IMPLEMENTATION OF THE STRATEGIC ACTION PROGRAMME (SAP) OF THE DINARIC KARST AQUIFER SYSTEM: IMPROVING GROUNDWATER GOVERNANCE AND SUSTAINABILITY OF RELATED ECOSYSTEMS

OUTPUT 2.1.

BILATERAL GROUNDWATER GOVERNANCE DIAGNOSTIC ANALYSIS TBA UNA

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1 Introduction

1.1 Purpose and Scope of the Bilateral GGDA for TBA Una

The Bilateral Groundwater Governance Diagnostic Analysis (BGGDA) for the Una Transboundary Area (TBA) is designed to provide a harmonized assessment of groundwater governance across the Croatian and Bosnian-Herzegovinian segments of this transboundary area of concern. Its overarching purpose is to identify governance gaps, opportunities, and priority measures that will strengthen sustainable management of the TBA in line with regional and international standards.

This analysis builds upon the foundational work of the DIKTAS I project, including the Transboundary Diagnostic Analysis (TDA) and the Strategic Action Programme (SAP), and is implemented under DIKTAS II to advance institutional cooperation and policy alignment. It applies the methodological principles of the Global Framework for Action to Achieve the Vision on Groundwater Governance, developed under the GEF/FAO initiative, ensuring consistency with globally recognized best practices.

The scope of the BGGDA encompasses three core dimensions of groundwater governance:

- Legal and regulatory frameworks, including compliance with EU Water Framework Directive and Groundwater Directive provisions;
- Policy and planning instruments, with emphasis on integration across sectors such as water, agriculture, energy, and spatial development;
- Socio-economic drivers and indicators, addressing pressures from tourism, agriculture, and infrastructure development in the Dinaric karst region.

The analysis will systematically review institutional arrangements, enforcement capacities, and data-sharing mechanisms, highlighting disparities and opportunities for harmonization between the two countries. It will also consider the socio-economic reliance on groundwater for drinking water supply, energy production, and biodiversity conservation.

By providing a comparative diagnostic, the BGGDA aims to establish a common understanding of governance challenges and to propose actionable recommendations for bilateral cooperation. These recommendations will serve as a basis for the future joint action program, monitoring programs, and capacity-building initiatives, contributing to the long-term resilience of the TBA Una under changing climatic and socio-economic conditions.

1.2 Methodological Approach and Alignment with DIKTAS II Framework

The Bilateral Groundwater Governance Diagnostic Analysis (BGGDA) for the TBA Una adopts a structured, comparative methodology grounded in internationally recognized principles of groundwater governance. It follows the Global Framework for Action to Achieve the Vision on Groundwater Governance, ensuring consistency with global best practices and DIKTAS II objectives. The approach builds on the outputs of DIKTAS I, particularly the TDA and SAP, and integrates lessons learned from national governance diagnostics in Croatia and Bosnia and Herzegovina.

The methodology emphasizes a stepwise diagnostic process, starting with stocktaking of legal, policy, and institutional frameworks, followed by identification of gaps, opportunities, and priority measures for harmonization. It applies a three-dimensional governance lens - legal and regulatory frameworks, policy and planning instruments, and socio-economic drivers - while incorporating cross-cutting issues such as enforcement capacity, stakeholder participation, and gender mainstreaming. Comparative

analysis is central to the approach, enabling identification of asymmetries and convergence points between the two countries.

Alignment with DIKTAS II is ensured through direct linkage to Component 2 (Institutional Strengthening for Improved Groundwater Governance) and its outputs, particularly Output 2.1 on governance diagnostics in all project countries and Output 2.2 on harmonization of legal and policy instruments. The BGGDA also supports Component 1 (Facilitating Multi-country Cooperation) by providing evidence for bilateral agreements and joint management mechanisms. Methodological tools include indicator frameworks for monitoring governance performance and participatory processes involving national institutions and stakeholders.

The analysis adopts an adaptive management approach, allowing flexibility to incorporate available data, stakeholder's role, and evolving policy contexts during implementation. It ensures coherence with EU Water Framework Directive (WFD) and Groundwater Directive (GWD) requirements, while respecting national legal systems and bilateral agreements. Ultimately, the methodological design aims to produce actionable recommendations that are scientifically robust, institutionally feasible, and aligned with the long-term vision of sustainable and equitable management of the Una TBA under DIKTAS II.

