provides its members with policy support, training, exchange of practice and representation towards entity-level institutions. This gives the association a direct role in the replication of WATERVILL results: solutions tested in individual municipalities can be documented as practice, presented through the association's working bodies and networks, and adapted by other member municipalities operating under comparable conditions. Association-level dissemination is particularly relevant for small and rural systems, where individual municipalities rarely have the capacity to identify, assess and adapt technical solutions on their own.

The most relevant territories for the uptake of WATERVILL solutions are remote rural and village settlements, mountainous areas and transitional zones between urban and rural areas. In these territories, technical problems such as water losses and ageing infrastructure often exist together with institutional fragmentation, limited management capacities and weaker financial sustainability.

3.2 Bulgaria – Bulgarian Water Association (BWA)

3.2.1 Governance, service provision and water resource management

In Bulgaria, drinking water supply is organised through a regionalised public utility model. Service delivery is primarily ensured by regional Water Supply and Sewerage Operators, commonly referred to as ViK operators.

In most cases, one operator serves an entire administrative region, although some exceptions still exist. This model creates a relatively centralised and regionally structured system compared with countries where municipalities directly operate water supply services.

Water supply infrastructure is predominantly publicly owned. Assets are generally owned either by the state or by municipalities, while regional water utilities are responsible for operation, maintenance and service delivery. Municipalities therefore remain important infrastructure owners and local stakeholders, but they usually do not directly operate or regulate drinking water services. Their role is mainly expressed through participation in regional water associations, cooperation with operators and involvement in local planning processes.

At national level, the Ministry of Regional Development and Public Works coordinates strategic planning for water supply and sanitation infrastructure. Investment planning is implemented through regional master plans and business plans prepared by water utilities. The Ministry of Environment and Water, through the Basin Directorates, is responsible for water resource management and the issuing of water abstraction permits. Drinking water quality compliance is monitored by the Ministry of Health through Regional Health Inspectorates, while environmental authorities and basin directorates also participate in monitoring water resources and abstraction.

Municipalities play a key role in water resource management through source protection and land-use planning

Water resources in Bulgaria are considered public state property. This includes groundwater, rivers, reservoirs and springs used for public water supply. Municipalities do not directly own water resources, but they have a limited yet relevant role in source protection zones, land-use planning, environmental protection measures and cooperation with water operators and basin authorities. Direct management of water resources remains primarily a national responsibility.

Small-scale and village water supply systems are present in Bulgaria, especially in mountain villages, remote rural settlements, seasonal settlements and areas located outside the service area of larger operators. Most of these systems formally fall within the public water service framework, but some are managed directly by municipalities or local entities under specific arrangements. In principle, such systems are subject to public health monitoring and water abstraction permitting requirements, although enforcement and technical supervision may be more limited than in larger regional systems.

3.2.2 Financing, tariffs and regulatory framework

The financing of drinking water supply infrastructure in Bulgaria relies on a combination of EU funds, state budget support, utility revenues, tariffs and loans from international financial institutions.

EU Structural and Cohesion Funds, including the Environment Programme and previous Operational Programme Environment, represent a major source of financing for infrastructure modernisation.

State budget support and loans from institutions such as the European Investment Bank, the European Bank for Reconstruction and Development and the World Bank also play an important role. Municipal funding exists, but it generally has a limited role compared with national, EU and utility-based sources.

Water tariffs are regulated nationally by the Energy and Water Regulatory Commission. Water utilities prepare business plans and tariff proposals, which are reviewed and approved by the regulator. Tariff setting is therefore highly regulated and subject to affordability criteria. This limits the flexibility of municipalities and operators to increase tariffs above regulatory thresholds, even when higher revenues would be needed to finance infrastructure renewal, improve service quality or reduce water losses.

This creates a structural constraint for sparsely populated and rural regions. In such areas, the cost of service provision is often higher because of low customer density, dispersed settlements, difficult terrain and ageing infrastructure. At the same time, tariff increases are constrained by affordability requirements and social considerations. As a result, utilities in remote and mountainous areas may face difficulties in generating sufficient revenues for long-term investment and maintenance.

The main regulatory documents governing the Bulgarian water sector include the Water Act, the Act on Regulation of Water Supply and Sewerage Services, River Basin Management Plans and Drought Risk Management Plans. The Water Act regulates water resources management, permits and river basin management. The Act on Regulation of Water Supply and Sewerage Services regulates economic aspects of water services, tariff setting and operator performance. River Basin Management Plans and Drought Risk Management Plans provide the strategic framework for water resource protection, climate resilience and drought preparedness.

The main regulatory challenges are linked to the balance between affordability, cost recovery and investment needs. A highly regulated tariff system protects consumers but can reduce the investment capacity of operators.

Additional challenges include lengthy permitting procedures, fragmented responsibilities among institutions and difficulties in financing operation and maintenance after infrastructure or pilot investments are completed.

3.2.3 Rural and mountainous area challenges

Ageing infrastructure is one of the most important issues

Rural and mountainous areas in Bulgaria face several structural and operational challenges in drinking water supply. Ageing infrastructure is one of the most important issues. Many small settlements rely on water supply systems constructed several decades ago, with pipelines, reservoirs and other assets that require rehabilitation or replacement. The condition of these systems contributes to high levels of non-revenue water and physical water losses.

Dispersed population and low customer density create additional difficulties. In remote and mountainous territories, water networks often serve small settlements located across challenging terrain. This increases the cost of construction, operation and maintenance per user, while the revenue base remains limited. These conditions make it difficult for operators to finance major investments from tariff revenues alone.

Seasonal population fluctuations also affect service provision. Some rural and mountainous areas experience increased demand during tourism seasons, while the permanent population may be small or declining. This creates operational pressure on systems that are already technically vulnerable and financially constrained. In some areas, droughts and climate change impacts further increase the risk of reduced water availability and seasonal shortages.

Another important challenge is **the shortage of qualified technical personnel**. Smaller and more remote areas may have limited access to specialised staff, modern monitoring tools and digital asset management systems. This weakens the ability of operators and municipalities to detect leakages, plan maintenance, monitor small systems and respond quickly to operational problems.

Small-scale and village systems are particularly vulnerable. Although many are formally part of the public water service framework, technical supervision and enforcement may be weaker than in larger systems. These systems often require better registration, monitoring, asset documentation, water quality control and integration into wider regional planning and investment processes.

3.2.4 Relevance for WATERVILL replication and transfer

Based on the Bulgarian national context, the successful replication of WATERVILL solutions would depend primarily on cooperation between municipalities, regional water utilities and relevant national institutions.

Since drinking water services in Bulgaria are organised mainly through regional water supply and sewerage operators, any transfer of WATERVILL solutions should be aligned with regional planning processes, utility business plans and available financing mechanisms.

The main preconditions for implementation are the availability of reliable monitoring data, adequate technical capacity at local level and access to financing for both investment and long-term operation. These conditions are particularly important in smaller municipalities and rural areas, where financial and technical resources are more limited.

The main constraints that could limit implementation are the highly regulated tariff system, limited financial resources of small municipalities, lengthy permitting procedures, fragmented institutional responsibilities and difficulties in financing operation and maintenance after pilot implementation.

The most transferable WATERVILL solutions in Bulgaria are digital monitoring and early-warning systems, smart metering, leakage detection technologies, asset management tools, stakeholder engagement models and decision-support systems for small and rural water operators. These solutions are especially relevant for mountainous municipalities, remote rural settlements, water-stressed areas, tourist regions with seasonal demand fluctuations and peri-urban settlements facing infrastructure expansion challenges.

In this context, BWA can support replication through its professional network, technical expertise and capacity-building role in the Bulgarian water sector. This is relevant because Bulgaria’s water sector is undergoing gradual modernisation supported by EU funding and regulatory reforms, while rural and mountainous areas continue to face challenges related to ageing infrastructure, demographic decline, climate change impacts and financial sustainability.

3.3 Slovenia - Association of Municipalities and Towns of Slovenia (SOS)

3.3.1 Governance, service provision and water resource management

In Slovenia, drinking water supply is primarily organised at the municipal level. Municipalities have a central role in ensuring drinking water supply service delivery, owning and managing public water supply infrastructure, planning and financing investments, and formally approving tariffs. They are also responsible for organising the mandatory local public service of drinking water supply on their territory, either through public utility companies, municipal direct service units or inter-municipal utilities.

Although municipalities are the main implementing actors, the national level defines the overall legal and regulatory framework. This includes water resource management, drinking water quality requirements, tariff calculation methodology, public service obligations and the general rules for water abstraction and use. Municipalities therefore operate within a national framework, but they retain a strong role in service organisation, infrastructure management and local implementation.

The main model of drinking water service provision in Slovenia is public service provision through municipal or inter-municipal structures. In more urbanised and densely populated areas, services are usually organised through larger public utility companies or inter-municipal utilities. In rural, remote and mountainous areas, smaller local systems and village-based water supply systems are also present. These systems may be managed by municipalities, public providers, local communities or village structures, depending on their size, legal status and inclusion in the municipal drinking water supply programme.

Small-scale and village water supply systems are particularly relevant for the WATERVILL context. They are present mainly in rural, remote and mountainous areas with dispersed settlement patterns. Some of these systems operate within the formal public service framework, while others remain outside the main public water supply network, especially in cases of self-supply or where connection to a larger public system is technically or economically difficult.

Slovenian policy increasingly encourages the integration of smaller systems into formal public water supply structures where feasible, in order to improve operational reliability, water quality control and compliance with national and EU standards.

Water resources in Slovenia are constitutionally protected. The Constitution recognises the right to drinking water and defines water resources as a public good managed by the state. Under the Slovenian Water Act, water is considered a public natural resource managed by the Republic of Slovenia. The state is responsible for water management policy, water protection, issuing water rights and permits, and ensuring the sustainable use of water resources.

Water abstraction and use are subject to water rights and permits issued by the competent national authority, the Directorate of the Republic of Slovenia for Water. Depending on the type and scale of water use, abstraction may require a water right, water permit or water concession. Municipalities do not own water resources, but they play an important role in protecting drinking water sources, spatial planning, organising public drinking water supply services and protecting catchment areas at local level.

3.3.2 Financing, tariffs and regulatory framework

Water tariffs in Slovenia are regulated through a nationally prescribed methodology. All municipalities and public service providers must follow the Decree on the methodology for setting prices of mandatory municipal public environmental services when calculating drinking water supply tariffs. However, despite the unified methodology, tariff levels differ between municipalities due to local conditions such as settlement dispersion, terrain configuration, network length, population density, infrastructure condition, water availability and operational costs.

Tariffs are formally approved by municipal councils, based on proposals prepared by the mayor and supported by tariff calculation reports prepared by public service providers. This means that tariff setting combines a national methodological framework with local political and administrative approval. Municipalities may also provide subsidies for water supply services from municipal budgets, in accordance with national regulations.

> A major challenge is long-term financial sustainability

The main sources of financing for drinking water supply services are user payments through water tariffs, municipal budgets, national and EU funds, and borrowing or loans for larger infrastructure projects. Water tariffs generally consist of the service price, which covers operation and maintenance costs, and the infrastructure charge, which is intended to finance the use and renewal of public infrastructure. Municipal budgets may finance investments, network reconstruction and expansion, subsidies for service prices or infrastructure charges, and co-financing of service provision in areas where full cost recovery through tariffs is difficult to achieve.

A major challenge is long-term financial sustainability. Although the national tariff methodology formally includes infrastructure depreciation through network charges, many municipalities do not collect network charges at the full depreciation value, particularly for infrastructure not financed through EU funds.

Smaller and financially weaker municipalities often face political and social pressure to maintain affordable water tariffs. As a result, they may not generate sufficient own-source revenue for long-term infrastructure renewal and are therefore highly dependent on external funding sources and borrowing capacity.

The regulatory framework for drinking water supply in Slovenia includes several key documents. These include the Constitution of the Republic of Slovenia, the Water Act, the Act on Drinking Water Supply and Collection and Treatment of Municipal Wastewater, the Decree on Drinking Water Supply, the Decree on Drinking Water, the Decree on the Methodology for Setting Prices of Mandatory Municipal Public Environmental Services, and the Operational Programme for Drinking Water Supply 2022–2027. Together, these documents define water as a public good, regulate water rights and water permits, set drinking water quality and monitoring requirements, define municipal public service obligations and establish the methodology for water tariff calculation.

Drinking water quality monitoring combines operator-level responsibilities and national oversight. Operators, which may include municipalities, public utility providers or other designated managers of water supply systems, are responsible for internal monitoring, maintenance and ensuring water safety. External monitoring is carried out through the national drinking water monitoring system, while compliance and health-related enforcement are supervised by the relevant national health authorities.

3.3.3 Rural and mountainous area challenges

Rural and mountainous areas in Slovenia face several structural challenges in drinking water supply. A significant share of local water supply systems in small and rural municipalities is technically outdated, fragmented and difficult to manage efficiently. Many systems require modernisation, better interconnection and stronger integration into more effective governance and management models.

High water losses and non-revenue water are important operational challenges. They are particularly problematic in older rural networks, where deteriorated pipelines, insufficient monitoring and limited digitalisation make systematic water loss management difficult.

According to the Operational Programme for Drinking Water Supply 2022–2027, approximately 45.1% of public water supply pipelines are expected to be older than 30 years by 2027. In addition, around 6,551 km of pipelines will have exceeded their amortisation period and will require rehabilitation or replacement.

Dispersed settlements and difficult terrain further increase the cost and complexity of service provision. Mountainous and sparsely populated areas often require long network sections to serve a limited number of users. This reduces economic efficiency and increases the costs of construction, operation and maintenance. Small-scale systems serving individual villages or groups of households are therefore more exposed to financial, technical and managerial weaknesses.

Climate pressures are also becoming more relevant. Longer drought periods,

> *Limited technical and governance capacity is another important challenge. Small municipalities and independent village systems often lack sufficient staff, technical expertise, financial resources and organisational capacity for long-term planning, monitoring and maintenance.*

unpredictable precipitation patterns and increased seasonal demand, especially in tourism-oriented areas, increase the risk of drinking water shortages. This creates a need to improve climate resilience, strengthen reserve water sources and introduce better monitoring systems that can support earlier detection of shortages, losses and operational stress.

This is particularly evident in non-integrated local water systems operating outside formal public service frameworks. Such systems may face difficulties in meeting monitoring requirements, ensuring consistent water quality and planning long-term rehabilitation.

> *The regulatory treatment of very small self-supply systems also remains a challenge. Systems serving fewer than 50 people are generally outside regular national drinking water monitoring and remain largely under the responsibility of users or local communities.*

This creates potential public health and reliability risks, especially in remote areas where microbiological contamination, drought vulnerability or insufficient maintenance may be more difficult to detect and address.

3.3.4 Relevance for WATERVILL replication and transfer

In Slovenia, the replication of WATERVILL solutions is particularly relevant for small, village, rural and mountainous water supply areas.

> *Although the Slovenian regulatory framework for drinking water supply is well developed and does not represent a major legal barrier to implementation, the main challenges are related to the financial capacity of smaller municipalities, the condition of local infrastructure and the management of smaller systems*

The main preconditions for successful implementation include better integration of small and village water supply systems into formal management structures, financial support for infrastructure renewal in smaller and rural municipalities, capacity building of local operators, improved water quality monitoring, and stronger cooperation between municipalities, public utility companies and local communities.

Digital and governance solutions are the most easily transferable in the Slovenian context because they can be implemented within the existing regulatory framework and mainly require organisational adaptation, training and strengthening of local capacities. Such solutions may include improved system monitoring, infrastructure records, digital monitoring of water losses, decision-support systems and better coordination between local stakeholders.

Technical solutions are also relevant, particularly in areas with ageing and fragmented infrastructure, but their implementation depends more strongly on the availability of financial resources, investment priorities and the specific condition of the local network. For this reason, technical solutions are most applicable where clear infrastructure problems exist and where financing sources are available for system renewal or modernisation.

The most relevant territories for the uptake of WATERVILL solutions in Slovenia are mountainous and remote rural areas with small and geographically dispersed water supply systems. Peri-urban areas may also benefit from specific solutions, especially where settlement development and growing demand create additional pressure on existing water supply infrastructure.

3.4 Croatia – University of Zagreb, Faculty of Mechanical Engineering and Naval Architecture (UNIZAG)

3.4.1 Governance, service provision and water resource management

In Croatia, drinking water supply and wastewater services are governed mainly by the Water Act and the Water Services Act. At the national level, water management falls within the competence of the Ministry of Environmental Protection and Green Transition, while Croatian Waters (Hrvatske vode) is responsible for water management tasks, water resources management, water-related permits and the implementation of water policy.

Service delivery is generally ensured through municipal public utility companies (komunalna društva), which are established and owned by municipalities. In larger urban areas, regional water supply companies may cover several municipalities. Concession models exist, but they are less common, while municipal department-based management is rare and mostly limited to very small municipalities.

Municipalities in Croatia have an important role as owners and service organisers. They usually own the water supply infrastructure and delegate operational service delivery to publicly owned utility companies. Infrastructure ownership typically rests with municipalities, while planning and financing of investments is shared between municipalities, counties, the national budget and EU funding sources.

Small and rural water supply systems often operate outside formal structures

Water resources, including groundwater and surface water, are classified as public goods under the Water Act. Their ownership and management are vested in the state and administered through Croatian Waters. Croatian Waters is responsible for water management planning, protection of water bodies and issuing water abstraction and use permits. Municipalities do not own water resources directly, but they have an important role in spatial planning, especially where water protection zones intersect with land-use plans, and in managing communal water supply infrastructure.

Small-scale and village water supply systems are present in Croatia, especially in rural and mountainous areas. These local systems, often referred to as “lokalni vodovodi”, operate largely outside formal public service structures.

Many of Small-scale and village water supply systems were built by local communities or agricultural cooperatives and have never been formally transferred to public utility management. As a result, their legal status is often uncertain, they are frequently not officially registered, and they are subject to limited formal oversight and only partial regulation.

There are notable regional differences in service organisation. Coastal and urban areas, including Zagreb, Split, Rijeka and Osijek, generally have better organised and financially stronger utility companies. In contrast, inland, rural and mountainous areas such as Lika, Gorski Kotar, the Dalmatian hinterland and parts of Slavonia face more fragmented service organisation and a stronger presence of small-scale or independent systems.

3.4.2 Financing, tariffs and regulatory framework

The financing of drinking water supply infrastructure in Croatia is based on several sources. These include local budgets, EU Structural and Cohesion Funds, the Environmental Protection and Energy Efficiency Fund, national financing mechanisms and, to a limited extent, loan financing through the Croatian Bank for Reconstruction and Development (HBOR). EU funding has an important role in supporting larger infrastructure investments and modernisation.

Water service prices are determined by public water service providers under the Water Services Act, through a formal decision on the price of water services. The legality of tariff decisions, development charges and related matters is supervised by the Council for Water Services (Vijeće za vodne usluge).

Although tariffs are expected to cover the costs of service delivery, they are often affected by local political and social pressures. This is particularly relevant in smaller and rural municipalities, where below-cost tariffs can reduce the financial capacity of utilities to finance maintenance, rehabilitation and modernisation.

As a result, smaller utility companies often have limited ability to raise capital for infrastructure renewal and innovation.