1.3 Overview of the TBA Una: Hydrogeological, Geographical and Environmental Context

Extending across Croatia and Bosnia and Herzegovina within the Black Sea basin, the TBA Una occupies a predominantly karstified landscape formed in thick Mesozoic limestones and dolomites. These carbonate formations, deeply fractured and faulted, create highly permeable aquifers with rapid groundwater circulation through conduits and fissures. Recharge occurs mainly from precipitation and sinking streams, with infiltration rates often exceeding sixty percent of rainfall, while groundwater velocities can reach several centimetres per second, reflecting the system's responsiveness to seasonal variations.

The region's physiography is marked by rugged relief, dolines, ponors, and poljes, with surface water largely absent except for the River Una and its tributaries. Climatic conditions combine continental and Mediterranean influences, producing high annual precipitation concentrated in wet seasons and pronounced fluctuations in water availability during dry periods. Despite abundant reserves and numerous large springs, the aquifer's vulnerability is significant due to its limited natural filtration capacity, making it highly sensitive to contamination from surface activities.

Groundwater from the TBA Una is a primary source of drinking water for local communities and sustains ecosystems of exceptional ecological value, including Plitvice Lakes National Park, a UNESCO World Heritage Site. These ecosystems depend on stable hydrological conditions and clean water, yet they face growing pressures from tourism, agriculture, and urban development. Water quality is generally good, but sporadic microbiological contamination and traces of pollutants such as ammonia and phosphates have been recorded, alongside localized risks from inadequate wastewater treatment and legacy pollution sites.

Socio-economic activities in the zone of influence - particularly tourism and hydropower - intensify seasonal demand for water and increase environmental stress. While both countries have legal provisions prohibiting direct wastewater discharge into groundwater, enforcement remains weak, and there is no harmonized approach to delineating sanitary protection zones or implementing integrated monitoring. Current monitoring systems are fragmented, and data gaps persist, especially near pollution sources and in rural areas where decentralized water supply is common.

The TBA Una exemplifies the challenges of managing shared karst resources: its hydrogeological complexity, ecological significance, and socio-economic importance require coordinated governance.

1.4 Structure of the Bilateral GGDA

The Bilateral Groundwater Governance Diagnostic Analysis (BGGDA) for the TBA Una is organized into eight chapters, each addressing a specific dimension of governance. Following the introductory chapter, which explains the purpose, scope, and methodology, the analysis begins with a detailed review of the legal framework. This section compares national legislation and EU directives focusing on groundwater ownership, permitting, pollution control, and enforcement mechanisms, and identifies gaps and opportunities for harmonization. The next chapter examines institutional arrangements and cross- sectoral coordination in Croatia and BIH including institutions and stakeholders directly relevant for TBA Una. The following chapter elaborate policy and planning instruments, assessing national water strategies, river basin plans, and sectoral policies, while highlighting integration with EU requirements.

Socio-economic indicators and pressures are then analysed to provide a comparative profile of demographic trends, groundwater use, infrastructure status, and environmental risks, including contamination and waste management challenges. Transboundary cooperation forms the core of the sixth chapter, evaluating international and bilateral arrangements. Based on these findings, the recommendations chapter outlines targeted measures for legal harmonization, policy integration, socio-economic resilience, and improved monitoring, supported by an indicator framework aligned with DIKTAS II objectives.

The concluding chapter synthesizes key insights and defines strategic priorities for governance improvement. Annexes provide supporting materials such as legal and policy references, stakeholder lists, and methodological tools for indicator tracking and monitoring.

The structure of the BGGDA ensures a logical progression from diagnostic assessment to actionable recommendations, offering a comprehensive yet practical framework for strengthening bilateral groundwater governance in TBA Una.

2. Legal Framework Analysis – TBA Una

2.1 International instruments, EU Directives and Bilateral Agreement Relevant to TBA Una

Bosnia and Herzegovina and Croatia are signatories to most of the same international conventions and frameworks on transboundary water management. Both countries are contracting parties to the **UNECE Water Convention (1992)** and the **Danube Convention (1994, ratified 1996)**, as well as signatories of the **Framework Agreement on the Sava River Basin (2002, ratified 2003)**. which promotes joint planning and data exchange.