The main regulatory challenges in Croatia's water supply sector include the fragmented legal status of independent village water systems, insufficient financial sustainability of small utility companies, complex permitting procedures, limited institutional capacity at the local level and inadequate data on the extent and condition of rural water infrastructure. The uncertain status of local village water systems creates gaps in enforcement, water quality control and access to public financing instruments.

Relevant policy and regulatory documents include the Water Act, the Croatian Water Management Plan 2022–2027 and the Act on Communal Services. The Water Act regulates water resources management, abstraction permits, water body protection and the transposition of the Water Framework Directive. The Croatian Water Management Plan 2022–2027 addresses issues such as reducing water losses, improving rural water supply, digital management and climate resilience. The Act on Communal Services is relevant for public utility services, municipal ownership, tariff setting and local service organisation.

3.4.3 Rural and mountainous area challenges

Rural and mountainous areas of Croatia face a combination of structural and operational challenges in drinking water supply. These challenges are particularly visible in regions such as Lika, Gorski Kotar, the Dalmatian hinterland and parts of Slavonia.

Ageing infrastructure is one of the main problems. Many systems were built during the 1960s, 1970s and 1980s and have exceeded their expected service life. This contributes to high levels of physical water losses, with non-revenue water commonly exceeding 40–50% in many systems.

Old pipelines, limited monitoring and weak asset management make systematic leakage reduction difficult.

Limited technical and financial capacity is another major challenge. Small municipal utilities often lack sufficient resources for routine maintenance, long-term planning and capital investments. Below-cost tariffs further reduce their ability to finance rehabilitation and modernisation from their own revenues.

Dispersed population patterns make service provision more expensive and less economically viable. Rural and mountainous settlements often require long network sections to serve a relatively small number of users, which increases per-capita infrastructure costs. This is particularly difficult in areas where the population is declining or where settlements are geographically scattered.

Seasonal water scarcity is becoming an increasing concern due to climate change. Karst aquifers, which dominate the Croatian coastal hinterland and mountainous regions, show increased variability in recharge rates. This can affect the reliability of local sources, especially during dry periods and periods of increased seasonal demand.

Independent village water systems are especially vulnerable. Many of these systems lack professional management, systematic water quality monitoring and emergency response capacity. This creates risks for service reliability, public health protection and long-term sustainability.

These are the types of systems where WATERVILL solutions related to smart management, leak detection and climate-resilient infrastructure are particularly relevant.

3.4.4 Relevance for WATERVILL replication and transfer

In Croatia, the replication of WATERVILL solutions is particularly relevant for rural and mountainous areas where independent village water supply systems are still present and where infrastructure is often ageing, fragmented and exposed to climate-related pressures.

Successful implementation would depend on the willingness of local utility companies and municipalities to adopt smart water management technologies, together with the availability of co-financing mechanisms for capital investments.

A key precondition is technical capacity building at the local level, especially for small utilities responsible for rural water systems. In addition, legal and regulatory clarity regarding the status of independent village water systems is important, particularly in relation to their possible integration into formal public service frameworks. The involvement of Croatian Waters is also relevant for linking pilot findings with national water management and investment planning.

The main institutional and legal constraints include the fragmented legal status of village water systems, which can limit their access to public financing instruments. Below-cost tariffs reduce the financial capacity of utilities to invest in innovation, while public procurement procedures may slow down the adoption of new technologies. Limited inter-municipal cooperation structures in rural water services can also make implementation more difficult.

The most transferable WATERVILL solutions in Croatia are digital and technical solutions, such as leakage detection sensors, smart metering, remote monitoring and SCADA systems. These solutions can be adopted modularly, do not require major changes to the legal framework and have a clear practical value through the reduction of non-revenue water. Governance models for community-managed systems are also transferable, provided that they are adapted to the Croatian legal and institutional context.

Nature-based solutions are also relevant in Croatian karst and mountain hydrology contexts, particularly in areas such as Lika, Gorski Kotar and the Dalmatian hinterland. The territories with the highest uptake potential are mountainous and remote rural areas, especially Lika-Senj County, Karlovac County and Gorski Kotar / Primorje-Gorski Kotar County, where independent village water systems are more common, infrastructure is older and climate pressures on water resources are more pronounced.

As an academic and research partner, UNIZAG can support replication by providing methodological expertise in climate proofing of infrastructure and by disseminating project findings through scientific and professional networks. This is relevant in the Croatian context, where rural water infrastructure investments are expected under the 2021–2027 EU programming period.

3.5 Greece – University of Western Macedonia (UOWM)

3.5.1 Governance, service provision and water resource management

In Greece, drinking water supply is organised through a multi-level governance structure in which responsibilities are distributed between national, regional, municipal and regulatory institutions. At the national level, the Ministry of Environment and Energy is responsible for water resources management and national water policy. The General Directorate for Natural Environment and Water prepares and updates River Basin Management Plans for the 14 River Basin Districts, oversees compliance with EU water legislation and coordinates water-related investment programmes co-financed through EU instruments.

Since 2023, part of the regulatory responsibility has been assigned to the Waste, Energy and Water Regulatory Authority. This authority is responsible for the economic regulation of water services, including tariff oversight, provider certification and dispute resolution. However, core responsibilities related to water resources management, river basin planning and environmental compliance remain with the Ministry of Environment and Energy and the Decentralised Water Directorates.

At the operational level, Greece has a predominantly public model of drinking water service provision. The two largest urban systems are operated by EYDAP in Athens and EYATH in Thessaloniki. These state-majority-owned utilities serve the two main metropolitan areas and operate under concession-type arrangements with the Greek state. Outside Athens and Thessaloniki, drinking water supply is mainly organised through Municipal Water Supply and Sewerage Companies, known as DEYAs, and through municipal technical services departments in smaller and more remote settlements.

Municipalities have a central role in the Greek water supply system. They act as service owners and organisers, establish and supervise DEYAs, define investment priorities within their territory and approve tariff structures through municipal councils. However, formal enforcement authority lies primarily with national and regulatory bodies, particularly the Ministry of Environment and Energy, the Decentralised Water Directorates and the Waste, Energy and Water Regulatory Authority.

Water resources in Greece are legally defined as public goods held under state responsibility. No municipality, private entity or individual may own water resources directly. Access to and use of water resources is regulated through public permits. Water abstraction and use permits are issued by the competent Decentralised Water Directorates, while municipalities, DEYAs and other users must apply for permits in order to lawfully abstract surface water or groundwater.

Small-scale and village water supply systems are present in rural and mountainous areas. These systems often take the form of gravity-fed spring systems, pumped borehole systems or local distribution networks serving one or several settlements. They are not formally defined as a separate category of water service provision. In principle, they fall under the broader municipal water supply mandate, but in practice many of them operate with limited institutional oversight, informal maintenance arrangements and insufficient systematic water quality monitoring.

3.5.2 Financing, tariffs and regulatory framework

Water infrastructure investment in Greece is financed through a combination of public funding, EU funding and utility-level resources. EU Cohesion Policy funding, including the European Regional Development Fund and the Cohesion Fund under the 2021–2027 Partnership Agreement, represents one of the most important sources of capital investment. The Recovery and Resilience Facility is also relevant for water-related investments. At utility level, DEYAs rely primarily on tariff revenues to finance operational expenditure and, to a more limited extent, capital works.

> Low tariffs and limited investment constrain the modernisation of rural water supply systems

Tariff setting in Greece has historically been strongly decentralised at the municipal level, which contributed to significant geographic variation in water prices. The establishment of the Waste, Energy and Water Regulatory Authority introduced a stronger national regulatory framework for tariff approval and economic oversight. Nevertheless, important constraints remain.

A major issue is the political sensitivity of tariff increases.

> *Municipal councils are often reluctant to approve higher water prices, especially in smaller and economically weaker municipalities. This has contributed to systematic underpricing and insufficient cost recovery, particularly in rural and mountainous areas.*

As a result, many smaller DEYAs have limited revenue available for infrastructure renewal, leakage reduction and digitalisation.

The national costing and pricing framework is defined by Joint Ministerial Decision 135275/2017. It establishes rules for the costing and pricing of water services and defines cost recovery on the basis of financial cost, environmental cost and resource cost. Water service providers are required to calculate and report their full financial cost and progressively align tariffs with cost recovery principles. However, implementation has been inconsistent, especially among smaller DEYAs and municipal technical departments with limited administrative and technical capacity.

The regulatory framework relevant to drinking water supply in Greece includes Law 3199/2003 on water protection and management, Presidential Decree 51/2007, Joint Ministerial Decision 135275/2017 on costing and pricing of water services, Law 5037/2023 establishing the Waste, Energy and Water Regulatory Authority, River Basin Management Plans, the National Water Strategy 2025 and legislation governing municipal water supply and sewerage companies.

> *The main regulatory challenges relate to fragmented institutional responsibilities, limited capacity of competent authorities, incomplete data systems and the gap between formal legal obligations and actual implementation at local level.*

3.5.3 Rural and mountainous area challenges

Mountainous regions may receive higher precipitation, but they often consist of small and scattered settlements with low population density. This makes the construction, maintenance and renewal of water infrastructure more expensive per user.

> *Rural and mountainous areas in Greece face specific drinking water supply challenges linked to the country's diverse topography, dispersed settlement patterns and uneven water availability.*

Ageing infrastructure is one of the main challenges. Many local distribution networks in smaller municipalities were constructed decades ago and have not undergone systematic renewal. Pipe deterioration, inadequate pressure management and outdated storage facilities contribute to high levels of non-revenue water and reduced operational efficiency.

Limited technical and financial capacity is also a structural constraint. Smaller DEYAs and municipal technical departments often operate with limited staffing, weak asset management practices and insufficient access to external financing. Systematic underpricing of water services further reduces the funds available for infrastructure renewal and operational improvements. This creates a cycle in which low tariffs limit investment, while inadequate investment contributes to higher water losses and weaker service reliability.

Dispersed population patterns create additional operational difficulties. Many rural and mountainous municipalities consist of several small and geographically separated settlements, often served by separate local systems. Managing and renewing these systems is costly relative to the limited revenue base of small local providers. In some cases, individual settlements rely on springs or shallow boreholes that are not adequately managed or monitored.

Seasonal water scarcity is an increasing concern due to climate change. Prolonged droughts can reduce the availability of surface water and groundwater sources used by small rural systems. At the same time, summer demand from tourism and agriculture increases pressure on water supply systems. Overall, ageing infrastructure, institutional fragmentation, limited technical and financial capacity and growing resource stress define the operating context of rural and mountainous water supply systems in Greece.

3.5.4 Relevance for WATERVILL replication and transfer

The Greek national context provides both important opportunities and clear constraints for the replication of WATERVILL solutions. On the enabling side, Greece has a clear municipal mandate for water supply delivery, an established regulatory framework for water management and costing, and access to EU co-financing mechanisms through the 2021–2027 programming period and the Recovery and Resilience Facility. The National Water Strategy 2025 also reflects growing recognition of the structural vulnerabilities of the Greek water sector.

Successful replication of WATERVILL solutions would depend on the ability of smaller DEYAs and municipal technical departments to adopt, operate and maintain new technical and digital tools. This requires dedicated support, capacity building and better data availability. The academic and technical capacity of the University of Western Macedonia is particularly relevant. UOWM leads the development of the Decision Support System under Activity 1.4, and leads Work Package 2, covering local community engagement in water supply systems, the preparation of pilot demonstration cases, and the assessment and monitoring of pilot demonstration results. This dual role creates a direct link between the state-of-the-art findings, DSS development and their practical testing through the WATERVILL pilots.

The main constraints are linked to limited technical and financial capacity in smaller DEYAs and municipal departments. Systematic underpricing and insufficient cost recovery reduce investment budgets for infrastructure upgrades and technology integration. In addition, regulatory complexity and fragmented responsibilities can slow down decision-making and implementation.

The most transferable WATERVILL solutions in Greece are technical and digital solutions focused on water loss detection, real-time network monitoring and decision support for operational management. These solutions are relatively easy to transfer because they do not require major institutional restructuring and can deliver measurable operational improvements within shorter timeframes.

Governance and capacity-building solutions are also relevant, especially where they support clearer responsibilities, better coordination between municipalities and utilities, improved asset management and stronger monitoring of small systems. The territories most relevant for uptake are rural and mountainous municipalities with dispersed settlements, ageing infrastructure, limited technical capacity and exposure to seasonal water scarcity. Municipalities in Western Macedonia and similar rural and mountainous regions are particularly relevant for the transfer and testing of WATERVILL solutions.

3.6 Spain – Polytechnic University of Valencia (UPV)

3.6.1 Governance, service provision and water resource management

Spain has a decentralised and multi-level governance model for drinking water supply. Municipalities are the core competent authorities for the provision of household drinking water services, while the State, river basin authorities and Autonomous Communities retain key responsibilities for water resources, hydrological planning, sanitary surveillance and regulatory enforcement.

Drinking water supply is a mandatory local public service in all municipalities. Municipalities are responsible for organising and guaranteeing service delivery, either directly or through delegated, indirect, mixed or supramunicipal management arrangements.

In municipalities with fewer than 20,000 inhabitants, Provincial Councils or equivalent entities may coordinate the provision of drinking water and wastewater services, which is particularly relevant for small rural and mountainous municipalities with limited technical and financial capacity.

The Spanish service provision model is best described as a mixed and decentralised municipal model. Depending on local conditions, drinking water services may be provided through direct municipal management, local public utility companies, supramunicipal entities, private concessions, mixed public-private companies, mancomunidades, consortia, provincial councils, island councils or metropolitan entities. This creates a flexible but heterogeneous service landscape, where the practical organisation of water supply varies significantly between territories.

Regional and territorial differences are important. Large metropolitan areas often rely on specialised public utilities, metropolitan entities, mixed companies or long-term concession arrangements with professional operators. In contrast, rural, inland and mountainous areas more often depend on small municipal systems, direct municipal management or supramunicipal technical support. Mediterranean, island and south-eastern regions often face more complex water-resource conditions, including groundwater stress, reservoirs, desalination, interconnections and drought-management needs, while northern and mountain areas may rely more on local springs and surface-water sources.

Small-scale drinking water supply systems are present in Spain, especially in rural, mountainous and sparsely populated territories. They can be found in small municipalities, hamlets, dispersed settlements, isolated rural nuclei, mountain villages, peri-urban settlements and autonomous supplies linked to farms, rural tourism facilities or isolated public and commercial activities.

These systems should not generally be described as informal or unregulated village systems. When they supply water for human consumption, they fall within the national drinking water quality framework and are recognised as supply zones.

Water resources in Spain form part of the public hydraulic domain. This includes continental surface waters and renewable groundwater. Municipalities and service operators may own and manage drinking water infrastructure such as local networks, reservoirs, pumping stations and treatment facilities, but they do not own the water resource itself. The use of water for public supply normally requires an administrative water right, usually a concession or equivalent authorisation.

The competent authority for water abstraction and use depends on the type of river basin. In intercommunity river basins, which extend across more than one Autonomous Community, the responsible authority is the State hydraulic administration through the relevant River Basin Organisation. In intracommunity river basins, located entirely within one Autonomous Community, the responsible authority is the hydraulic administration of the Autonomous Community. Municipalities therefore organise the drinking water service, but abstraction rights are controlled by the competent basin-level or regional hydraulic authority.

Spain plans to invest EUR 2.2 billion in water supply infrastructure by 2027

Municipalities still play an important indirect role in water resource protection. They may hold or manage water-use rights for public supply, protect local wells, springs and catchments through planning and land-use control, coordinate with health and hydraulic authorities during droughts or contamination events, carry out municipal surveillance at the consumer tap, and participate in emergency response, demand restrictions and public communication.

3.6.2 Financing, tariffs and regulatory framework

Financing of drinking water supply systems in Spain comes from several sources. These include user charges through municipal fees, tariffs or equivalent public charges; municipal budgets; provincial cooperation plans; regional government programmes;

State-level investment for works of general interest; EU funds, including ERDF, Cohesion Policy funds and NextGenerationEU instruments; and private or concessionaire investment where contractually foreseen.

Under the current third-cycle hydrological planning framework, Spain has planned more than EUR 22.8 billion in water-related measures up to 2027, including more than EUR 2.2 billion for water-supply infrastructure.

This shows that water supply investment is embedded in a broader national and river-basin planning framework, but local implementation still depends strongly on municipal capacity, supramunicipal support and access to financing.

Spain does not have a single national economic regulator for urban drinking water services. Tariff regulation is therefore fragmented and depends on local and regional legal arrangements. Municipalities normally approve the tariff structure, but the applicable legal instrument may differ depending on whether the service is managed directly, indirectly, through a mixed company or under a concession model. Charges may take the form of local fees, public prices, tariffs or non-tax public patrimonial charges.

For direct municipal provision, the Spanish Local Finance Act limits the total amount of the fee to the real or foreseeable cost of the service. In other management models, tariff approval may be linked to concession contracts, municipal ordinances and regional price-authorisation procedures. In addition, water supply for population use is treated as an authorised price of regional scope, meaning that Autonomous Community price commissions or equivalent bodies may intervene in tariff approval procedures where applicable.

Affordability is an important constraint. Royal Decree 3/2023 requires local administrations to improve access to drinking water for vulnerable groups and allows affordability mechanisms to be reflected in tariffs, water fees or solidarity funds. This is especially relevant in small rural municipalities, where the number of users is limited and full cost recovery may be difficult without creating social pressure.

The regulatory framework is comprehensive but complex. Key documents include Royal Decree 3/2023 on drinking water quality, control and supply; Royal Legislative Decree 1/2001 approving the consolidated Spanish Water Act; Royal Decree 849/1986 on the Public Hydraulic Domain Regulation; Royal Decree 907/2007 on Hydrological Planning; Royal Decree 35/2023 approving the third-cycle River Basin Management Plans 2022–2027; the Special Drought Plans; the National Climate Change Adaptation Plan 2021–2030; the PERTE for the Digitalisation of the Water Cycle; Law 7/1985 on Local Government; Royal Legislative Decree 2/2004 on Local Finance; and Law 9/2017 on Public Sector

The main regulatory challenge is not the absence of legislation, but the gap between a sophisticated legal framework and the practical implementation capacity of small municipalities.

Contracts.

Drinking water supply involves municipalities, operators, river basin authorities, Autonomous Community health authorities and, in some cases, provincial or supramunicipal entities. This multi-level structure can create coordination difficulties, especially where small rural municipalities lack specialised staff, digital tools, legal expertise or financial resources.

3.6.3 Rural and mountainous area challenges

Rural and mountainous areas in Spain face a combination of structural, technical, hydrological and institutional challenges. Although the national regulatory framework applies across the country, the operational capacity of small municipalities and dispersed settlements is often much weaker than that of urban or metropolitan systems.

Ageing infrastructure is one of the main challenges. Many rural supply systems rely on old distribution networks, small reservoirs, local springs, wells, pumping stations and chlorination systems that were built decades ago and have not been renewed at an adequate rate. This can lead to pipe bursts, service interruptions, low hydraulic efficiency, reduced reliability and increased risk of contamination through pressure losses or intrusion events.

High water losses and low hydraulic efficiency are also common problems. Small rural systems often have limited sectorisation, scarce flow metering, insufficient pressure control and incomplete digital monitoring. In mountainous areas, steep elevation differences can create excessive pressure in lower network zones, increasing leakage, bursts and operational instability.

Limited technical and financial capacity is a critical constraint. Many small municipalities have limited specialised staff, small operational budgets and insufficient internal capacity to prepare technical projects, apply for funding, manage procurement, operate digital systems, implement Water Safety Plans or comply with increasingly demanding monitoring and reporting obligations.