The Draft Articles on the Law of Transboundary Aquifers annexed to the UNGA Resolutions 63/124 (2008) and 68/118 (2013) offer guidance to governments for cooperation and arrangements on their transboundary aquifers.,

Republic Croatia and B&H are member countries of the **International Sava River Basin Commission (ISRBC),** established in **2006.** The other member countries are also Slovenia and Serbia. It was created to implement the Framework Agreement on the Sava River Basin. Main tasks of the commission are: establish an international navigation regime on the Sava River; ensure sustainable water management; prevent and limit hazards such as floods, droughts, and pollution

In Croatia, implementation is led by the Ministry of Environmental Protection and Green Transition, with operational roles carried out by Croatian Waters, the State Hydrometeorological Institute and sava Commission in Zagreb. In Bosnia and Herzegovina, implementation of international instruments is primary responsibility of state Ministry of Foreign Trade and Economic Relations (MoFTER) which needs to coordinate the implementation and compliance to international obligations with the entity-level ministries and agencies.

Collaboration in the Adriatic Sea catchment is regulated by the **Barcelona Convention** (1976, revised 1995) and both countries are the parties of this Convention. Croatia is additionally party to the Athens Protocol (1980, revised 1995). For these frameworks, the Ministry of Economy and the Ministry of Environmental Protection and Green Transition are responsible for implementation, including the ICZM Protocol and national coastal strategies.

Both countries are signatory of the **Convention on the Transboundary Effects of Industrial Accidents (1992)**, while Croatia has additionally ratified the **Protocol on Water and Health**.

Both countries are active participants in the **Adriatic Ionian Initiative (2000)**, which provides a platform for regional cooperation among Albania, Bosnia and Herzegovina, Croatia, Greece, Italy, Slovenia, and Serbia & Montenegro. The **Joint Commission for the Protection of Adriatic Waters (1977)**, based on the 1974 Agreement between Yugoslavia and Italy, continues to function with Croatia, Italy, Slovenia, and Montenegro as members.

While Croatia benefits from a consolidated institutional framework, Bosnia and Herzegovina faces slow coordination process between entities and limitations in institutional capacities for effective transboundary water management.

The bilateral agreement between Croatia and Bosnia and Herzegovina on water management relations (1996) establishes obligations for coordinated measures in transboundary basins, including the TBA Una. However, this agreement is largely generic and does not explicitly address groundwater, focusing instead on general water management, pollution control, and infrastructure maintenance. Updating this agreement, specifically in relation to groundwater monitoring, data exchange, and aquifer-specific management, would significantly strengthen transboundary governance and make it more effective for DIKTAS II objectives. The details of this update are provided in *Chapter 6.1.*

The governance of transboundary groundwater in the TBA Una region is primarily shaped by the EU Water Framework Directive (WFD) and the Groundwater Directive (GWD), which set the foundation for integrated water resource management and the achievement of “good status” for all water bodies. Croatia has fully transposed these directives through its Water Act and River Basin Management Plan (RBMP), ensuring systematic monitoring, delineation of groundwater bodies, and the application of threshold values for pollutants. While Bosnia and Herzegovina advance in WFD implementation, with FBiH achieving over 90% alignment, progress in RS remains lower. Compliance with the GW Directive is considerably lower across both entities, with gaps in defining groundwater-dependent ecosystems and harmonizing methodologies for chemical status assessment.

Beyond WFD and GWD, several other EU directives influence groundwater governance in the TBA Una context. The Environmental Liability Directive (2004/35/EC) underpins remediation obligations and accountability for environmental damage, while the Public Access to Environmental Information Directive (2003/4/EC) promotes transparency and stakeholder engagement. The Nitrates Directive (91/676/EEC) is relevant for controlling diffuse agricultural pollution, a significant pressure in karst areas. Additionally, the Habitats Directive (92/43/EEC) and Birds Directive (2009/147/EC) safeguard

groundwater-dependent ecosystems within Natura 2000 sites, reinforcing biodiversity protection. The Urban Waste Water Treatment Directive (91/271/EEC) addresses wastewater management, which is critical for reducing contamination risks in sensitive recharge zones. Croatia has integrated these directives into its legal framework, whereas Bosnia and Herzegovina has only partially aligned, with implementation gaps in ecological connectivity and nutrient management.