This creates dependence on provincial councils, mancomunidades, regional agencies, supramunicipal entities or external operators.

Dispersed population patterns and weak economies of scale further increase the cost of service provision. Long pipe lengths, isolated hamlets, low population density and seasonal settlements make it difficult to recover costs through tariffs while keeping water affordable. This affects preventive maintenance, infrastructure renewal, laboratory control, digitalisation and emergency preparedness.

Seasonal water scarcity and drought vulnerability are especially relevant in Mediterranean, inland and south-eastern areas. Many rural and mountain systems depend on springs, shallow wells, small reservoirs or local surface-water intakes. These sources may be sensitive to drought, reduced snowpack, declining groundwater recharge and climate-change impacts. During drought episodes, municipalities may need emergency wells, tanker supply, interconnections, demand restrictions or temporary alternative resources.

Water quality vulnerability is another issue. Small systems may be exposed to episodic turbidity, microbiological contamination, nitrate pollution, pesticide residues, salinisation, arsenic or other geogenic constituents, depending on local hydrogeology and land use. Mountain sources can deteriorate rapidly after intense rainfall, snowmelt or wildfire events, while groundwater-dependent systems may face aquifer overexploitation, diffuse agricultural pollution or declining water levels.

The operational complexity of mountain terrain increases maintenance needs. Steep gradients, difficult access to intakes and reservoirs, snow and frost exposure, landslide and rockfall risk, limited telecommunications coverage and high pumping costs can reduce system robustness during extreme weather events. These conditions make rural and mountainous Spain highly relevant for WATERVILL solutions focused on monitoring, leakage reduction, pressure management, drought preparedness and supramunicipal technical support.

3.6.4 Relevance for WATERVILL replication and transfer

Spain is highly relevant for WATERVILL replication because it combines a strong legal and institutional framework with significant territorial heterogeneity. The country has a well-developed regulatory system for drinking water quality, water-resource management, hydrological planning, drought management, digitalisation and public service provision, but small rural and mountainous municipalities may lack the capacity to implement these requirements without external support.

Successful replication of WATERVILL solutions in Spain depends on several preconditions. Solutions need to be aligned with municipal service responsibility, the existing service-management model, the competent operator's technical capacity, the national drinking water quality framework, water abstraction rights and available financing sources.

> *Replication will be most effective where municipalities are supported by supramunicipal technical structures and where solutions are designed as practical tools for leakage reduction, risk management, drought resilience, digital monitoring and operational decision-making.*

The main institutional constraints are linked to the decentralised organisation of drinking water services and the multi-level governance of water resources. Drinking water supply is a municipal responsibility, while water resources are managed by river basin authorities or Autonomous Community hydraulic administrations, and sanitary surveillance is carried out by Autonomous Community health authorities. This can slow down implementation where a solution requires coordinated decisions on infrastructure, abstraction rights, water quality, investment planning and risk management.

The most easily transferable solutions are digital and technical-operational measures that can be introduced within the existing municipal or supramunicipal service framework. These include GIS-based asset inventories, telemetry for reservoirs and pumping stations, smart or semi-smart metering, pressure and flow monitoring, leakage detection, water-balance dashboards, alarm systems, digital maintenance logs and basic SCADA-light systems for rural networks.

Leakage reduction and network efficiency solutions are particularly relevant. These include sectorisation, district metered areas, pressure management, night-flow analysis, active leakage control, renewal prioritisation, pipe-burst databases and hydraulic performance indicators. Such solutions are compatible with the current drinking water framework and can provide direct operational and economic benefits without requiring major institutional restructuring.

Risk-based drinking water safety tools are also highly transferable. Templates and methodologies for Water Safety Plans, risk matrices, incident protocols, catchment-to-tap risk assessment, source protection and emergency quality protocols can help small municipalities comply with the preventive approach introduced by Royal Decree 3/2023.

Governance and capacity-building solutions are important, but they should strengthen existing institutional arrangements rather than replace them. Useful models include shared technical assistance services, intermunicipal cooperation, provincial support schemes, common procurement of monitoring equipment, shared laboratory services, joint emergency planning and standardised technical specifications for small municipalities.

The highest uptake potential is found in mountainous, remote rural and demographically fragile municipalities, followed by drought-prone Mediterranean rural areas and peri-urban or tourist-influenced small municipalities with strong seasonal demand variability. These territories are most likely to benefit from WATERVILL solutions focused on leakage reduction, basic digitalisation, water safety planning, source protection, drought preparedness and supramunicipal technical cooperation.

A specific Spanish contribution to WATERVILL is the emphasis on conjunctive management of groundwater and surface water. In rural and mountainous areas, supply resilience can be strengthened by combining different sources according to hydrological conditions, water availability, energy costs and water quality status. This approach should be linked with source protection, catchment-risk assessment, Water Safety Plans, drought contingency planning and operational redundancy.

3.7 North Macedonia – Association of the Units of Local Self-Government of the Republic of North Macedonia (ZELS)

3.7.1 Governance, service provision and water resource management

In North Macedonia, municipalities have a central operational and governance role in drinking water supply. They are responsible for organising public drinking water supply services, establishing and supervising public utility companies, managing municipal infrastructure assets, planning infrastructure development, approving tariffs and coordinating local investment priorities.

Drinking water supply services are generally provided through municipal public utility companies. These companies are responsible for the operation and maintenance of water supply systems, billing, monitoring and customer services. In some cases, especially in remote rural settlements, water supply may also be organised through inter-municipal utility arrangements, local communities, village water boards or informal local arrangements.

Infrastructure ownership and management are shared between municipalities and public utility companies. Municipalities usually own or manage the infrastructure assets, while public utility companies are responsible for daily operation and maintenance. Investment planning is primarily carried out by municipalities, often with support from national programmes, EU funds and donor financing.

Water resources in North Macedonia are considered public goods. The state has the main responsibility for water policy, protection of water resources, issuing water rights and regulating water use. Water abstraction permits are issued by the Ministry of Environment and Physical Planning under the Law on Waters. Municipalities do not own water resources, but they have important responsibilities related to the protection of local sources, spatial planning, pollution prevention and the organisation of drinking water supply.

Small-scale and village water supply systems are widespread, especially in mountainous areas, remote rural settlements and villages not connected to larger municipal systems.

These systems often rely on springs, local groundwater sources and small reservoirs.

Their legal and operational status is mixed. Some are integrated into municipal public services, while others continue to operate separately due to historical arrangements, limited municipal capacity and high integration costs. According to the legal framework, all systems should be integrated into the public water supply system, but this remains a practical challenge in many rural areas.

3.7.2 Financing, tariffs and regulatory framework

Drinking water infrastructure in North Macedonia is financed through several sources. These include user payments through water tariffs, municipal budgets, national investment programmes, EU pre-accession funds, international financial institutions, donor-funded projects, loans and borrowing.

Municipal budgets are commonly used for urgent repairs, network extensions, co-financing of donor projects and local infrastructure improvements. However, smaller rural municipalities often have limited financial capacity for major rehabilitation projects.

Water tariffs are proposed by public utility companies and approved by municipal councils. Although tariff setting is regulated through national legislation and a regulated methodology, significant differences exist between municipalities because of local conditions. Tariff levels depend on factors such as the size and age of the water supply network, availability and quality of water sources, terrain configuration, population density, number of connected users, operational costs, pumping energy costs and the level of non-revenue water.

A major challenge for municipalities is achieving full cost recovery. Many municipalities face social pressure to maintain affordable water prices, while tariff revenues are often insufficient to cover infrastructure renewal, network expansion, leakage reduction and the introduction of digital monitoring systems.

As a result, larger investments often depend on national, donor and EU financing.

The regulatory and policy framework includes the Law on Waters, the Law on Local Self-Government, the Law on Public Utility Services, Drinking Water Quality Regulation, the Law on Determining Tariffs for Water Services, the National Water Strategy and municipal development plans. These documents regulate water resources, permits, municipal responsibilities, public service organisation, drinking water quality standards, tariff ranges and long-term water management.

The main regulatory challenges include insufficient financing for infrastructure renewal, weak integration of small village systems and a digitalisation gap in many utilities. Many local systems still operate with limited telemetry, GIS, SCADA and automated monitoring. This reduces the ability of municipalities and utilities to manage water losses, plan investments and improve operational performance.

3.7.3 Rural and mountainous area challenges

Rural and mountainous municipalities in North Macedonia face several specific challenges in drinking water supply. Ageing infrastructure is one of the main issues. Many local systems were constructed decades ago and require rehabilitation, pipeline replacement and improvements to reservoirs and pumping stations.

High water losses and non-revenue water are also major operational problems. The main causes include leakages, illegal connections, lack of flow measurement and insufficient monitoring. Many utilities do not have district metered areas, modern pressure management, SCADA systems or digital asset management tools. This makes it difficult to detect losses, control pressure and plan targeted rehabilitation.

Dispersed settlements create additional cost and management challenges. Mountain municipalities often operate long and technically complex networks that serve a small number of users. As a result, the cost per user is significantly higher than in urban areas. This weakens the economic sustainability of water supply services in remote and low-density areas.

Climate pressures are becoming increasingly important. Climate change increases the risk of drought, reduced spring capacity, seasonal shortages and stronger competition for water resources. Municipalities therefore increasingly need alternative water sources, improved storage capacity and drought management plans.

Limited technical capacity is another major challenge. Smaller municipalities often lack specialised engineers, digital systems, financial resources and long-term planning capacity. This limits their ability to manage infrastructure renewal, monitor water quality, reduce losses and prepare investment projects. Capacity building and inter-municipal cooperation are therefore important for improving the resilience and sustainability of rural water supply systems.

3.7.4 Relevance for WATERVILL replication and transfer

The North Macedonian context is highly relevant for WATERVILL replication because many rural and mountainous municipalities face the same types of challenges addressed by the project: ageing infrastructure, high water losses, limited monitoring, weak digitalisation, insufficient investment capacity and the partial integration of small village water supply systems.

> The most transferable solutions are governance, digital and selected technical solutions

Successful replication of WATERVILL solutions would require stronger municipal capacity, improved management of rural water systems, better integration of village systems, investment in infrastructure rehabilitation, introduction of digital monitoring and stronger cooperation between municipalities and public utility companies.

The main constraints that could limit implementation include limited municipal budgets, insufficient technical staff, fragmented water supply systems, limited data availability and weak asset management practices. These barriers are especially relevant in smaller rural municipalities, where financial and human resources are often insufficient for systematic planning, digitalisation and infrastructure renewal.

The most transferable solutions are governance, digital and selected technical solutions. Governance solutions may include inter-municipal cooperation, improved utility management and clearer allocation of responsibilities. Digital solutions may include GIS-based network mapping, telemetry, SCADA systems, leakage monitoring and water balance management. Technical solutions may include rehabilitation of critical network sections, pressure management, improvement of reservoirs and source protection.

The territories most relevant for WATERVILL uptake are mountainous municipalities, remote rural settlements, municipalities with dispersed villages and areas affected by drought. In these territories, WATERVILL can contribute to strengthening the role of municipalities as the key level responsible for water service delivery, while improving resilience, efficiency and compliance with EU water standards.

3.8 Comparative Synthesis of National and Partner-Level Framework Conditions

The partner-level overviews show that the WATERVILL countries do not face identical water governance problems, but they do share a common structural pattern: rural and mountainous water supply systems are technically more vulnerable, financially weaker and institutionally more difficult to manage than larger urban systems.

> *The main differences between countries relate less to the existence of these problems and more to how each national framework distributes responsibility, financing, regulation and operational capacity.*

From a governance perspective, the analysed countries can be grouped into four broad models.

The first group consists of strongly municipal systems, where municipalities are central service organisers, infrastructure owners or founders of public utilities. This model is most visible in the Republic of Srpska, Slovenia, Croatia and North Macedonia, and also in Greece (only in Athens and Thessaloniki the water utilities are state-majority-owned). In these contexts, municipalities are close to local problems and can directly influence local priorities, but they often lack sufficient technical staff, financial capacity and long-term planning resources, especially in smaller rural areas.

The second model is the regionalised operator model, represented most clearly by Bulgaria. In Bulgaria, drinking water supply is organised mainly through regional ViK operators, usually serving entire administrative regions. This makes Bulgaria different from the more fragmented municipal systems. Its advantage is that regional operators can potentially achieve stronger technical capacity, larger planning units and better integration with regional master plans. However, this model does not automatically solve rural problems, because remote settlements may still suffer from ageing infrastructure, weak technical supervision, affordability constraints and limited investment capacity.

The third model is a mixed metropolitan–municipal model, most evident in Greece. Athens and Thessaloniki are served by large state-majority utilities with greater economies of scale and technical capacity, while the rest of the country depends mainly on municipal water companies and municipal technical departments. This creates a strong internal contrast: large urban systems are institutionally stronger, while rural and mountainous systems remain fragmented, under-resourced and often poorly documented. Croatia and Slovenia also show some internal contrast between stronger urban or inter-municipal utilities and weaker rural or village systems. In Greece, this contrast is reinforced by the regulatory framework itself: state-majority utilities operate under concession-type arrangements. However, both municipal water utilities and the state-majority-owned utilities of Athens and Thessaloniki fall under the national costing and regulatory framework. In particular, the state-majority-owned utilities operate under state control. The municipal water utilities and the municipal technical services show limited technical and administrative capacity with some exceptions. This gap is further amplified in isolated and mountainous municipalities, where dispersed settlements, difficult terrain and small user bases make even basic compliance and monitoring disproportionately costly relative to the local revenue base.

The fourth model is the decentralised mixed municipal model, represented by Spain. In Spain, municipalities are the core competent authorities for household drinking water supply, but the actual organisation of service provision is highly heterogeneous. Depending on local conditions, drinking water services may be provided through direct municipal management, local public utilities, supramunicipal entities, private concessions, mixed public-private companies, mancomunidades, consortia, provincial councils, island councils or metropolitan entities. This makes Spain different from simpler municipal systems because municipal responsibility remains legally central, while practical implementation depends strongly on the service-management model, operator capacity, contractual arrangements and the availability of supramunicipal technical support.

A major commonality across all countries is that water resources are treated as public goods and are managed primarily by the state or national/entity-level authorities, regional authorities or river basin authorities.

Municipalities generally do not own raw water resources directly. Their role is mostly linked to service organisation, infrastructure ownership, spatial planning, source protection and local implementation.

This means that WATERVILL solutions related to operational water management can be implemented locally, but solutions affecting abstraction rights, water permits, river basin management or strategic resource allocation require coordination with national or regional water authorities.

The strongest similarity between the Republic of Srpska, Croatia and North Macedonia is the unresolved or partially resolved status of small-scale and village water supply systems.

In these contexts, many small systems operate through local communities, informal arrangements, municipal technical departments or partial public utility oversight. They often face unclear ownership, weak monitoring, insufficient professional management and limited access to public financing. North Macedonia has a formal expectation that such systems should be integrated into the public supply system, but practical integration

Slovenia, Bulgaria and Spain partly stand apart from this group, although for different reasons.

remains difficult. Croatia and the Republic of Srpska face similar problems with local or village systems that are not fully integrated into formal public service structures.

Slovenia has the most developed formal framework for small systems, especially through registration, monitoring obligations, water permits and national rules for systems serving more than 50 persons or more than 10 m³/day. Bulgaria also formally places many village systems within the public water service framework and municipal or utility asset inventories. Spain also treats small rural systems as part of the drinking water regulatory framework when they supply water for human consumption. These systems are recognised as supply zones and may be subject to formal sanitary oversight, reporting and risk-management obligations. Therefore, Spanish small systems should not be described as fully informal or unregulated village systems. However, all three countries still face practical rural challenges: Slovenia with very small self-supply systems and infrastructure renewal, Bulgaria with weaker enforcement and technical supervision in

Financing and tariffs form the most important cross-cutting constraint. In all countries, there is a tension between affordability and cost recovery.

remote areas, and Spain with very small, dispersed and mountainous systems that depend strongly on municipal, provincial or supramunicipal technical support.

Slovenia and Bulgaria have more formalised national tariff methodologies, while Bulgaria applies national economic regulation through EWRC. Recently, Greece has introduced WEWRA as a water regulator, showing significant progress in regulating the service providers (domestic and agricultural water use). Croatia, North Macedonia and the Republic of Srpska remain more exposed to local political and social pressures in tariff setting. Spain also faces tariff fragmentation because it does not have a single national economic regulator for urban drinking water services. Tariffs are usually approved locally, but the legal instrument may differ depending on whether the service is directly managed, concessioned, mixed or organised through a supramunicipal structure, while regional price-authorisation procedures may also be relevant. The result is similar across countries: tariffs often do not generate enough revenue for long-term infrastructure renewal, leakage reduction, digitalisation and climate adaptation. This makes EU funds, national programmes, regional programmes, donor finance, loans and supramunicipal investment support essential for larger investments.

Technically, the countries are highly similar. Rural and mountainous systems commonly face ageing infrastructure, high non-revenue water, dispersed settlements, low customer density, difficult terrain, limited technical staff, weak asset management and insufficient digital monitoring. These challenges are particularly severe where long networks serve a small number of users. In such conditions, even technically simple measures become financially difficult, because the cost per user is high and the revenue base is weak. This pattern appears across all countries.

The most universally applicable WATERVILL solutions are therefore basic digital and operational tools: flow and pressure monitoring, leakage detection, smart metering, GIS-based network mapping, digital asset registers, SCADA or telemetry where feasible, water balance management and decision-support tools. These solutions are relevant in all countries because they directly address the same operational weakness: utilities and municipalities often do not know precisely where water is lost, which network sections are most critical, which assets should be prioritised, or how seasonal and climate pressures affect system performance.

However, not all solutions are equally transferable everywhere. In Bulgaria, WATERVILL solutions should be aligned with regional ViK operators, regional planning documents and utility business plans. In Slovenia, solutions can be introduced within an already relatively mature regulatory framework, but should focus on smaller rural systems, self-supply

A key comparative insight is that full institutional consolidation is not always realistic or necessary. In many countries, municipalities may not be able or willing to merge into a single water service provider, and legal frameworks may not support rapid restructuring.

cases, monitoring, asset renewal and digital integration. In Croatia, the priority is the combination of digital monitoring, leakage reduction and clarification of the legal status of local water supply systems. In North Macedonia and the Republic of Srpska, the strongest need is capacity building, municipal support, integration of village systems, basic digitalisation and practical leakage reduction, water quality control and rehabilitation of ageing infrastructure. In Greece, digital and decision-support solutions are highly relevant. Large water utilities implement many digital tools in everyday operations, where smaller water utilities often lack staff, data systems and cost-recovery capacity. In Spain, WATERVILL solutions should be aligned with municipal service responsibility, the existing service-management model, the competent operator, public procurement rules, water abstraction rights, sanitary surveillance obligations and available supramunicipal support.

For this reason, one of the potential WATERVILL replication pathways is a shared technical and digital support model. Under this model, municipalities and local utilities would keep their legal responsibilities, while a centralised or inter-municipal technical unit would monitor flow, pressure, losses and critical infrastructure across several systems. A small group of specialised engineers could analyse data, identify priority interventions, prepare technical reports and support municipalities that cannot individually afford such expertise. This model is especially relevant for North Macedonia, the Republic of Srpska, Croatia and Greece, but it could also support smaller rural areas in Slovenia, Bulgaria and Spain.

Comparative dimension	Common pattern across partner contexts	Main differences between countries	Relevance for WATERVILL
Governance and service organisation	Public authorities and public utilities have the main responsibility for drinking water supply.	Some systems are strongly municipal, while others are regionalised or involve stronger national regulation.	Solutions must be adapted to the authority responsible for operation, investment and long-term maintenance.
Small-scale and village systems	Small and village systems are present in rural and mountainous areas.	Their legal status ranges from formally regulated to partially integrated or informally managed.	WATERVILL can support better integration, monitoring and management of these systems.
Financing and tariffs	Full cost recovery is difficult, especially in smaller and rural systems.	Tariff regulation ranges from municipal approval to national regulatory oversight.	Replication depends on co-financing, investment planning and realistic

			operation and maintenance costs.
Rural and mountainous challenges	Ageing infrastructure, water losses, dispersed settlements and limited capacity are common.	The intensity of challenges differs depending on terrain, population density, tourism and climate exposure.	Priority should be given to remote, mountainous and water-stressed territories.
Transferable solutions	Digital monitoring, leakage detection, smart metering, GIS and decision-support tools are widely relevant.	Governance and regulatory solutions require stronger adaptation to national frameworks	The most effective approach combines technical, digital, governance and capacity-building measures.

4. State of the Art in Case Study Municipalities

This chapter presents the state-of-the-art assessment of the WATERVILL case study municipalities. While Chapter 3 focused on national and partner-level framework conditions, this chapter examines the actual local situation in the selected pilot areas. The analysis focuses on municipal governance, water service organisation, water resources, infrastructure condition, operational performance, water quality management, financial sustainability, climate resilience, digitalisation needs and transferability potential.

Each case study follows the same structure in order to ensure comparability between municipalities. The assessment is based on the municipal questionnaires and available technical, financial, operational and environmental data provided by the pilot municipalities and project partners.

4.1 Case Study 1: Municipality of Žabljak, Montenegro

The Municipality of Žabljak represents the Montenegrin case study area within the WATERVILL project. It is a highly relevant pilot area because it combines several typical characteristics of rural and mountainous water supply systems: dispersed settlements, karst terrain, strong seasonal population changes, local and community-managed water supply systems, unresolved property and legal relations, limited monitoring, absence of systematic digital tools in most rural systems, and vulnerability to drought-related reduction of source capacity.

Unlike some other case study municipalities, the Žabljak input is not based on a single consolidated technical dataset for one unified water supply system. Instead, the municipality provided separate information for several rural water supply systems: Bosača, Dobri Nugo, Njegovuđa, Šaranci, Tepca and Virak / the Komarsko–Pošćenski area.

An additional note was provided for settlements without organised water supply systems, including Mala Crna Gora, Rudanca, Studenca, Brajkovača, Pašino Polje and Nadgora. This structure is itself an important finding because it shows that rural water supply in Žabljak is not one uniform system, but a group of different local systems with different ownership, management, financing and technical conditions.

4.1.1 Municipal context, governance and service provision

The drinking water supply situation in Žabljak is characterised by a mixed municipal and community-based service model. Around 90% of the municipal population is reported to be served by public water supply systems, while approximately 10% is served by small-scale or village systems. However, the practical organisation differs strongly between individual rural settlements.

The rural water supply systems in Žabljak can be grouped into four main categories. The first category includes rural settlements connected to the public water supply system managed by the municipal utility / Waterworks Žabljak. Njegovuđa and Virak belong to this category, although Virak also shows elements of joint management with the local community. The second category includes systems built and managed independently by local residents, such as Bosača. The third category includes systems built by the Municipality or through public investment, but not fully operated as regular Waterworks Žabljak systems. Dobri Nugo, Šaranci and Tepca belong mostly to this group. The fourth category includes settlements without organised public or community-managed water supply systems, such as Mala Crna Gora, Rudanca, Studenca, Brajkovača, Pašino Polje and

Nadgora.

In Bosača, the system is fully self-managed by the village community, including operation, maintenance, repairs, planning and financing. In Dobri Nugo, Šaranci and Tepca, local

This means that Žabljak has a very practical rural water governance challenge: the municipality is involved in water supply planning, investment and major repairs, but daily operation in several settlements still depends on local residents.

residents perform daily operation and report failures, while the Municipality forwards repair requests to the Municipal Waterworks or utility company, which carries out repairs and equipment servicing, with costs often borne by the Municipality. In Njegovuđa, Waterworks Žabljak is directly responsible for operation, maintenance and repairs. In Virak / the Komarsko–Pošćenski area, the Municipality / Waterworks Žabljak operates jointly with the local community.

Water resources are owned and managed at state level. The State Water Administration and the Ministry of Agriculture are identified as responsible for water abstraction and use permits. The Municipality of Žabljak does not directly manage water resources, but it has a role in source protection, local infrastructure, water supply decisions and communication with local communities. In several systems, the questionnaires identify overlapping competences between the State Water Administration, the Energy and Water Regulatory Agency of Montenegro, the Environmental Protection Agency, Durmitor National Park and the Municipality of Žabljak.

Property and legal issues are among the most important governance barriers. Several systems have reservoirs, pipelines, boreholes or water sources located on private property.

In Bosača, the questionnaire notes that ownership of the water supply system was returned to the village following an Administrative Court decision. In other systems, unresolved property relations affect reservoirs, pipelines, boreholes or pumping facilities. These issues directly influence the ability to integrate small systems into formal public service structures, establish protection zones, install chlorination equipment and plan infrastructure investments.

The main governance conclusion is that Žabljak does not only need technical upgrades. It also needs clearer ownership arrangements, stronger institutional coordination and a more systematic model for supporting rural systems that currently depend on local communities.

4.1.2 Water resources, infrastructure and operational performance

The rural water supply systems in Žabljak mainly depend on underground sources, developed springs, boreholes and, in the case of Virak / the Komarsko–Pošćenski area, a combination of underground developed sources and overflow from Modro Lake. The hydrogeological context is predominantly karst, which is important because karst systems can be highly sensitive to seasonal recharge, drought and rapid changes in source capacity. The level of evidence differs strongly between the individual Žabljak systems. Njegovuđa provides a relatively complete quantitative dataset, while Virak and several semi-managed systems report only partial operational figures. For the remaining systems, and for the settlements without organised water supply, no metering, water balance or time-series data were available. The findings for these systems are therefore derived from qualitative descriptions provided by the Municipality and local system operators, and should be understood as indicative of the type and direction of the problem rather than as measured values.

The available technical data show major differences between systems.

Rural water supply system	Population / users	Main source	Network length	Main management model
Bosača	Winter approx. 10; summer over 40; approx. 20 connections	Underground water sources leading to a water pool	Approx. 4 km	Fully self-managed by local residents
Dobri Nugo	Approx. 100 inhabitants; 45 connections	Borehole with pumping	Approx. 4 km	Municipality-owned system, daily operation by residents, repairs through Waterworks
Njegovuđa	Approx. 350 inhabitants; approx. 250 connections; 160 meters	Underground borehole, approx. 120,000 m³/year	Approx. 20 km	Operated by Waterworks Žabljak
Šaranci	Winter approx. 30; summer over 250; approx. 90 connections	Developed water sources	Approx. 20 km	Municipality / local community, daily operation by residents
Tepca	Winter approx. 20; summer up to 80; 15 connections	Underground developed water sources	Approx. 4 km	Local community with municipal/utility support for repairs
Virak / Komarsko–Pošćenski area	Approx. 2,400 inhabitants; approx. 600 connections; winter approx. 200, summer over 2,000	Underground developed sources and overflow from Modro Lake	Approx. 40 km	Municipality / Waterworks Žabljak with local community participation

Settlements without organised system	Mala Crna Gora, Rudanca, Studenca, Brajkovača, Pašino Polje, Nadgora	Rainwater cisterns for technical water; natural springs for drinking water	Not applicable	No public or community-managed system

Bosača has a small system of approximately 4 km, built at the end of the 1990s, with PVC pipes and around 40% aged infrastructure. No annual production, consumption or water loss data are available. Leakage is identified through visible failures or malfunctions, which are repaired periodically by local residents. This confirms that the system operates without systematic monitoring or planned asset management.

Dobri Nugo has approximately 45 service connections and a 4 km network supplied from one borehole with pumping. The system was built around 2016 and is not structurally old compared with some other systems, but it still faces technical failures and unresolved property issues. Annual maintenance costs are estimated at around EUR 4,000, of which approximately EUR 1,117 relates to electricity.

Njegovuđa provides the most complete technical and financial dataset among the rural systems. It has approximately 250 connected users, 160 water meters, a network length of around 20 km and annual water production of around 120,000 m^3/year. Reported consumption is approximately 84,000 m^3/year, implying significant non-revenue water. The annual water loss percentage is reported at around 30%, with an estimated annual cost of losses of EUR 25,000. Total annual revenues are approximately EUR 24,000, while total annual expenses are EUR 25,000. This means that revenues do not cover expenses, including materials, employee salaries and electricity costs. The mean operating pressure is around 6 bar, and high pressure together with older asbestos-cement sections is identified as one of the main causes of leakage.

Šaranci has a strong seasonal pattern, with around 30 inhabitants in winter and more than 250 in summer. The system has approximately 90 service connections and around 20 km of PVC network built between 2014 and 2018. Five malfunctions were reported in the previous year. Although the system is relatively recent, it still faces high pressure, delayed failure repairs, absence of systematic metering and insufficient water quantities during the summer period. Reported annual maintenance costs are approximately EUR 2,000, while electricity costs and malfunction-related costs are also recorded.

Tepca is a small local system with around 15 service connections, around 4 km of network and only about 30% of the local community population served. The system was built at the end of the 1990s and uses PVC pipes. Reported annual expenses and maintenance costs are around EUR 9,000. A 500 m section of the water supply network was reconstructed, which indicates that rehabilitation has already started, but the system still lacks SCADA, smart systems, a simulation model and pressure management.

Virak / the Komarsko–Pošćenski area is the largest rural system covered by the Žabljak data. It serves approximately 600 connections and has a total network length of around 40 km. The system combines underground developed sources with overflow from Modro Lake. It has strong seasonal demand: winter consumption is reported at around 12 m^3/h, while summer consumption can reach around 40 m^3/h. Five faults were repaired in 2025, and the estimated cost of water losses in 2025 was approximately EUR 17,000. The mean operating pressure is about 5 bar. A key infrastructure need is the reconstruction of the water supply system and the construction of a reservoir with an approximate capacity of 800 m^3.

The most severe service gap is found in the settlements without organised water supply systems: Mala Crna Gora, Rudanca, Studenca, Brajkovača, Pašino Polje and Nadgora. Residents rely on individual concrete cisterns with capacities between 5 and 30 m^3. These cisterns collect rainwater and are refilled during dry periods by municipal water tankers or, where road access is difficult, by fire-service vehicles. Because water remains stagnant for months, it is used only for technical purposes, while drinking water is obtained from natural springs, in some cases located several kilometres from consumers. This represents a basic access, reliability and public health concern.

4.1.3 Water quality management, maintenance and financial sustainability

Drinking water quality in the Žabljak systems is regulated under the Water Law. The Institute of Public Health is identified as the main institution responsible for water quality monitoring and inspections in several questionnaires. The standard requirements refer mainly to chemical and bacteriological safety. However, the level of monitoring differs strongly between systems.

In systems operated by Waterworks Žabljak, such as Njegovuđa and parts of the Virak / Komarsko–Pošćenski area, water quality monitoring is more structured. In Njegovuđa, chlorine levels are monitored daily, while samples for chemical and bacteriological safety are taken periodically by the Institute of Public Health, three to four times per year. In case of non-compliance, the Institute of Public Health notifies the sanitary inspector and Municipal Services and Waterworks Žabljak. In Virak, chlorine concentration and turbidity are measured using monitoring equipment, and the Institute of Public Health collects samples for laboratory analysis.

In the self-managed and semi-managed rural systems, the situation is weaker.

Bosača, Šaranci and Tepca identify the lack of chlorination and the absence of water protection zones as important problems.

Several questionnaires state that chlorination equipment and protection zones are necessary before systems can be better integrated or managed as part of the public service. In rural systems where water is not chlorinated, monitoring is less systematic and the chain of responsibility is less clear.

Maintenance practices also differ between systems. In Bosača, residents are responsible for operation, maintenance, identifying failures and repairing failures. There is no preventive maintenance plan. In Dobri Nugo, Šaranci and Tepca, local residents usually identify and report failures, while the Municipality forwards requests to the Municipal Waterworks or utility company for repair. Repairs are mainly reactive and carried out after failures occur. In Njegovuđa, Waterworks Žabljak performs maintenance and network testing, while in Virak the Municipality, the Municipal Utility Company and the local community all participate in maintenance.

Financial sustainability is one of the main weaknesses of the rural systems. In several systems, users are not charged for water consumption.

This is explicitly reported for Bosača, Dobri Nugo, Šaranci, Tepca and Virak. Where there is no water charging, there is no stable revenue base for maintenance, monitoring, chlorination, metering or systematic rehabilitation. This makes the systems dependent on municipal support, user contributions, ad hoc repairs or external funding.

Njegovuđa is an exception because users are charged and the system has a more formal utility-based model. However, even in Njegovuđa the financial balance is weak: annual revenues of approximately EUR 24,000 do not cover total annual expenses of approximately EUR 25,000, and the cost of water losses is estimated at around EUR 25,000 per year. This shows that even when billing exists, high losses and operating costs can still undermine sustainability.

The financial picture is therefore mixed but generally fragile.

The main problem is not only lack of money, but the absence of a regular financing mechanism for small systems.

Without stable tariffs, metering or structured contributions, rural systems cannot reliably finance preventive maintenance, water quality testing, chlorination equipment, flow meters, source protection or long-term replacement of ageing pipes.

4.1.4 Climate resilience, hydrogeological conditions and environmental pressures

Žabljak is a mountainous municipality with strong seasonal and climate-related pressures. The rural systems are located in karst terrain, and several questionnaires state that drought conditions reduce the capacity of water sources. This is especially important because many systems depend on small local sources, boreholes, developed springs or groundwater.

Seasonal population variation is one of the defining characteristics of the area. In Bosača, the population increases from around 10 in winter to more than 40 in summer. In Šaranci, it increases from around 30 in winter to more than 250 in summer. In Tepca, it increases from around 20 in winter to up to 80. In Virak / the Komarsko–Pošćenski area, the difference is even stronger: around 200 people are present in winter, while the summer population can exceed 2,000. This creates peak summer demand on systems that often have limited storage, limited monitoring and small pipe diameters.

Summer drought is a recurring pressure. Šaranci reports summer drought conditions and significantly reduced source capacity. Tepca reports water shortages during dry periods. Dobri Nugo also notes reduced source capacity in drought conditions. Virak reports summer water shortages and pipe diameter limitations. These findings show that water scarcity in Žabljak is not only a future climate risk, but already a practical operational issue in some rural systems.

There are no reported natural buffer zones or infiltration zones used specifically to improve local water retention. The questionnaires also generally report that there are no specific local policies or regulations addressing drought management or water scarcity. This is important because the systems face drought-related risks, but management is still mainly reactive rather than based on formal drought planning.

The location of some sources and facilities inside or near Durmitor National Park creates an additional environmental and institutional layer. In Virak, the water source is located in the first zone of Durmitor National Park, and the questionnaire identifies overlapping competences between the Environmental Protection Agency, Durmitor National Park and the Municipality of Žabljak. Similar restrictions and overlapping responsibilities are reported in other systems, together with unresolved property and legal relations. These conditions can slow down construction, reconstruction, reservoir development, protection zone establishment and source improvements.

Agricultural water demand appears limited in scale, but it is still relevant locally. Several questionnaires mention small vegetable plantations that are usually irrigated from the water supply system. In small rural systems, even limited irrigation use can create additional stress during dry summer periods, especially where the number of consumers increases seasonally and source capacity declines.

4.1.5 Digitalisation, innovation needs and transferability potential

Digitalisation in the rural water supply systems of Žabljak is uneven and generally limited. Most small systems do not have SCADA, water balance assessment, simulation models, pressure management or systematic time-series data. Bosača, Tepca and several semi-managed systems explicitly report no SCADA system and no simulation model. Šaranci reports no time-series data and no registry of small or village systems. Several systems also report the absence of flow meters, smart meters and remote monitoring as important gaps.

Njegovuđa and Virak show a more advanced starting point. Njegovuđa reports that SCADA exists in the town but not in rural areas, while smart meters are used in the town and a tender is underway for flow meters at the end sections of the network and for all consumers. Virak reports installed flow meters and instruments for monitoring chlorine concentration and turbidity at the filtration station. It also reports an ongoing procurement tender for flow meters on each branch of the water supply network and smart water meters for all consumers.

The main digital needs are consistent across the rural systems. They include flow meters, smart meters, remote sensors, pressure monitoring, level sensors for pump operation, GIS mapping, SCADA or SCADA-light systems, smart billing / AMR, and basic water balance tools. These measures would directly address the current weaknesses: lack of reliable data, delayed detection of failures, unknown water losses, high pressure, no systematic consumption monitoring and weak prioritisation of repairs.

The transferability potential of Žabljak is not based on an already advanced technical model, but on its value as a realistic rural and mountainous case. It shows several types of rural water supply arrangements in one municipality: fully self-managed systems, municipality-owned but community-operated systems, utility-managed systems, jointly managed systems and settlements without organised water supply. This makes Žabljak highly useful for testing WATERVILL solutions that can be adapted to different maturity levels.

For more advanced systems such as Njegovuđa and Virak, WATERVILL can support the expansion of monitoring, smart metering, water balance assessment and pressure management. For systems such as Bosača, Šaranci and Tepca, the first priority is more basic: chlorination, protection zones, flow metering, failure detection, clarification of ownership, and a regular financing mechanism. For settlements without organised supply, WATERVILL can support baseline assessment, mapping of cistern dependence, source accessibility and identification of technically realistic supply options.

The Žabljak case indicates that rural water supply improvement should not begin only with advanced digital tools. In several settlements, the available inputs show that more basic preconditions still need to be addressed, including clarification of responsibilities, property relations, water safety obligations and basic technical documentation. Digitalisation becomes more useful when it is connected with maintenance, financing, source protection and clear decision-making.

4.1.6 Key findings for WATERVILL

Žabljak is a highly relevant WATERVILL case study because it shows the full complexity of rural and mountainous water supply in a small municipality. The case includes community-managed systems, semi-formal systems, utility-managed rural systems and settlements without organised water supply. This makes it particularly useful for testing modular and scalable WATERVILL solutions. The limited availability of operational data across most of these systems is in itself one of the main findings of the assessment, because it defines the starting point for any further modelling, digitalisation or decision-support work in the municipality.

The strongest governance priority is the clarification of ownership, responsibilities and legal status of rural systems. Several systems face unresolved property and legal relations, overlapping competences and uncertainty over ownership of reservoirs, pipelines, boreholes or sources. Without resolving or at least managing these issues, technical investments, integration into public service, source protection and chlorination may remain difficult.

The strongest water safety priority is the establishment of chlorination and protection zones in rural systems. Bosača, Šaranci and Tepca explicitly identify lack of chlorination and lack of protection zones as key problems. In the systems managed by Waterworks Žabljak, water quality monitoring is more structured, but smaller systems still require stronger and more consistent monitoring arrangements.