Overall, while Croatia exhibits strong alignment with EU directives and robust institutional mechanisms, Bosnia and Herzegovina faces structural and operational challenges that hinder full compliance and effective transboundary governance

2.2 National Legal Instruments Governing Groundwater (Croatia and BiH)

Groundwater governance in the TBA Una is shaped by two distinct yet partially harmonized legal frameworks: Croatia's system, which is fully aligned with European Union directives, and Bosnia and Herzegovina's decentralized structure, which reflects its complex constitutional arrangement and ongoing EU approximation process. Both countries recognize groundwater as a public good and regulate its use, protection, and monitoring through primary water legislation complemented by environmental, spatial planning, and sectoral laws. However, the scope, clarity, and operationalization of these instruments differ significantly, influencing the effectiveness of transboundary groundwater management.

2.2.1. Core Legal Frameworks

In Croatia, the Water Act (Official Gazette Nos. 66/2019, 84/2021, 47/2023) serves as the cornerstone of groundwater governance. It fully transposes the EU Water Framework Directive (2000/60/EC) and the Groundwater Directive (2006/118/EC, 2014/80/EU), establishing environmental objectives, defining groundwater bodies, and prescribing monitoring obligations. The Act is operationalized through the River Basin Management Plan (RBMP) until 2027, which integrates chemical and quantitative status assessment, threshold values, and measures for groundwater-dependent ecosystems. Croatia's legal framework is complemented by the Environmental Protection Act, the Nature Protection Act, and sectoral regulations such as the Rulebook on Sanitary Protection Zones, which provide detailed hydrogeological criteria for karst aquifers - highly relevant for the Una basin.

Bosnia and Herzegovina regulates groundwater primarily through entity-level Water Laws: FBIH Water Law, Official Gazette 70/06 and the RS Water Law (Official Gazette Nos. 50/06, 92/09, 121/12, 39/13, 44/15, 19/16, 1/20).) that are operationalized by RBMP. However, BIH has no dedicated legislation for groundwater management, nor karst systems, despite their dominance in the national hydrogeological setting Water laws define water as public property and require permits for abstraction and discharge. However, as WFD principles such as integrated river basin management and ecological flow are embedded, the Groundwater Directive is implemented to a limited extent, with gaps in chemical status assessment, trend reversal, and threshold values, as not all WFD parameters are covered. Consequently, groundwater protection in both entities is treated only as a subset of surface water regulation, without recognition of the particular vulnerabilities of karstic aquifers or their ecological and quantitative dynamics. Reliance on entity water legislation creates fragmentation, for both, surface and groundwater bodies impacting efficient management of transboundary aquifers. BIH legal framework is complemented by the entities' Environmental Laws the Nature Protection Laws contribute to groundwater protection only indirectly through requiring environmental impact assessments for potential water-related impacts as well as establishing a framework for biodiversity conservation and designate protected areas. According to the entities

Laws on Geological researches, Geological Surveys in Zvornik in RS and in Sarajevo in FBi hold valuable archives on aquifer stratigraphy, springs, and karst morphology—most of which exist only in analogue or unpublished formats.

2.2.2. Monitoring and Status Assessment

Croatia applies a standardized methodology for groundwater monitoring, aligned with EU Common Implementation Strategy guidance. The Regulation on Water Quality Standards defines chemical status criteria and threshold values, incorporating site-specific considerations for karst systems. Monitoring networks cover quantitative and chemical parameters, ecological flows, and groundwater-dependent ecosystems, ensuring compliance with WFD and GWD requirements. Data are integrated into national information systems and made accessible under the INSPIRE Directive and the Act on the Right of Access to Information, promoting transparency.

In Bosnia and Herzegovina, monitoring obligations are legally prescribed but operationally weak. Entity rulebooks such as the Rulebook on Monitoring of Surface and Groundwater (FBiH) and the Rulebook on Monitoring of Water Quality (RS) - define parameters and frequency, yet implementation remains partial and uneven. Monitoring of groundwater bodies is carried out on several groundwater bodies in the Sava basin in F BiH, but it typically focuses on drinking-water sources—such as karst springs—rather than on groundwater bodies as integrated hydrogeological units and ecological indicators are rarely included. The lack of harmonized and coordinated methodologies, insufficient technical capacity, and limited data exchange between entities hinder comprehensive status assessment, particularly in karst areas where rapid infiltration and high vulnerability demand specialized approaches.

2.2.3. Sanitary Protection Zones

Both countries mandate sanitary protection zones for drinking water sources though approaches differ.

Sanitary protection zones in Croatia are regulated by the Rulebook on Conditions for Establishing Sanitary Protection Zones of Water Sources. The regulation prescribes up to four zones for karst aquifers, ranging from strict protection around the intake structure to broader zones that may extend to the hydrogeological catchment. Delineation is based primarily on hydrogeological investigations and flow-time calculations; vulnerability mapping, while recommended in technical practice, is not legally required. The Rulebook mandates an inventory of potential pollution sources (*details elaborated in Chapter 2.3.3.)* and prescribes protective measures; however, obligations are unevenly implemented. Municipal delays and weak enforcement leave SPZs and recharge areas vulnerable to legacy contamination, as further discussed *in Chapter 2.3.3.*

Bosnia and Herzegovina lacks harmonized methodologies across entities, resulting in inconsistent enforcement and monitoring. Sanitary protection zones in FBiH are governed by the Regulation on the Method for Determining Zones and Areas of Sanitary Protection of Water Sources. (“Official Gazette of FBiH”, 88/12). This regulation prescribes up to four zones for karst environments and requires hydrogeological studies and vulnerability assessments as part of the delineation process. Protective measures include restrictions on construction, waste disposal, and certain agricultural practices. While the regulation provides a relatively detailed framework, implementation is inconsistent. Many municipalities have not adopted formal decisions on SPZs or integrated them into spatial plans, despite clear legal obligations. RS Regulation on Protection Measures, Designation, Maintenance, and Marking of Sanitary Protection Zones (“Official Gazette RS”, No. 76/16) defines three zones of sanitary

protection, their spatial extent, and protection measures. Under the current Regulation in the RS, there are no specific criteria for delineating zones in karst areas i.e. it does not differentiate between karst and non-karst hydrogeological conditions. In both entities, monitoring within zones is very limited and remediation of existing pollution sources is rarely carried out. Enforcement is very limited taking into account lack of finance and human resources in inspection sector.

A critical gap in BiH is the lack of standardized entities methodologies for vulnerability assessment and uniform application of technical criteria. Furthermore, SPZ requirements are not systematically integrated into sectoral policies such as agriculture, tourism, and spatial planning, increasing the likelihood of land-use conflicts and cumulative pressures on groundwater resources.

2.2.4. Regulation of Water Use and Discharge

Croatia enforces a clear permitting system for groundwater abstraction and wastewater discharge, supported by concession rules for large-scale uses. The Water Act prohibits direct discharges into groundwater and allows indirect discharges only under strict conditions, requiring risk assessments and compliance with emission limit values. However, regulation of artificial recharge remains underdeveloped, lacking detailed technical guidelines—a gap relevant for future climate adaptation measures in karst regions.

Bosnia and Herzegovina's Water Laws similarly prohibit direct discharges and regulate indirect discharges only under strict conditions through entity-level bylaws, such as the Rulebooks on Conditions for Discharging Wastewater into the Environment (FBIH) and Discharging Wastewater into surface waters and in Public Sewage Systems (RS) Yet, enforcement is weak, and compliance monitoring is sporadic. Legal provisions for artificial recharge exist in principle but are not operationalized, leaving karst aquifers vulnerable to uncontrolled interventions.

2.2.5. Economic Instruments and Enforcement

Croatia integrates the polluter pays and cost recovery principles into its water legislation, aligning with Article 9 of the WFD. The Water Management Financing Act and related bylaws establish pricing methodologies that incorporate resource and environmental costs. Enforcement capacity is supported by Croatian Waters and the State Inspectorate, which conduct inspections and impose penalties for non-compliance.

In Bosnia and Herzegovina, these principles are legally recognized but not fully implemented. Fee structures for water abstraction and discharge exist, yet they do not reflect environmental costs.. Law enforcement relies on entity water inspectorates, which face chronic understaffing and limited budgets, resulting in reactive rather than preventive compliance monitoring.