The strongest technical priority is improved monitoring of flows, pressure, losses and failures. Quantitative data on water production, consumption and losses are missing for most systems. Njegovuđa is the only system with relatively complete data, including annual production, consumption, losses, revenues and expenses. This lack of data should be treated as an important finding, not only as a limitation. It confirms the need for basic metering, water balance assessment and digital records.

The strongest infrastructure priority is targeted rehabilitation and storage improvement. Several systems use PVC networks built in the late 1990s or between 2014 and 2018, while Njegovuđa also reports old asbestos-cement sections as a leakage cause. Virak identifies the need for reconstruction and construction of an approximately 800 m³ reservoir. Tepca already reconstructed 500 m of network, but still faces dry-period shortages and limited coverage.

The strongest financial priority is the creation of a more stable financing model for rural water supply systems. Many systems do not charge users for water, which limits maintenance capacity and makes them dependent on municipal budgets or ad hoc repairs. Even in Njegovuđa, where billing exists, revenues do not cover expenses and the cost of losses is very high relative to the system’s financial capacity.

The strongest climate-resilience priority is drought and seasonal-demand management. Karst terrain, reduced source capacity during droughts, strong summer population increases and occasional irrigation from the drinking water system create pressure on rural systems. Measures such as source monitoring, reservoir planning, leakage reduction, metering, demand management and alternative supply planning are therefore directly relevant.

The strongest digital priority is the introduction of a staged digitalisation approach. For the least developed systems, this should begin with basic flow meters, pressure monitoring, asset mapping and simple reporting. For larger systems such as Njegovuđa and Virak, WATERVILL can support SCADA expansion, smart metering, water balance tools, leakage analysis and decision-support functions.

Overall, Žabljak should be treated as a case where technical, governance, financial, water safety and climate-resilience measures must be implemented together. The municipality does not need one uniform solution for all rural systems. It needs a differentiated model: basic legal, safety and monitoring support for self-managed systems; improved municipal and utility support for semi-managed systems; and more advanced digital monitoring for larger rural systems connected to Waterworks Žabljak. This makes Žabljak a strong demonstration case for WATERVILL because it clearly shows why rural water supply resilience depends on the connection between infrastructure, data, institutions, financing and local community capacity.

4.2 Case Study 2: Municipality of Bitola, North Macedonia

4.2.1 Municipal context, governance and service provision

The Municipality of Bitola represents the North Macedonian case study area within the WATERVILL project. The water supply system is relevant for the project because it combines an urban public utility model with rural and mountainous settlements, seasonal scarcity pressures, high water losses, limited digital monitoring coverage and dependence on both local mountain water sources and the Streževo surface water system.

Water supply infrastructure is owned by the Municipality of Bitola, while water resources are owned and regulated by the Republic of North Macedonia. There is no private ownership in the system. The Municipality acts as the owner and service coordinator, while the Public Utility Enterprise “Vodovod” Bitola operates the system. The utility is responsible for daily operation, maintenance, identifying and repairing network failures, billing and customer service.

The main model of drinking water service provision is a public utility company model. PUE Vodovod Bitola provides water supply services not only for Bitola, but also for the neighbouring municipalities of Novaci and Mogila. This cross-municipal service arrangement is one of the important strengths of the case study because it shows how a larger urban utility can provide operational support to smaller rural municipalities.

The municipality plays a central role as founder of the public utility and as a contracting authority. Investment planning is shared between the Government, the Municipality of Bitola and PUE Vodovod Bitola. The Ministry of Environment and Physical Planning, the Ministry of Transport and the Municipality are involved in major investment planning, while annual plans are proposed by the utility. Major upgrades and co-financed capital projects require approval from relevant national ministries, while the Municipal Council approves annual plans and reports.

Service coverage is high in the urban and peri-urban parts of the municipality.

Approximately 85–90% of the population is served by public water supply systems, while around 10–15% of the population, mainly in remote or mountain villages, is served by small-scale or village systems operating under local community councils or informal arrangements.

These rural systems are important for WATERVILL because they face weaker monitoring, weaker financial enforcement and greater integration challenges.

4.2.2 Water resources, infrastructure and operational performance

The Bitola water supply system relies on a combination of Baba mountain springs and groundwater, supplemented by surface water from the Streževo reservoir system. Mountain spring capacities depend strongly on winter snowfall and hydrological conditions. During summer, spring yields decline while water demand increases, especially because of agricultural and garden irrigation. This creates a supply deficit that requires additional pumping from the Streževo system, which increases energy costs and creates operational dependence on another state-managed water system.

The system serves a regional coverage area of approximately 85,000 inhabitants. It has 46,892 connected users or service connections and 53,492 water meters. The reported public water supply coverage in Bitola Municipality is approximately 85–90%. Domestic water use accounts for around 75% of total consumption, while commercial and industrial uses each account for around 10%, and public or municipal use accounts for around 5%.

The total water supply network length is approximately 493 km. Pipe materials include asbestos-cement, PVC, PEHD and cast iron.

A major infrastructure concern is the age of the network: more than 60% of the infrastructure is reported as aged, with many sections built predominantly in the 1970s and 1980s. This ageing infrastructure is one of the main drivers of pipe failures, leakages and operational inefficiency.

The system shows very high levels of water losses. Total annual water production is reported at 15,817,513 m³/year, while annual water consumption is 6,019,807 m³/year.

Total annual leakage is estimated at 8,834,380 m³/year, with an annual water loss percentage of 50–60%. The estimated cost of water losses is approximately 5,968,807 EUR/year.

These figures indicate that non-revenue water is one of the most important technical and financial challenges in Bitola.

Failure frequency has decreased in recent years but remains significant.

Reported failures decreased from 852 in 2023 to 712 in 2024 and 667 in 2025. At the same time, the annual replacement rate declined from 1.7 km/year in 2023 to 1.4 km/year in 2024 and 1.2 km/year in 2025. This suggests that pipe replacement is taking place, but at a rate that is too low compared with the overall network length and the share of aged infrastructure.

The mean operating pressure is approximately 5 atm. Pressure management is applied only to a limited extent, mainly in selected sections of the main transmission and trunk pipelines. A comprehensive pressure management system covering the full network, especially rural and peripheral areas, has not yet been established. This is particularly important because high pressure fluctuations in mountainous terrain are identified as one of the major causes of leakage.

4.2.3 Water quality management, maintenance and financial sustainability

Drinking water quality in Bitola is regulated by the national Law on Waters and the Rulebook on Drinking Water Safety and Quality, which are aligned with EU directives. Water quality monitoring is carried out by PUE Vodovod Bitola through internal daily control and by the Institute of Public Health through regular external audits. Inspections and enforcement are carried out by the Food and Veterinary Agency and the State Sanitary and Health Inspectorate.

For the standard public network, the reporting chain begins with the internal laboratory of PUE Vodovod Bitola, continues through utility management and, where necessary, involves the Institute of Public Health, the Food and Veterinary Agency, public notification and corrective measures. In village systems, responsibility for reporting non-compliance lies with the local body managing the system, such as a local community council or water supply committee, which must notify the Municipality, the Regional Institute of Public Health and the competent inspection authorities.

Legally, the same drinking water quality standards apply to small-scale and village systems. However, in practice, oversight is less frequent in independent or remote systems because of access constraints and limited local capacity. This creates a gap between formal regulatory requirements and practical monitoring conditions in rural and mountainous areas.

Maintenance is the responsibility of PUE Vodovod Bitola, while major capital replacements are co-managed with the Municipality.

Although annual preventive maintenance plans exist for critical facilities and equipment, most interventions remain reactive and are carried out after failures occur or after reports from customers. This reactive maintenance pattern is linked to the limited digital monitoring coverage, especially in rural and mountainous areas where real-time data are not available.

The financial sustainability of the system is constrained by high non-revenue water, high energy costs and limited tariff-based investment capacity. Total annual revenues are reported at 4,716,846 EUR/year, while total annual expenses are 4,670,159 EUR/year. Although the utility appears close to operational balance, the estimated annual cost of water losses alone is 5,968,807 EUR/year, which is higher than total annual revenues. This shows the scale of the financial burden created by water losses.

Water tariffs are regulated nationally by the Regulatory Commission for Energy and Water Services, which sets the minimum and maximum tariff limits. The final tariff adoption still requires approval by the Municipal Council. This dual-approval system creates a gap between economic cost-recovery requirements and local political considerations. Operational costs are generally covered, maintenance costs are only partially covered, and major capital investments rely mainly on external grants, EU funds and municipal or state budgets.

Small-scale and village systems face weaker financial sustainability.

Publicly managed rural networks enforce payments, but informal community-managed systems often rely on minimal flat fees or no effective payment at all.

This undermines maintenance, creates weak incentives for water conservation and limits the ability to finance rehabilitation of rural infrastructure.

4.2.4 Climate resilience, hydrogeological conditions and environmental pressures

Bitola faces important climate-related and seasonal water supply pressures. Water availability depends strongly on winter snowfall, mountain spring recharge and summer hydrological conditions. During summer, mountain spring yields decline while water demand increases, particularly due to agricultural and garden irrigation. This creates pressure on the system and increases the need for pumping from the Streževo hydro-system.

Project documentation for the new supply pipeline from the Dovledzik pumping station to the Dihovo water treatment plant (WTP) has been prepared and revised. The implementation of this project will enable an increase in the volume of raw water pumped from the Streževo system.

The main climate-related risks affecting the system are prolonged summer droughts, depletion of shallow aquifers and springs, extreme heatwaves that increase water consumption, and intense flash floods that raise turbidity at mountain intakes. These turbidity events can temporarily overload treatment capacity and reduce operational reliability.

Tourism-related seasonal variation exists, especially in Pelister mountain villages and through diaspora visits, but the main summer stress factor is irrigation use rather than population fluctuation. Illegal or informal tapping into the drinking water network for backyard village gardens is identified as a major issue during summer periods.

This contributes to high water losses, makes demand harder to manage and creates additional stress on the drinking water supply system.

Hydrogeologically, the municipality combines mountainous and valley conditions. Mount Baba consists of granitic and metamorphic rocks and provides high-quality gravity-fed spring water. The Pelagonia valley consists of deep alluvial sediments that are suitable for groundwater wells. Rapid runoff in mountainous areas contributes to seasonal depletion of springs, while the Dragor River, a tributary of the Crna Reka, shows strong seasonal variation, with high flows in spring due to snowmelt and very low flows in late summer.

Agricultural water demand is relevant because Bitola is located in the Pelagonia valley, an intensive agricultural region where cereals, tobacco and sugar beet are important crops. Large-scale irrigation is legally separated from drinking water and managed through the Streževo open-canal system. However, informal use of drinking water for garden irrigation remains a major local pressure during dry periods.

4.2.5 Digitalisation, innovation needs and transferability potential

Bitola has a partial digital basis for water management, but coverage remains insufficient.

A SCADA system is partially implemented and covers approximately 30% of the network. It monitors flow rates and selected operational parameters, but does not cover the full system, especially rural and mountainous areas.

As a result, real-time monitoring and control are not available for large parts of the water supply infrastructure.

> *Smart water management systems have been introduced in selected parts of the network, but their coverage is less than 10% of the total system.*

This is not enough to significantly improve operational efficiency at system level. The municipality also has basic GIS mapping, mainly focused on urban areas, and standard digital billing. However, rural segments lack continuous sensor logging and systematic digital monitoring.

Pressure management is only partially implemented, and there is no simulation model for the water supply system. Water balance assessment is also only partial, based mainly on standard billing and production inputs. This limits the utility's ability to identify hidden leakages, establish district metered areas, optimise pressure and prioritise rehabilitation based on real-time performance data.

The most important digital needs include SCADA upgrades, remote pressure sensors, smart flow meters, AMR/AMI metering, district metered areas and improved real-time leakage detection. These tools are directly relevant because Bitola's biggest sustainability gaps are high non-revenue water, energy inefficiency linked to summer pumping and the absence of digital monitoring infrastructure in rural clusters.

Community involvement is currently moderate. It is mainly expressed through the reporting of network failures, participation in public consultations for infrastructure projects and cooperation with local community councils in rural areas. Stakeholder engagement could be strengthened through regular public consultations, educational campaigns on responsible water use, digital communication platforms and active citizen involvement in water resource protection.

Bitola also provides transferable examples for other WATERVILL partners. The cross-municipal service model, where PUE Vodovod Bitola provides water services to the neighbouring municipalities of Novaci and Mogila, shows how a larger utility can support smaller rural municipalities. This model is supported by the Law on Local Self-Government and formal bilateral agreements between the municipal councils. Another relevant practice is the development of the Sanitary Protection Zones Study, which links water source protection with spatial planning and local scientific expertise.

4.2.6 Key findings for WATERVILL

Bitola is a highly relevant WATERVILL case study because it combines several core project challenges: high water losses, ageing infrastructure, partial digitalisation, limited rural monitoring, summer water scarcity, energy-intensive pumping and the need for stronger integration of rural systems.

The strongest technical priority is non-revenue water reduction. The reported annual water loss rate of 50–60%, total annual leakage of 8,834,380 m^3/year and estimated annual loss cost of 5,968,807 EUR show that leakage reduction is both a technical and financial priority. Measures such as district metering, pressure management, leakage detection, network rehabilitation and improved asset management are therefore highly relevant.

The strongest infrastructure priority is renewal of aged pipelines. More than 60% of the network is reported as aged, and the current annual replacement rate of 1.2 km/year in 2025 is very low compared with the total network length of 493 km. This indicates that rehabilitation needs are much larger than the current pace of replacement.

The strongest digital priority is expansion of SCADA, telemetry and smart monitoring into rural and mountainous areas. Current SCADA coverage of around 30% and smart system coverage below 10% are insufficient for system-wide operational control. WATERVILL can support Bitola by linking digital monitoring, pressure sensing, flow measurement and decision-support tools with practical leakage reduction.

The strongest climate resilience priority is improved management of summer scarcity and dependence on the Streževo system. Reduced spring yields during summer, increased irrigation demand and energy-intensive pumping create both operational and financial pressure. Better demand management, drought planning, monitoring and control of illegal or informal water use are therefore important.

The strongest governance and transferability priority is strengthening inter-municipal and rural water management. The existing cross-municipal service model with Novaci and Mogila is a useful practice that can be shared with other partners, while rural and village systems still require better monitoring, clearer responsibilities and stronger financial sustainability.

Overall, Bitola should be treated as a case where technical, digital, financial and governance measures need to be combined. Leakage reduction alone would not be sufficient unless supported by improved monitoring, stronger pressure management, rural system integration, realistic investment planning and measures to address seasonal scarcity and energy costs.

4.3 Case Study 3: Municipality of Ilirska Bistrica, Slovenia

4.3.1 Municipal context, governance and service provision

The Municipality of Ilirska Bistrica represents the Slovenian case study area within the WATERVILL project. The municipality is particularly relevant because it combines a formal public water supply system managed by a public utility provider with several local or village water supply systems that are not part of the public drinking water supply framework. This creates a useful case for assessing rural water governance, local system integration, water quality risks, infrastructure ageing and digital monitoring needs.

Water supply infrastructure is generally owned by the municipality, or jointly by several municipalities in the case of regional systems. In Ilirska Bistrica, the public water supply system is operated and maintained by JP Komunala Ilirska Bistrica d.o.o., which is responsible for daily operation, maintenance activities, identification and reporting of network failures, and repair of failures.

The Municipality of Ilirska Bistrica is responsible for planning infrastructure investments, financing investments and taking decisions on major upgrades or expansions. Investment planning is carried out in cooperation with JP Komunala Ilirska Bistrica d.o.o., but the municipality remains the key decision-maker and infrastructure owner.

The main model of drinking water service provision is public utility provision, complemented by local community-managed systems.

Approximately 89% of the municipal population is served by public water supply systems, while around 11% is supplied through small-scale or village systems. At the national level, the reported figures are approximately 94% for public water supply systems and 6% for small-scale or village systems.

Non-public water supply systems are present in the villages of Vrbovo, Vrbica, Jablanica, Trpčane, Kuteževo, Podgraje and Zabiče. Together, these villages include 1,493 residents supplied from six local drinking water sources managed by local communities. These systems are not part of the public drinking water supply system, which makes them especially relevant for WATERVILL's focus on small, local and village water supply systems.

Water resources in Slovenia are public goods owned by the state. Water abstraction permits and water rights are issued by the competent national authorities in accordance with the Water Act. Municipalities do not own water resources, but they play an important role in implementing public water supply services, spatial planning, local infrastructure development and the protection of water sources through local environmental measures and cooperation in water protection zones.

4.3.2 Water resources, infrastructure and operational performance

Ilirska Bistrica relies primarily on karst water resources. The municipality depends on groundwater and karst spring systems that are highly sensitive to precipitation patterns, drought periods and contamination risks. This hydrogeological context is central to understanding both water availability and water quality challenges in the municipality.

The public water supply system serves 11,761 users and approximately 4,100 households. The reported annual water production is 1,637,377 m³/year, while the reported consumed water volume is 641,940 m³/year. This difference is reflected in the high reported level of water losses.

The total water supply network length is approximately 250 km. The network consists of several pipe materials, including PE, PVC, ductile iron, steel, cast iron and asbestos-cement pipes.

A major concern is infrastructure age: parts of the system are more than 40 years old, and approximately 70% of the infrastructure is reported as aged. This creates a direct link between infrastructure condition, failures and water losses.

Operational performance is strongly affected by non-revenue water.

The annual water loss percentage is reported at 61%, while total annual leakage is estimated at 995,437 m³/year. The estimated annual cost of water losses is approximately 2,448,775 EUR/year.

These figures show that leakage reduction is one of the most important technical and financial priorities for Ilirska Bistrica.

The reported failure frequency is approximately 200 failures per year. The main causes of leakage are the age of the water distribution system and improper historical installation of water supply pipes. Current measures to prevent leakages are mainly based on gradual reconstruction of sections of the water distribution network.

Operational management is further constrained by the physical characteristics of the system. The network is very long and highly branched, with only a limited number of measurement points, which makes leak localisation difficult. Access to parts of the network is also limited, as the terrain is overgrown, some sections cross private land and other sections have been built over. These conditions increase the time and cost of both leak detection and repair.

The system has SCADA in place, and pressure management techniques are partially applied. The reported mean operating pressure is around 4 atm. The municipality has also introduced remote-reading water meters for end users and installed 25 flow meters at the most critical sections of the distribution network. These flow meters are used to identify and monitor water losses in specific network sections.

4.3.3 Water quality management, maintenance and financial sustainability

Drinking water quality in Ilirska Bistrica is regulated by the Slovenian Drinking Water Supply Act, the Water Act and secondary legislation governing drinking water quality and public health requirements. The system is aligned with European Union drinking water legislation. Monitoring and supervision are carried out by competent ministries, health inspectorates and public health institutions.

Water quality monitoring is primarily performed by the National Institute of Public Health and other competent public health institutions. For systems managed by JP Komunala Ilirska Bistrica d.o.o., sampling and testing are carried out by a contracted provider. The monitoring frequency depends on the quantity of water supplied within each supply area. The questionnaire reports planned annual sampling frequencies of 4 samples for the Fabci system, 18 samples for the Knežak and Podstenjšek systems, and 70 regular samples for the Ilirska Bistrica water supply system.

A major water quality issue is reported in the Fabci water supply system. Testing in January 2025 showed that drinking water in this system was microbiologically unsafe and non-compliant with drinking water quality standards. The sample taken from the Fabci reservoir contained coliform bacteria, Escherichia coli, intestinal enterococci and Clostridium perfringens, together with increased turbidity.

These parameters indicated faecal contamination and led to the issuing of a long-term boil water advisory for drinking water intended for food preparation and consumption.

The Fabci case illustrates the vulnerability of small local systems. The village reservoir is reported to be in very poor technical condition and is no longer watertight, allowing external water to infiltrate the structure. This contributes to microbiological contamination and non-compliance. The system also lacks an adequate drain outlet that would allow full emptying, cleaning, disinfection and proper maintenance. Following inspection, measures were required to ensure that the reservoir is technically suitable and properly maintained, with the deadline for implementation set for 1 January 2027.

Maintenance responsibilities are divided between the operator and the municipality. The operator is responsible for regular cleaning, maintenance of water supply facilities, equipment and installations, while the municipality, as the sole owner of the public water supply infrastructure, is responsible for capital maintenance. In practice, many repairs are reactive because the network is long, aged and difficult to manage proactively.

Financial sustainability is affected by high water losses, ageing infrastructure and investment needs.

Annual maintenance costs are reported at 170,000 EUR/year, while water quality monitoring costs are reported at 30,000 EUR/year. However, the estimated cost of water losses, at approximately 2.45 million EUR/year, is much higher than the reported annual maintenance costs.

This indicates that the financial impact of non-revenue water is a major constraint for long-term system sustainability.

Local or village water supply systems are financed through user payments, and users are charged according to consumption. According to information from local communities, the available funds are considered sufficient for long-term sustainability. However, the Fabci case shows that even where local systems operate, technical condition, water quality compliance and maintenance capacity remain critical issues.

4.3.4 Climate resilience, hydrogeological conditions and environmental pressures

Climate resilience is a central issue for Ilirska Bistrica because the municipality relies on karst water sources. Karst aquifers are highly sensitive to weather conditions. Heavy rainfall can increase turbidity and affect raw water quality, while prolonged dry periods can reduce the availability of water from springs and groundwater sources.

The main climate-related risks include prolonged droughts, heatwaves, intense rainfall events, flooding and reduced groundwater recharge. Prolonged droughts can reduce karst spring yield and groundwater availability, especially during summer. Heatwaves increase water demand from households, agriculture and public services while reducing natural recharge. Intense rainfall can rapidly increase turbidity in karst water sources and require additional treatment measures.

Karst hydrogeology creates both advantages and vulnerabilities. Extensive karst aquifers allow precipitation to infiltrate rapidly and form underground groundwater reservoirs, which represent the main natural storage system for drinking water supply. Forest-covered recharge areas, especially in the wider area of the Snežnik Forests, help regulate runoff, reduce evaporation and improve groundwater recharge.

At the same time, karst systems have limited natural filtration capacity. Pollutants can travel rapidly through underground channels, which makes groundwater resources highly vulnerable to agricultural, industrial or urban contamination. This is particularly important for water source protection, land-use planning and monitoring after heavy rainfall events.

The municipality is also exposed to runoff and erosion issues during intense precipitation. Although infiltration is generally high in karst terrain, heavy rainfall can exceed local infiltration capacity, causing rapid surface runoff, local flooding and erosion. This can increase sediment transport into streams and water intake areas and increase water turbidity.

Tourism-related seasonal population variation exists but is relatively limited compared with major Slovenian tourist destinations. The municipality experiences some increase in visitors during summer because of its proximity to the Snežnik Forests, Lake Mola and hiking and cycling routes, but tourism does not create major population fluctuations. Seasonal stress is therefore more closely linked to drought, heatwaves, karst water variability and infrastructure performance than to tourism pressure alone.

4.3.5 Digitalisation, innovation needs and transferability potential

Ilirska Bistrica already has a relatively advanced starting point for digital water management compared with many rural and mountainous systems. The municipality uses remote-reading water meters for end-user consumption data, flow meters and remote sensors at critical points in the network, and digital asset databases and operational records for maintenance planning.

The system also has SCADA, although some functions remain partial or under development. Available digital data include partial hourly flow analysis, partial daily load monitoring, partial remote pressure sensing, well position data and pumping volume data. A GIS system is currently being implemented but is not yet operational. These tools provide a useful basis for improved operational control, leakage detection and asset management.

Important digital gaps remain. Further development is needed in advanced leak detection, pressure management, real-time hydraulic modelling, digital twins, predictive maintenance tools, integration of climate, hydrological and consumption data, AI-supported demand forecasting and integrated dashboards combining GIS, operational and customer data.

The municipality has already introduced 25 flow meters at critical sections of the network, which are used to identify and monitor water losses. This is directly relevant for WATERVILL because it shows a practical pathway for improving leakage management in a long and ageing rural water distribution network.

The 5G WAT ERR IB initiative is identified as one of the most important transferable practices. It uses sensors, real-time monitoring systems and 5G-enabled communication to improve oversight of water infrastructure and support rapid response to operational issues. The transferable benefits include early leak detection, continuous monitoring of network performance, faster response to service disruptions and improved data-based decision-making.

Another transferable practice is the integration of emergency response and water supply management. The municipality has explored linking water management with emergency response systems, particularly for climate-related events and natural disasters. This can improve preparedness for droughts, floods and infrastructure failures, while strengthening coordination between utility operators, municipal authorities and emergency services.

Community involvement is present through local communities, which manage several smaller local water supply systems. This indicates a degree of decentralised participation, especially in village systems.

However, WATERVILL could further support stakeholder engagement through public awareness campaigns, water conservation activities and stronger communication between the municipality, utility provider and local communities.

4.3.6 Key findings for WATERVILL

Ilirska Bistrica is a highly relevant WATERVILL case study because it combines several core project challenges: high water losses, ageing infrastructure, karst water vulnerability, local village systems, water quality risks, partial digitalisation and the need for stronger climate resilience.

The strongest technical priority is water loss reduction. The reported annual water loss rate of 61%, total annual leakage of 995,437 m^3/year and estimated annual cost of water losses of approximately 2.45 million EUR indicate a major need for leakage detection, flow monitoring, pressure management, pipe rehabilitation and improved asset management.

The strongest infrastructure priority is renewal of ageing network sections. Around 70% of the infrastructure is reported as aged, and the network is approximately 250 km long. The combination of old pipes, historical construction practices and approximately 200 annual failures shows that infrastructure rehabilitation is essential for improving reliability and reducing losses.

The strongest water quality priority is improving the safety and technical condition of local systems, especially the Fabci water supply system. The reported microbiological contamination, long-term boil water advisory and poor reservoir condition show that local systems require stronger monitoring, maintenance, rehabilitation and compliance support.

The strongest climate resilience priority is improved management of karst water vulnerability. Karst sources provide important groundwater resources but are sensitive to drought, reduced recharge, turbidity after heavy rainfall and rapid contamination pathways. WATERVILL can support better integration of hydrological, climate and operational data for drought preparedness and source

The strongest digital priority is to build on the existing monitoring base and move towards more integrated real-time management. Existing SCADA, remote-reading meters and flow meters provide a good starting point, but further development is needed in pressure monitoring, hydraulic modelling, predictive maintenance, digital twins, decision-support tools and implementation of GIS tools.

Overall, Ilirska Bistrica should be treated as a case where WATERVILL can combine technical, digital, water quality and climate-resilience measures. The municipality already has useful digital and monitoring practices that can be shared with other partners, but high water losses, ageing infrastructure and vulnerable local systems show that further investment and better integration of data, governance and maintenance planning are still needed.

4.4 Case Study 4: Municipality of Teslić, Bosnia and Herzegovina

4.4.1 Municipal context, governance and service provision

The City of Teslić represents one of the WATERVILL case study areas in Bosnia and Herzegovina / Republic of Srpska. The local drinking water supply system combines a formal public water utility model with the continued presence of smaller rural and village water supply systems. This makes Teslić particularly relevant for the WATERVILL assessment, as it reflects several challenges typical of rural and mountainous territories: fragmented service provision, water losses, ageing infrastructure, limited monitoring of rural systems and the need for stronger digital and governance solutions.

Teslić is located in the Republic of Srpska and therefore operates within the institutional and regulatory framework described in Section 3.1. Water supply services in Teslić are managed by PKD "Rad" a.d. Teslić, a public utility company in which the City of Teslić holds a majority ownership stake. The company is responsible for daily operation of the public water supply system, maintenance activities, identification and repair of failures, water distribution to end users and technical management of infrastructure. The City of Teslić has a broader strategic and financial role, particularly in planning major investments, supporting the expansion and modernisation of rural water supply systems and providing financial resources where larger interventions are required.

The municipality acts as owner or co-owner of infrastructure, founder and shareholder of the public utility company, contracting authority and strategic planning body. Infrastructure investments are planned jointly by the City of Teslić and PKD "Rad". The City is responsible for major investment planning, while the utility contributes technical expertise, operational knowledge and human resources. Financing sources include the city budget, foreign loans, international donor grants and user charges.

The main model of drinking water service provision is therefore a public utility model, complemented by community-managed rural systems.

The rural water supply systems in the municipality differ significantly from one another in terms of source type, technical condition, size, number of users, management arrangements and level of maintenance. Reliable data on source capacity, water quality, water losses and operational performance are not available for most of these systems. Their condition can therefore not currently be assessed on a comparable basis, and the figures reported in this assessment refer primarily to the public water supply system.

The public water distribution system supplies the majority of connected users, while the remaining population relies on water supply systems of different sizes that are managed by users themselves. These rural systems were often financed and constructed by local residents and do not have a formal operator. Maintenance and repairs are typically carried out by local community councils or by the residents themselves.

This dual structure creates a clear distinction between the formal public utility system and rural/village systems. The public system benefits from a designated operator, more systematic maintenance and formal institutional responsibilities. By contrast, rural systems face weaker legal and organisational arrangements, limited professional management and more uncertain financing. This difference is central to understanding the sustainability challenges in Teslić.

4.4.2 Water resources, infrastructure and operational performance

The main source of water for the public water supply system in Teslić is surface water from the Velika Usora River. Reported annual water production is 2,248,000 m³/year. The river is a key resource for the local system but is characterised by a torrential regime and highly variable flow conditions, which influence both water quantity and raw water quality. Recorded discharge values range from a minimum flow of 0.73 m³/s to a maximum flow of 476 m³/s.

The public water supply system serves approximately 29,500 connected users, corresponding to a reported coverage of 76% in the technical data table.

The total system length is approximately 455 km. The system includes asbestos-cement pipes, PVC pipes and PEHD pipes. The oldest reported asbestos-cement infrastructure dates from 1968, while PVC infrastructure dates from 1989.

Although the reported share of aged infrastructure is 7%, the presence of asbestos-cement sections and the age of parts of the network indicate a need for targeted rehabilitation and replacement.

The system includes 19 reservoirs and 18 pumping stations, including drinking water treatment infrastructure. The reported mean operating pressure is around 4 bar. Peak day demand is approximately 7,000–7,500 m³/day. The system has 12,750 water meters, and reported water use is dominated by domestic consumption, which accounts for approximately 83% of water use, while industrial use accounts for around 17%.

Operational performance is strongly affected by water losses and infrastructure condition. The annual water loss percentage is reported at 46%, while the estimated cost of water losses is approximately 900,000 EUR/year. The reported failure frequency is 630 breaks per year.

The main reported cause of leakage is outdated infrastructure, and leakage prevention is currently based mainly on occasional replacement of infrastructure, depending on available financial resources.

The municipality performs a water balance assessment through PKD “Rad”. A SCADA system is in place, and smart systems for water management have been introduced to some extent. However, pressure management techniques are not currently applied, and there is no simulation model for the water supply system. This indicates that Teslić has a partial digital and operational basis for improved water management, but further development is needed to support systematic leakage reduction, pressure optimisation and long-term asset management.

4.4.3 Water quality management, maintenance and financial sustainability

Drinking water quality in Teslić is regulated under the legal framework of the Republic of Srpska, including the Law on Waters, the Law on Communal Activities and the Rulebook on the Health Safety of Water Intended for Human Consumption. Water quality monitoring is carried out by PKD “Rad” a.d. Teslić, authorised public health institutions, the Public Health Institute of the Republic of Srpska and internal laboratory services.

In the public water supply system, water quality is monitored daily, while rural systems are monitored periodically. Samples are tested daily in the internal laboratory, and the Public Health Institute conducts testing three times per month. In case of irregularities, the Institute contacts the water utility company and inspection authorities, after which repeated monitoring and additional sampling are carried out. Compliance is enforced through sanitary inspection authorities, water management inspection authorities, public health authorities, relevant ministries and local authorities.

The same level of monitoring and regulatory control does not apply to all small-scale or village systems. This creates a significant difference between the public system and informal or community-managed systems.

In practice, most rural systems in the municipality do not have regular water quality control. Testing is occasional and depends on the capacity of individual local operators, on municipal support or on project-based activities. Compliance with drinking water quality requirements can therefore not be systematically verified for a significant part of the rural population.

Rural systems may have weaker monitoring arrangements and less clearly defined reporting chains, which increases potential risks for water quality management and public health protection.

Maintenance and asset management of the public water supply system are the responsibility of PKD “Rad”. The City of Teslić participates in strategic planning, infrastructure development and financing of major investments and reconstruction projects. Specialised contractors are engaged where necessary for large-scale reconstruction, pipeline construction and specialised technical works.

Although maintenance plans exist, repairs are mostly reactive. Network failures are identified by employees of PKD "Rad".

The main daily operational obstacles are lack of staff and insufficient technical equipment. These limitations reduce the ability of the operator to move from reactive maintenance towards predictive or preventive asset management.

Water tariffs are determined in accordance with decisions adopted by the Assembly of the City of Teslić, in cooperation with PKD "Rad". Tariff calculation is regulated by applicable legislation on water utility companies and local decisions, and tariffs are defined according to the operational and maintenance requirements of the public utility company. Current and planned tariffs are intended to cover operational costs and maintenance costs for the public system. However, major capital investments are generally financed through the city budget and international donor grants.

The financial situation of rural water supply systems is considerably weaker.

In some larger rural systems, users pay a monthly flat-rate fee for water use, and these funds are used for repairs. However, there is no formal legal entity responsible for management. The main financial challenges are irregular payment, lack of legal basis and the absence of allocated funds for depreciation or amortisation of the network.

While current tariffs allow long-term planning for the public service managed by PKD "Rad", the situation is much less sustainable in rural systems.

4.4.4 Climate resilience, hydrogeological conditions and environmental pressures

Water availability in Teslić does not currently show critical shortages throughout the year, but seasonal variations are present. Demand increases during the summer months due to higher temperatures and increased consumption. Seasonal population fluctuations linked to tourism, particularly visitors to Banja Vrućica, also contribute to higher water demand during peak periods.

The main climate-related risks affecting the system are flooding, increased turbidity of raw water during heavy rainfall, significant variability in river flow conditions, heatwaves that increase water demand and occasional drought periods. The Velika Usora River has a torrential character and is highly sensitive to precipitation patterns. This creates frequent fluctuations in both water quantity and raw water quality. Significant floods were recorded in 2014 and 2019, although no major damage to water infrastructure was reported.

There are currently no natural buffer zones or infiltration zones used specifically to improve local water retention. There is also no specific local drought management plan.

Instead, operational flexibility is applied within the water utility company in response to seasonal and climate variations. Water management is regulated through general national and local environmental and water protection legislation.

The municipality is characterised by mixed geological conditions that influence both surface water and groundwater behaviour. Infiltration capacity varies depending on soil type and geological structure, while surface runoff can be rapid during heavy rainfall. Soil stability is not considered a major issue, although intense precipitation may increase erosion and runoff. These conditions contribute to pronounced hydrological variability during extreme weather events.

The Velika Usora River is the main watercourse crossing the municipality and plays a key role in the local water supply system. At the same time, its torrential regime makes the system sensitive to weather-related changes, especially increased turbidity during heavy rainfall.

Rural areas are supplied by local springs and, in a significant number of systems, by water abstracted directly from open watercourses such as creeks and rivers. Reliable data on the capacity of these sources are not available. The use of open watercourses increases exposure to turbidity, microbiological contamination and flow variability, and the absence of reliable information on local source yields represents an important data gap for future climate resilience and scarcity assessment.

Agricultural land in Teslić is mainly dispersed, and agriculture is mostly traditional and subsistence-oriented. The predominant crops include maize, vegetables and grassland used for livestock farming. Irrigation is limited and not highly developed. There are no large or centralised irrigation systems, and water is typically abstracted informally from local surface or groundwater sources when needed. Agricultural water demand is therefore relatively low compared to municipal water supply needs.

4.4.5 Digitalisation, innovation needs and transferability potential

Teslić has an initial basis for digital water management, but important gaps remain. The municipal water supply system uses SCADA, and hourly flow analysis and daily load monitoring are available through the SCADA system. Wastewater treatment plant data are also available through SCADA, and river flow data are reported.

However, several important datasets are not available or not yet provided, including remote pressure sensing, GIS format maps of the municipality, topography data, geology data, groundwater levels, well locations, pumping volumes, precipitation data, temperature data, land use data and spatial distribution of crop types.

The absence of these datasets limits the ability to develop advanced modelling, spatial analysis, predictive maintenance and climate-resilience planning. It also limits the capacity to assess the interaction between water demand, climate conditions, surface runoff, groundwater behaviour, agricultural use and infrastructure performance.

The municipality does not have a simulation model for the water supply system, and pressure management techniques are not currently applied. Given the reported 46% annual water loss rate and the high estimated cost of water losses, improved leakage monitoring, district metering, pressure management, GIS-based asset mapping and hydraulic modelling would be particularly relevant for Teslić.

The biggest sustainability and efficiency gap identified in the questionnaire is energy inefficiency. Water reuse systems are not currently present, and there are no plans to implement them.

This suggests that WATERVILL interventions in Teslić should focus primarily on water loss reduction, operational efficiency, energy efficiency, monitoring and improved data management rather than on reuse.

Community involvement is present mainly through rural systems, where local residents and community councils manage, finance and maintain systems in the absence of formal operators. However, this model is not sufficiently structured for long-term sustainability. The questionnaire identifies the delegation of staff within the City Administration to work on water supply management as a measure that could improve stakeholder engagement and coordination.

No existing successful practices or tools were identified as transferable to other project partners. However, Teslić itself provides a valuable learning case for WATERVILL because it shows the practical challenges of combining a formal public utility system with informal rural systems. The case is relevant for testing solutions related to leakage reduction, monitoring, digitalisation, rural system integration, staff capacity and improved coordination between the city administration, utility company and local communities.

4.4.6 Key findings for WATERVILL

Teslić is a highly relevant case study area for WATERVILL because it combines several core project challenges: high water losses, ageing infrastructure, partial digitalisation, reactive maintenance, weak monitoring of rural systems, lack of a simulation model, absence of pressure management and limited long-term financial sustainability of village water systems.

The strongest technical priority is water loss reduction. The reported annual water loss rate of 46%, together with 630 breaks per year and an estimated annual cost of losses of 900,000 EUR, indicates a substantial opportunity for leakage detection, pressure management, asset rehabilitation and operational optimisation.

The strongest governance priority is the integration and improved management of rural and small-scale systems. These systems are managed by users, often without formal operators, legal entities or depreciation funds. This creates risks for long-term sustainability, water quality monitoring and investment planning.