2.2.6. Integration with Environmental and Spatial Planning Laws

Croatia's legal framework demonstrates strong integration of groundwater protection into spatial planning and nature conservation instruments. The Spatial Development Strategy explicitly recognizes groundwater as a strategic resource and mandates its inclusion in land-use planning, particularly through the delineation of sanitary protection zones around springs and wellfields. Natura 2000 provisions further reinforce this integration by safeguarding groundwater-dependent ecosystems within protected areas. Environmental Impact Assessments (EIAs) are mandatory for projects that may affect water resources, including infrastructure, tourism, and energy developments, ensuring that groundwater considerations are embedded in decision-making processes. Additionally, the Nature Protection Act transposes the Habitats and Birds Directives, linking biodiversity conservation with

groundwater protection. Croatia's planning instruments also require that sanitary protection zones be incorporated into municipal and regional spatial plans, supported by technical studies and hydrogeological assessments. However, while the legal framework is robust, practical implementation varies, with delays in updating spatial plans and inconsistencies in integrating groundwater vulnerability mapping into sectoral strategies such as transport and energy.

In Bosnia and Herzegovina, entities' spatial planning laws formally require the inclusion of water protection zones in planning documents, but implementation is uneven and often delayed. The FBiH mandates the integration of sanitary protection zones into urban and spatial plans, based on hydrogeological studies, while RS applies similar requirements under its Spatial Planning and Construction Law. Despite these provisions, many municipalities have not adopted formal decisions or incorporated zones into planning instruments, primarily due to limited administration capacity and financing sources for protection measures implementation. According toi the entities' Environmental Laws, Environmental impact assessments are legally required for projects with potential water-related impacts, but enforcement is inconsistent, and groundwater-specific criteria are often absent. In both FBIH and RS, nature protection Laws provide a framework for biodiversity conservation and designate protected areas, but their linkage with groundwater protection is indirect and implementation remains uneven.

2.2.7. Observations for the TBA Una

From a comparative perspective, Croatia and Bosnia and Herzegovina exhibit different levels of regulatory development and operational capacity in groundwater governance, but neither country can be considered fully effective in practice. Croatia's legal framework is formally aligned with EU directives and provides a structured basis for groundwater protection, including requirements for sanitary protection zones and integration into spatial planning. However, implementation remains uneven. Delays in updating spatial plans, inconsistent enforcement of zoning restrictions, and gaps in vulnerability mapping persist, particularly in rural and karst areas. While Natura 2000 provisions and the Spatial Development Strategy reference groundwater-dependent ecosystems, these commitments are not always translated into concrete measures at the local level. Environmental impact assessments are mandatory, yet groundwater-specific criteria are often applied superficially, and cumulative impacts from tourism and infrastructure projects are rarely assessed comprehensively.

Entity-level Spatial laws require the inclusion of sanitary protection zones in spatial plans, but enforcement is sporadic and often delayed. Vulnerability mapping and ecological connectivity assessments are largely absent, leaving transboundary aquifers exposed to cumulative pressures from land-use changes and seasonal water demand. Environmental impact assessments exist in law but lack standardized groundwater-related methodologies, and compliance monitoring is weak. Groundwater considerations are rarely mainstreamed into sectoral strategies such as agriculture, energy, and tourism, despite their significant influence on karst aquifers.

For the TBA Una, these shortcomings translate into practical challenges for harmonized monitoring, risk assessment, and protection of shared groundwater resources. Croatia's regulatory framework offers a stronger starting point for transboundary cooperation, but its operational gaps - particularly in enforcement and cross-sectoral integration - limit effectiveness. Bosnia and Herzegovina's fragmented governing system requires significant strengthening to achieve comparable standards.

The absence of explicit groundwater provisions in the 1996 bilateral agreement between the two countries further underscores the need for legal and institutional convergence. Updating this

agreement to include groundwater-specific would provide a critical step toward integrated governance and improved resilience of the TBA Una. (*More details in Chapter 6.1.)*

2.2.8. Key Implications for joint groundwater governance in the TBA Una (Croatia and BIH)

The analysis of national legal instruments and planning frameworks for Croatia and Bosnia and Herzegovina reveals several critical implications for groundwater governance in the TBA Una. While Croatia's legal framework is formally aligned with EU directives and provides a solid foundation for groundwater protection, implementation on the ground is uneven and faces structural and operational challenges. Bosnia and Herzegovina, on the other hand, continues to struggle with fragmentation and limited technical capacity, which significantly constrains effective governance.