The strongest digital priority is the expansion of data availability and system modelling. Existing SCADA and flow monitoring provide a useful starting point, but the lack of GIS data, pressure sensing, hydraulic modelling, groundwater data, climate data and spatial land-use data limits advanced decision-making. WATERVILL can therefore support Teslić by linking existing monitoring capacity with improved data collection, feeding DSS indicators that account for the current GIS and hydraulic-modelling gap

The strongest climate resilience priority is improved management of risks related to the Velika Usora River. The river is essential for water supply but has highly variable flow conditions and increased turbidity during heavy rainfall. Future measures should consider flood-related turbidity, seasonal demand increases, drought periods and the lack of reliable data on rural spring capacities.

Overall, Teslić should be treated as a case where technical, digital, governance and capacity-building measures need to be combined. A purely technical intervention would not be sufficient unless accompanied by better data, stronger institutional coordination, improved rural system management and a realistic financing strategy for infrastructure renewal. A specific need identified by the municipality is a dedicated study analysing each of the major rural water supply systems individually, covering source capacity and yield, water quality, water losses, technical condition and management arrangements, and providing system-specific recommendations for improvement. Such a study would establish a comparable evidence base for the rural systems and would allow concrete measures to be defined and incorporated into the next Teslić development strategy, which is scheduled for adoption in 2028.

4.5 Comparative Data Matrix for Case Study Municipalities

The four WATERVILL case study municipalities show different levels of data availability, technical maturity and institutional capacity. Bitola, Ilirska Bistrica and Teslić provide detailed operational and financial indicators, while the available Žabljak data are fragmented across several rural water supply systems rather than consolidated into one municipal dataset. This difference in data availability is itself an important finding, because it reflects the uneven digital and monitoring readiness of rural and mountainous water supply systems.

	Žabljak, Montenegro	Bitola, North Macedonia	Ilirska Bistrica, Slovenia	Teslić, Bosnia and Herzegovina
Case study profile	Mountainous tourist municipality with fragmented rural water supply systems and strong seasonal demand	Urban utility system combined with rural and mountainous settlements	Public utility system combined with local village water systems	Public utility system combined with user-managed rural systems
Main service model	Mixed model: public utility, municipality-supported village systems and community-managed systems	Public Utility Enterprise "Vodovod" Bitola; also serves Novaci and Mogila	JP Komunala Ilirska Bistrica d.o.o.; local systems managed by communities	PKD "Rad" a.d. Teslić; rural systems managed by users/local communities
Public water supply coverage	Approx. 90% public water supply systems; approx. 10% small-scale / village systems. Six settlements without organised water supply: n/a for system-level indicators.	Approx. 85–90%	Approx. 89% municipal public supply; 11% local systems	Approx. 76% according to technical data
Population / users served	Six rural systems analysed; approx. 1,020 service connections; strong summer population increase	Approx. 85,000 inhabitants in regional coverage area; 46,892 connections	11,761 public system users; 1,493 residents in local non-public systems	Approx. 29,500 connected users
Main water sources	Springs, boreholes, underground sources, Modro Lake overflow; some villages rely on rainwater cisterns and distant springs	Baba mountain springs and groundwater; Streževo surface water system	Karst groundwater and spring systems	Velika Usora River; rural areas also use local springs and open watercourses (creeks and rivers)
Network length	Approx. 92 km across six analysed rural systems	Approx. 493 km	Approx. 250 km	Approx. 455 km
Main pipe materials	Mostly PVC pipes; Njegovuđa also reports older asbestos-cement	Asbestos-cement, PVC, PEHD, cast iron	PE, PVC, ductile iron, steel, cast iron, asbestos-	Asbestos-cement, PVC, PEHD

	sections		cement	
Ageing infrastructure	Mixed age; several systems from late 1990s, Šaranci from 2014–2018; Bosača reports approx. 40% aged infrastructure	More than 60% reported as aged	Approx. 70% reported as aged; parts older than 40 years	Aged infrastructure officially reported at 7%, but older asbestos-cement sections date from 1968
Annual water production	Njegovuđa approx. 120,000 m³/year; other analysed systems n.m.	15,817,513 m³/year	1,637,377 m³/year	2,248,000 m³/year (public system); rural systems n.d.
Annual water consumption	Njegovuđa approx. 84,000 m³/year; other analysed systems n.m.	6,019,807 m³/year	641,940 m³/year	n.d. (billed volume not reported)
Reported water losses	Njegovuđa approx. 30%; other systems n.m. — leakage, high pressure and delayed repairs reported qualitatively, without water balance data	50–60%; 8,834,380 m³/year leakage	61%; 995,437 m³/year leakage	46%
Estimated annual cost of losses	Njegovuđa approx. 25,000 EUR/year; Virak approx. 17,000 EUR (2025); other systems n.m.	Approx. 5,968,807 EUR/year	Approx. 2,448,775 EUR/year	Approx. 900,000 EUR/year
Failure frequency	Approx. 2–5 failures/year reported by several systems (estimates); remaining systems n.d.	667 failures in 2025; decrease from 852 in 2023	Approx. 200 failures/year	Approx. 630 breaks/year
Operating pressure	Njegovuđa approx. 6 bar; Virak approx. 5 bar; other systems n.m.	Approx. 5 atm	Approx. 4 atm	Approx. 4 bar
Reservoirs / pumping stations	n.d. at municipal level; boreholes, reservoirs, pumps and a filtration station reported in individual systems	n.d.	n.d.	19 reservoirs and 18 pumping stations
Water quality	Lack of chlorination	Rural systems	Fabci system	Public system

concern	and protection zones in several rural systems; cistern water used only for technical purposes in some villages	monitored less frequently than the public system	has microbiological contamination and long-term boil water advisory	monitored daily; rural systems monitored periodically
Financial sustainability issue	Many rural systems do not charge users; maintenance depends on municipality, residents or ad hoc repairs	Cost of water losses exceeds annual revenues	Cost of water losses is much higher than annual maintenance costs	Rural systems lack formal financing and depreciation funds
Digitalisation level	Limited and uneven; most rural systems lack SCADA, smart meters, water balance and simulation models	SCADA covers approx. 30%; smart systems below 10%; basic urban GIS	SCADA, remote-reading meters and 25 flow meters at critical points	SCADA and water balance available; no pressure management or simulation model
Main digital gaps	Flow meters, pressure monitoring, smart meters, GIS records, SCADA coverage and water balance assessment	Rural SCADA coverage, pressure sensors, DMA zones, smart metering and real-time leakage detection	Advanced leak detection, GIS, hydraulic modelling, digital twins and integrated dashboards	GIS data, pressure sensing, hydraulic modelling, climate/spatial datasets and pressure management
Main climate pressure	Summer demand peaks, drought-related source reduction, karst terrain and limited storage	Summer scarcity, reduced spring yield, irrigation demand and dependence on Streževo pumping	Karst drought vulnerability, turbidity after heavy rainfall and contamination risks	Flood-related turbidity, variable river flows, summer demand and lack of local drought plan
Main WATERVILL priority	Clarify responsibilities, improve chlorination/protection zones, introduce metering, monitoring and leakage control	Reduce NRW, expand SCADA/telemetry, improve pressure management and rural monitoring	Reduce losses, improve local system safety, integrate monitoring and strengthen karst resilience	Reduce losses, improve rural system governance, expand digital data and introduce pressure

				management
Transferable practice / lesson	Useful case for comparing self-managed, municipality-supported, utility-managed and non-organised rural systems	Cross-municipal service model supporting Novaci and Mogila	Existing flow meters, SCADA, 5G-enabled monitoring initiative	Learning case for combining formal utility service with informal rural systems

Notation: n.d. – data not provided by the municipality or utility; n/a – not applicable to the system; n.m. – not measured, no metering or monitoring equipment in place; 0 – confirmed zero value. Where data are available only for part of the municipal territory, the value is given together with the name of the system it refers to.

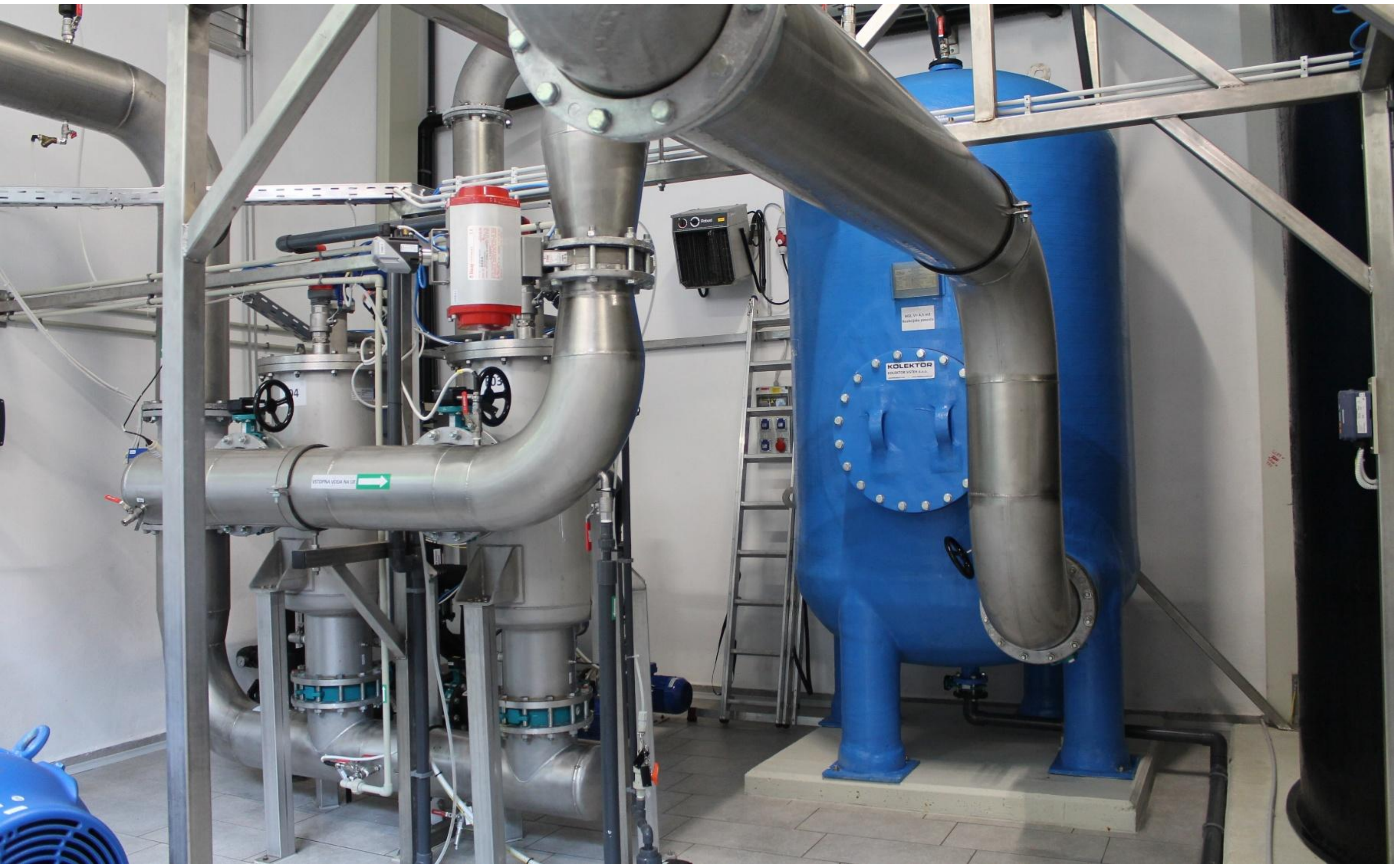
The matrix shows that the strongest common challenge across the case study municipalities is non-revenue water and the wider problem of insufficient control over water losses. Bitola, Ilirska Bistrica and Teslić all report very high water loss levels, ranging from 46% in Teslić to 50–60% in Bitola and 61% in Ilirska Bistrica. Žabljak also confirms the relevance of this problem, although the data are not available as one consolidated municipal water balance. Instead, the available Žabljak inputs provide partial system-level data, with Njegovuđa reporting approximately 30% water losses, while other rural systems identify leakage, high pressure, delayed repairs and lack of metering as key operational problems. These findings confirm that leakage reduction, pressure management, flow monitoring and asset renewal are central WATERVILL priorities.

A second common issue is the gap between formal public utility systems and rural or village systems. Bitola, Ilirska Bistrica and Teslić all combine a formal public operator with smaller rural or local systems that have weaker monitoring, weaker financial sustainability or less professional management. Žabljak shows this pattern very clearly because its rural water supply is not organised as one uniform system. The municipality includes utility-managed systems, community-managed systems, municipality-supported village systems and settlements without organised water supply. This confirms the relevance of WATERVILL solutions for small, fragmented and locally managed systems, especially where ownership, maintenance, financing and water quality responsibilities are not fully standardised.

The municipalities differ most in their digital readiness. Ilirska Bistrica has the strongest starting point, with SCADA, remote-reading meters and flow meters already in use and is currently implementing GIS. Bitola has partial SCADA coverage but weak rural monitoring. Teslić has SCADA and water balance data, but lacks pressure management, GIS and hydraulic modelling. Žabljak has a more uneven digital situation: most rural systems lack SCADA, smart metering, water balance assessment and simulation models, while some larger systems, such as Njegovuđa and Virak / the Komarsko–Pošćenski area, already show partial monitoring elements or planned installation of flow meters and smart meters. This means that Žabljak requires a staged approach, starting with basic metering, data collection and asset mapping before more advanced digital tools can be fully applied.

Overall, the comparative matrix confirms that WATERVILL should not focus on only one type of intervention. The most relevant approach is a combined package of water loss reduction, digital monitoring, pressure management, GIS-based asset mapping, rural system governance, capacity building and climate-resilient planning. For municipalities with limited technical staff, such as rural and mountainous areas, these measures could be supported through a shared technical monitoring model rather than through full institutional consolidation. Žabljak is particularly relevant for this approach because it shows that different types of rural systems may coexist within one municipality and may require different levels of support, from basic water safety and legal clarification to more advanced monitoring and smart metering.

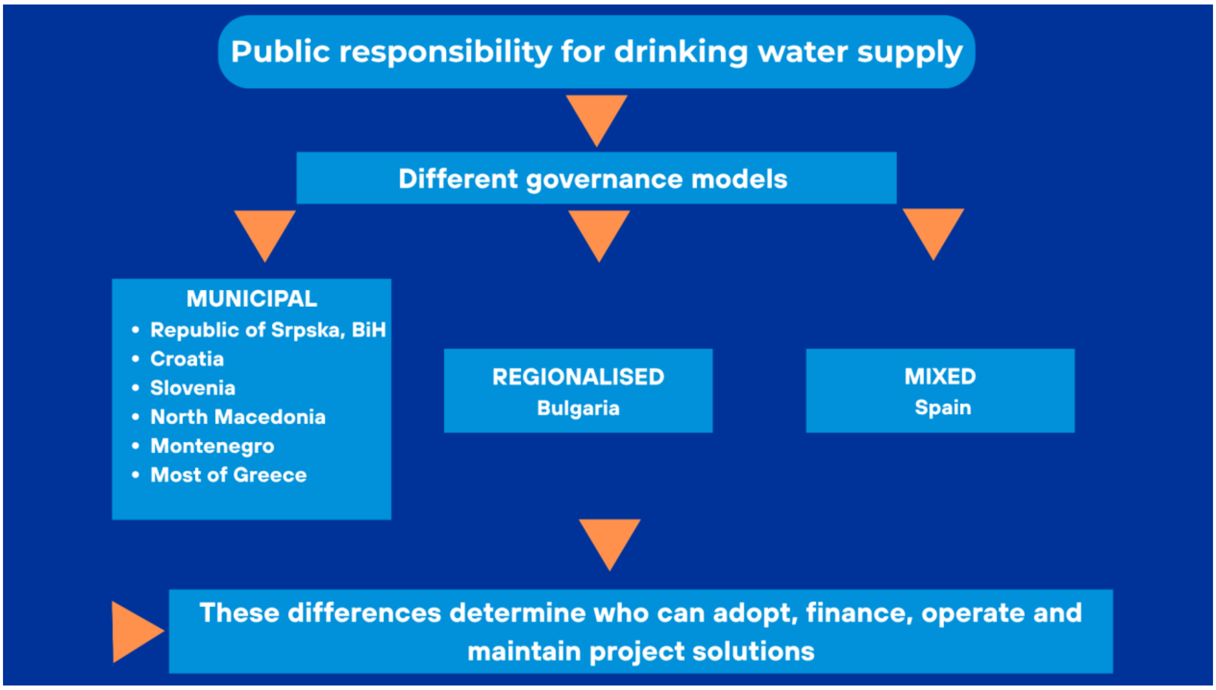
5. Comparative Analysis and Key Challenges



The national and local assessments show that the main challenges of rural and mountainous drinking water supply systems are not isolated technical problems. They result from the interaction between infrastructure condition, governance arrangements, financial capacity, digital readiness, water resource vulnerability and the organisation of small-scale or village systems.

The comparison of national frameworks in Chapter 3 and the case study municipalities in Chapter 4 therefore confirms that WATERVILL solutions need to address water supply systems as integrated socio-technical systems, rather than as infrastructure networks alone.

5.1 From national frameworks to local implementation realities



The partner-level analysis shows that all countries recognise drinking water supply as a public responsibility, but they organise this responsibility in different ways. Some contexts rely strongly on municipalities and local public utilities, such as the Republic of Srpska, Croatia, Slovenia, North Macedonia, Montenegro and most of Greece outside the major metropolitan areas. Bulgaria follows a more regionalised operator model, while Spain combines municipal responsibility with a wide range of direct, delegated, concessionary, mixed and supramunicipal service models.

These differences matter because they determine who can adopt, finance, operate and maintain WATERVILL solutions. In strongly municipal systems, implementation depends heavily on municipal capacity and the ability of local public utilities to manage investments and new technologies. In Bulgaria, implementation must be aligned with regional ViK operators and their business and investment plans. In Greece, solutions must bridge the gap between stronger metropolitan utilities and weaker municipal providers. In Spain, implementation depends on the specific local service-management model, because the municipality remains responsible for the service, but operation may be carried out by a municipal department, public utility, concessionaire, mixed company, mancomunidad, consortium, provincial council or other supramunicipal structure.

Despite these governance differences, the local case studies show a similar implementation reality.

In Žabljak, Bitola, Ilirska Bistrica and Teslić, rural and mountainous water supply systems are affected by limited local capacity, fragmented small systems, ageing infrastructure, weak monitoring and high investment needs.

This confirms that national governance models influence implementation conditions, but they do not remove the basic vulnerability of small rural systems.

The comparison also shows that the formal legal framework is often stronger than the practical implementation capacity. Several countries have detailed legislation, tariff methodologies, water quality rules, river basin plans, digitalisation strategies or strategic documents. Spain is a good example of this pattern: it has a sophisticated regulatory framework for drinking water quality, water-resource management, hydrological planning, drought management and digitalisation, but small rural and mountainous municipalities may still lack the technical, administrative and financial capacity to implement these requirements without supramunicipal support.

This gap between formal obligations and operational capacity is one of the central challenges identified by the report.

5.2 Water losses as the central technical and financial challenge

The most visible common technical challenge across the pilot municipalities is non-revenue water. Bitola reports water losses of 50–60%, Ilirska Bistrica 61% and Teslić 46%. These values are not only technical indicators, but also financial and governance indicators. High water losses show that networks are old, monitoring is insufficient, pressure management is incomplete and rehabilitation is not keeping pace with infrastructure deterioration.

Žabljak also confirms the relevance of this challenge, although the available data are not presented as one consolidated municipal water balance. Instead, the data are fragmented by individual rural systems. Njegovuđa reports approximately 30% water losses, with annual production of around 120,000 m³ and consumption of around 84,000 m³. Other rural systems do not provide complete water balance data, but they identify leakage, high pressure, delayed repair of failures and lack of flow metering as important operational problems. This is especially relevant because several Žabljak rural systems are managed locally or semi-formally, which makes systematic detection and quantification of losses more difficult.

The economic impact is substantial. In Bitola, the estimated annual cost of water losses is higher than total annual revenues. In Ilirska Bistrica, the estimated cost of losses is much higher than annual maintenance costs. In Teslić, water losses represent a major financial burden for a system that also faces frequent failures and limited pressure management. In Žabljak, the available data show the same problem at a smaller rural-system scale:

Njegovuđa reports an estimated annual cost of water losses of around 25,000 EUR, while its annual revenues are approximately 24,000 EUR and total expenses approximately 25,000 EUR. Virak / the Komarsko–Pošćenski area also reports an estimated cost of water losses of around 17,000 EUR in 2025. In several other Žabljak rural systems, users are not charged for water consumption, which means that losses do not only represent a technical inefficiency, but also a barrier to stable maintenance financing.

These examples show that leakage reduction is not only an efficiency measure, but a precondition for financial sustainability. Reducing water losses may not always directly increase revenues if tariffs remain unchanged, but it reduces unnecessary abstraction, pumping, treatment, energy use, emergency repairs and pressure on limited local sources. In small rural systems, it can also delay the need for new sources, reservoirs or pumping capacity.

The national assessments confirm that this problem is not limited to the four pilot municipalities. Ageing infrastructure, high non-revenue water and insufficient monitoring are repeatedly identified in rural and mountainous areas across partner countries. Therefore, leakage detection, pressure and flow monitoring, district metering, GIS-based asset mapping, water balance analysis and targeted rehabilitation should be treated as core WATERVILL priorities.

Therefore, leakage detection, pressure and flow monitoring, district metering, GIS-based asset mapping, water balance analysis and targeted rehabilitation should be treated as core WATERVILL priorities.

5.3 Rural and village systems as the main governance challenge

A second key challenge is the relationship between formal public utility systems and smaller rural or village systems. In several partner contexts, these systems are only partly integrated into formal public service structures or are managed through local communities, user groups or informal arrangements. This is visible in the national assessments for the Republic of Srpska, Croatia, North Macedonia and Montenegro, and it is directly reflected in the case studies of Bitola, Ilirska Bistrica, Teslić and Žabljak.

The case studies show that these systems create a specific type of vulnerability. They may have weaker water quality monitoring, unclear maintenance responsibilities, limited professional management, irregular financing and incomplete technical documentation. In Teslić, rural systems are often managed by users without a formal operator or depreciation funds. In Ilirska Bistrica, local systems exist alongside the public system, and the Fabci case shows how weak infrastructure condition can directly lead to microbiological contamination and long-term boil-water measures. In Bitola, rural systems have weaker monitoring and financing mechanisms than the main public network.

Žabljak shows this challenge particularly clearly because its rural water supply is not organised as one uniform system. The available inputs identify several different models within the same municipality: fully community-managed systems, municipality-supported village systems, utility-managed rural systems, jointly managed systems and settlements without organised water supply. Bosača is operated, maintained and financed by local residents. Dobri Nugo, Šaranci and Tepca rely on local residents for daily operation and failure reporting, while the Municipality and Waterworks Žabljak provide support for major repairs. Njegovuđa is operated by Waterworks Žabljak, while Virak / the Komarsko–Pošćenski area combines municipal, utility and local community involvement. In addition, Mala Crna Gora, Rudanca, Studenca, Brajkovača, Pašino Polje and Nadgora do not have an organised water supply system and rely on rainwater cisterns for technical water and natural springs for drinking water.

This makes Žabljak an important example of how rural water supply systems can differ significantly even within one municipality. The main governance problem is not only the existence of small systems, but the coexistence of different ownership, operation, maintenance and financing models. Several systems also face unresolved property and legal relations, overlapping institutional competences, lack of protection zones and lack of chlorination. These issues make it harder to integrate small systems into formal public service structures and to plan long-term investments.

This shows that village systems should not be treated only as small technical networks. They are governance systems. Their performance depends on who is responsible, who finances maintenance, who monitors water quality, who keeps asset records, who responds to failures and how the system is connected to municipal or utility-level planning.

For WATERVILL, this means that technical measures must be combined with clearer responsibilities, capacity building and practical models for integrating or supporting small systems.

In Žabljak, this is especially relevant because different rural systems require different levels of intervention: some need basic water safety measures and legal clarification, while others are ready for improved metering, monitoring and digital management.

5.4 Digitalisation gap and uneven monitoring readiness

The comparison of pilot municipalities shows strong differences in digital readiness. Ilirska Bistrica has the strongest starting point, with SCADA, remote-reading meters and flow meters already in use and is currently implementing GIS. Bitola has partial SCADA coverage, but rural and mountainous parts of the system remain weakly monitored. Teslić has SCADA and water balance data, but lacks pressure management, GIS data and hydraulic modelling. Žabljak has uneven digital readiness across its rural systems: most smaller systems lack SCADA, smart metering, water balance assessment and pressure monitoring, while some larger systems, such as Njegovuđa and Virak / the Komarsko–Pošćenski area, already show partial monitoring capacity or planned digital upgrades.

This uneven digital readiness is important for future WATERVILL implementation. Digital solutions cannot be introduced in the same way everywhere In Ilirska Bistrica, WATERVILL can build on existing SCADA and metering infrastructure, where the immediate priority is completing the GIS system as the basis for asset records and leak localisation, followed by integration, analytics and more advanced decision support. In Bitola, the priority is to expand monitoring coverage towards rural and mountainous areas. In Teslić, the priority is to complement existing SCADA and water balance data with pressure management, GIS records and hydraulic modelling. In Žabljak, the first step is staged digitalisation, starting with basic metering, flow and pressure monitoring, asset mapping and simple water balance assessment in fragmented rural systems.

The national-level findings confirm the same pattern.

> *Most partner contexts identify digitalisation as necessary, but many small municipalities and rural operators lack the staff, data systems and financial resources needed to maintain advanced tools.*

This means that digitalisation should not be understood only as equipment installation. Sensors, meters, SCADA, GIS and dashboards become useful only if there are procedures and people able to interpret data, prepare recommendations and implement corrective measures.

5.5 Financial sustainability and tariff constraints

Financial sustainability is a cross-cutting limitation across both national and local levels.

> *National assessments show that tariffs are often politically and socially sensitive, particularly in smaller municipalities and rural areas.*

Even where formal tariff methodologies or regulatory systems exist, affordability concerns can limit the ability of utilities to recover the full costs of operation, maintenance, infrastructure renewal, digitalisation and climate adaptation.

The pilot case studies show the practical consequences of this problem. High water losses reduce effective revenue and increase operating costs. Ageing infrastructure requires investment, but local systems often cannot finance renewal from tariffs alone. Rural and village systems may have even weaker financial structures, relying on flat-rate payments, irregular user contributions or municipal support. In several cases, major investments depend on municipal budgets, national programmes, EU funds, donor support or loans.

This creates a structural dilemma for WATERVILL replication.

> *Technical and digital solutions can reduce costs and improve performance, but they also require initial investment and long-term operation and maintenance funding.*

Therefore, each pilot or replication measure should include a realistic financing logic: who pays for installation, who maintains the system, who analyses the data, who finances repairs, and how savings from reduced losses can support future investments.

5.6 Climate resilience and source vulnerability

Climate-related pressures are present across the national assessments and pilot municipalities, but their form differs by territory. In Bitola, the main issue is summer scarcity, reduced mountain spring yield, irrigation pressure and dependence on the Streževo system. In Ilirska Bistrica, karst groundwater creates vulnerability to drought, reduced recharge, turbidity and rapid contamination pathways. In Teslić, the Velika Usora River is essential for supply but has highly variable flows and increased turbidity during heavy rainfall. In Žabljak, climate pressure is mainly linked to karst terrain, strong seasonal demand, drought-related reduction of source capacity and limited storage and monitoring in rural systems. Several Žabljak systems report significant summer population increases, while some smaller settlements without organised water supply rely on rainwater cisterns for technical water and natural springs for drinking water.

A recurring pattern in rural systems across the pilot municipalities is a significant reduction in the yield of springs and watercourses used for supply during the summer period. This leads to reduced or interrupted water delivery to users in exactly the period when demand is highest, and it affects systems that generally have no storage capacity, no monitoring and no alternative source available.

The national assessments also show that drought, reduced spring capacity, variable precipitation, tourism peaks, karst vulnerability, groundwater stress and water quality risks are becoming more important in rural and mountain systems. These pressures are particularly problematic where monitoring is weak, where alternative sources are not well planned and where utilities lack data on source yield, consumption patterns and climate-sensitive demand.

For WATERVILL, climate resilience should therefore be linked directly to operational management. Drought planning, source protection, monitoring of spring and reservoir levels, alternative-source planning, turbidity response, demand management and leakage reduction should be treated as connected measures. Reducing water losses is itself a climate-resilience measure, because it reduces pressure on limited sources during dry periods.

5.7 Shared technical support as a practical governance response

One of the strongest integrated findings is that full institutional consolidation is not always realistic, but shared technical capacity is highly relevant. Many small municipalities cannot individually maintain specialised engineering staff, SCADA experts, GIS specialists, leakage analysts or hydraulic modellers. At the same time, they still need these capacities in order to manage increasingly complex infrastructure, regulatory requirements and climate risks. This points to a practical WATERVILL replication pathway: a shared or centralised technical monitoring and support model. Under such a model, municipalities and local utilities would retain their existing legal responsibilities, while a shared technical unit would support several systems by collecting and analysing data, monitoring losses, identifying critical sections, preparing technical reports and helping prioritise investments.

This approach is particularly relevant for municipal and fragmented systems such as North Macedonia, the Republic of Srpska, Croatia, Montenegro and Greece, but it could also support small rural systems in Slovenia, Bulgaria and Spain. It does not require immediate merger of utilities or ownership structures. Instead, it centralises scarce expertise while keeping local responsibility in place. However, it requires minimum data availability, clear reporting procedures, data-sharing rules, stable financing and agreement on how municipalities will respond to technical recommendations. National associations of local governments are a natural institutional channel for such a model, as they already work with all municipalities within a given system, can host or coordinate shared technical services, and can transfer documented practice between their members.

5.8 Key implementation priorities for WATERVILL

The integrated analysis confirms that WATERVILL should not promote a single uniform solution for all territories. Although the underlying problems are similar across rural and mountainous water supply systems, the institutional, financial, technical and digital conditions for implementation differ significantly. For this reason, the most appropriate approach is a modular package of measures that can be adapted to the governance model, infrastructure condition, data availability and technical maturity of each municipality.

Key implementation priorities

1 WATER LOSS REDUCTION

Includes flow and pressure monitoring, leakage detection, district metering, night-flow analysis, pressure management, water balance assessment and targeted rehabilitation of critical network sections. The case study municipalities show that non-revenue water is not only a technical problem, but also a financial and organisational constraint, because high losses reduce effective revenues, increase operating costs and weaken the ability of utilities to invest in system renewal.

2 DIGITAL AND SPATIAL DATA DEVELOPMENT

Includes GIS-based asset registers, digital maintenance records, SCADA or SCADA-light systems, telemetry, smart or semi-smart metering, operational dashboards and decision-support tools. However, digitalisation should not be understood only as the installation of equipment. Its value depends on the ability of municipalities and operators to interpret data, identify priorities and translate monitoring results into operational and investment decisions.

3 IMPROVED MANAGEMENT OF RURAL AND VILLAGE WATER SUPPLY SYSTEMS

Includes clearer responsibilities, stronger monitoring, better financial arrangements, technical documentation, water quality procedures and integration or support models adapted to each national framework. The analysis shows that small and village systems are often the weakest part of the water supply chain, not only because of their technical condition, but also because of unclear responsibilities, limited professional management and weak long-term financing.

4 REALISTIC FINANCIAL PLANNING

WATERVILL measures should be linked to operation and maintenance costs, available municipal resources, national and EU funding opportunities, and the expected economic benefits of reducing water losses. Without a financing model for maintenance, repair and data management, even technically successful pilot measures may have limited long-term impact.

5 CLIMATE-RESILIENT WATER SUPPLY PLANNING

Includes drought preparedness, source protection, alternative-source planning, storage and redundancy, turbidity response, demand management and the integration of climate and hydrological data into operational decisions. Climate resilience should therefore be treated as part of everyday water system management, not only as an emergency response issue.

Overall, the comparative analysis shows that the most successful WATERVILL interventions will be those that combine technical measures with governance support, financial planning and capacity building. Leakage detection without financing for repairs will have limited effect. Sensors without staff to interpret data will not improve decision-making. Formal responsibilities without operational capacity will not ensure safe and resilient service.

The central challenge is therefore to connect infrastructure, data, institutions and financing into a practical management model for rural and mountainous water supply systems.

5.9 Digital and Modelling Readiness of the Pilot Municipalities

The preceding chapters describe the current state of the water supply systems in the four pilot municipalities. This section translates that description into structured inputs for the subsequent WP1 activities, namely water system modelling, development of the digital knowledge base and the Decision Support System.

The matrix below summarises, for each pilot municipality, the data currently available, the main data gaps, the monitoring and digital tools already in place, the minimum additional data required before modelling can begin, the resulting level of digital and modelling readiness, and the categories of solutions relevant for subsequent activities. The categories are indicative and are not intended to pre-empt the selection of specific technologies, which will be addressed in later activities.

Readiness is expressed in three levels. Basic indicates that essential operational data are not systematically collected and that modelling is not yet possible. Developing indicates that core volumetric data exist but that spatial, pressure or time-series data remain incomplete. Intermediate indicates that operational monitoring is established and that the main remaining constraint is the absence of asset-level and modelling data.

Table 5.9 – Digital and modelling readiness of the pilot municipalities

	Žabljak (ME)	**Bitola (MK)**	**Ilirska Bistrica (SI)**	**Teslić (BA)**
Available data	Njegovuđa: full dataset Virak: partial figures Other systems: not measured	Production, consumption, leakage, cost of losses Failure and replacement rates 2023–2025 Mean pressure	Production, consumption, leakage, cost of losses Failure frequency, mean pressure Share of aged network	Production, losses, network length Reservoirs, pumping stations, meters Peak day demand, failures, cost of losses Water balance performed
Key data gaps	No consolidated water balance No production, consumption, pressure or loss data No registry of village	Rural monitoring data Reservoir and pumping station inventory No district-level water balance	No spatial asset records Asset attributes not linked to failures	Billed consumption not reported Rural systems undocumented

	Žabljak (ME)	Bitola (MK)	Ilirska Bistrica (SI)	Teslić (BA)
	systems			
Existing monitoring and digital tools	SCADA in town only Smart meters in town Flow meters and chlorine/turbidity instruments in Virak Metering procurement ongoing	SCADA approx. 30% Smart systems below 10% Basic urban GIS Pressure management on trunk mains only	SCADA, remote-reading meters 25 flow meters at critical points Digital asset databases 5G monitoring initiative GIS being implemented	SCADA Water balance assessment Limited smart water management No pressure management, no model
Minimum additional data required	Flow metering at sources and branches Basic pressure monitoring Asset mapping Failure log Per-system water balance Registry of village systems	District metered areas and night flow SCADA and pressure sensors in rural systems Complete asset inventory	Completion of GIS Asset attributes linked to failures Continuous pressure logging Zone-level night flow	Billed volumes Spatial asset records Continuous pressure logging Rural system inventory Climate and spatial datasets
Readiness level	BASIC Modelling not yet feasible; Njegovuđa and Virak emerging	DEVELOPING Urban system ready; rural systems not	INTERMEDIATE Monitoring established; modelling feasible once asset data complete	DEVELOPING Volumetric baseline set; spatial and pressure data missing
Categories of solutions for subsequent activities	Baseline data collection and asset mapping Basic flow and pressure metering Water safety (chlorination, protection zones) Ownership clarification Financing mechanism	NRW reduction through zoning and night flow Pressure management Rural monitoring Hydraulic modelling of urban network	Spatial asset management Active leak detection Hydraulic modelling, predictive maintenance Decision-support integration	Spatial asset management Pressure management Hydraulic modelling Rural governance and monitoring

The matrix shows that the four pilot municipalities enter the subsequent WP1 activities from different starting points, and that a single modelling or digitalisation approach would not be applicable to all of them. In Ilirska Bistrica and Teslić the main constraint is the absence of spatial and asset-level data rather than the absence of operational monitoring. In Bitola the constraint is the uneven coverage of monitoring between the urban and the rural parts of the system. In Žabljak the constraint is more fundamental, as basic operational data are not collected in most systems, which means that establishing measurement and record-keeping is itself a project intervention rather than a preparatory step preceding it.

Deliverable D1.1.1 completes the first two stages. The matrix above defines the minimum conditions under which each pilot municipality can enter the third stage, and identifies the data collection that has to take place in parallel with the subsequent activities.

6. Conclusion

The comparative analysis confirms that rural and mountainous drinking water supply systems in the WATERVILL partner territories face similar operational problems, although they function within different institutional, financial and regulatory frameworks. Ageing infrastructure, high water losses, limited digitalisation, weak technical capacity, financial constraints and increasing climate-related pressures are the main common challenges.

> The report shows that these challenges cannot be solved through isolated technical interventions alone. Leakage detection, pressure and flow monitoring, GIS mapping, SCADA systems and smart metering are highly relevant, but their long-term impact depends on governance capacity, financing for follow-up interventions, trained staff and clear responsibilities for operation and maintenance.
>
> Small-scale, rural and village water supply systems are the most vulnerable part of the analysed water supply contexts. Their sustainability depends on better monitoring, clearer institutional arrangements, more stable financing, stronger technical documentation and closer integration with municipal or utility-level planning.

The most appropriate WATERVILL approach is therefore a modular combination of technical, digital, governance, financial and capacity-building measures. These measures should be adapted to the maturity of each municipality and to the national framework in which it operates. In more digitally developed systems, the focus can move towards advanced analytics and decision-support tools, while in less documented systems the first priority should be baseline data collection, asset mapping and basic monitoring.

The assessment also shows that the absence of reliable operational data is not only a methodological limitation, but a substantive result. In several rural and mountainous systems, production, consumption, pressure and loss data are simply not collected. Establishing basic metering, records and reporting is therefore not a preparatory step before WATERVILL measures, but one of the measures itself.

Where rural systems are numerous, heterogeneous and largely undocumented, a dedicated system-by-system assessment is a necessary next step. Such an assessment should cover source capacity, water quality, losses, technical condition and management arrangements, and should provide individual recommendations for each system. This would give municipalities the evidence base required for investment planning and would allow water supply measures to be integrated into municipal development strategies and their planning cycles.

Overall, the findings provide a clear basis for the next WATERVILL activities, including the database of solutions, the Decision Support System, pilot demonstration cases, capacity-building activities and transferability measures. The central conclusion is that resilient rural and mountainous water supply requires the integration of infrastructure, data, institutions, financing and local capacity into practical and sustainable water management models.

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