First, the difference in regulatory development between the two countries is still a major barrier to coordinated management. Croatia has transposed the Water Framework Directive (WFD) and Groundwater Directive (GWD) into its national legislation, and sanitary protection zones are legally required to be integrated into spatial plans. However, delays in updating spatial plans, inconsistent enforcement of zoning restrictions, and gaps in vulnerability mapping persist, particularly in rural and karst areas. Bosnia and Herzegovina's entity-level water laws incorporate WFD principles but only partially reflect GWD requirements, leaving critical gaps in chemical status assessment, trend reversal, and ecological connectivity. Sanitary protection zones are required to be integrated into spatial plans. However, there is a lack of determination of sanitary protection for many water sources and legal binding decisions on their protection including inconsistent enforcement of zoning restrictions.

Second, technical standards for karst aquifer protection differ substantially. Croatia applies detailed hydrogeological criteria for delineating sanitary zones, yet practical enforcement is often weak, and remediation programs are inconsistently implemented. Illegal waste disposal and insufficient wastewater treatment continue to threaten groundwater quality even under a robust legal framework. Bosnia and Herzegovina lacks harmonized entities methodologies for vulnerability mapping and sanitary zone delineation, and monitoring remains focused on drinking water sources rather than groundwater bodies.

Third, enforcement capacity and institutional coordination are problematic in both countries, albeit to different degrees. Croatia benefits from centralized oversight by Croatian Waters and the Ministry of Environmental Protection and Green Transition, but resource constraints and uneven local capacities hinder systematic compliance monitoring. Bosnia and Herzegovina faces even greater challenges: inspectorates operate with minimal staff and budgets, resulting in reactive enforcement and weak deterrence. While both countries recognize the polluter pays and cost recovery principles, Croatia's application of these principles is partial and often contested, and Bosnia and Herzegovina lacks any consistent methodology for integrating environmental costs into water pricing.

Fourth, integration with environmental and spatial planning laws remains insufficient in practice. Croatia's Spatial Development Strategy and Natura 2000 provisions formally link groundwater protection with biodiversity conservation, yet sectoral strategies - such as energy and tourism - do not consistently operationalize these requirements. Bosnia and Herzegovina's planning instruments mandate the inclusion of sanitary zones, but implementation is sporadic, and groundwater considerations are rarely mainstreamed into agriculture or infrastructure development. Environmental impact assessments are legally required in both countries, but groundwater-specific criteria are often absent or inadequately applied. A draft plan for the Natura 2000 ecological network in BiH was prepared, proposing 122 areas covering 956,776 ha, about 20% of the state territory (Milanović and Golob, 2015). However, establishing entities ecological networks require further

activities. Harmonization of sectoral regulations with EU law is necessary, alongside identification of other ecologically significant areas (such as water protection zones, hunting and fishing areas) and their inclusion in the ecological networks.

Finally, as a particularly significant matter for transboundary cooperation, it should be noted that the provisions of the existing bilateral agreement between Croatia and Bosnia and Herzegovina, dating from 1996, are rather generic and do not explicitly address groundwater management. (*This issue is elaborated in a subsequent Chapter 4.3.2).*

Implications for the TBA Una governance can be summarized as follows:

- Harmonization of legal and technical standards for karst aquifer protection is essential.
- Integration of groundwater considerations into spatial planning and sectoral policies must move beyond formal requirements toward practical application and monitoring.
- Institutional capacity building and financing mechanisms require strengthening in both countries, with urgency in Bosnia and Herzegovina.
- Bilateral cooperation should evolve from declarative commitments to operational frameworks that include joint monitoring, data sharing, and adaptive management.
- Local governance reforms in the TBA Una should prioritize transparency, inclusive stakeholder participation, and ecosystem-based approaches to ensure the protection of groundwater-dependent ecosystems and drinking water sources.

2.3 Comparative Legal Analysis related to ownership, permitting and pollution control : Croatia vs BiH

This chapter provides a structured comparison of the legal frameworks governing groundwater in Croatia and Bosnia and Herzegovina, focusing on their relevance for the TBA Una. The analysis examines how each country defines and regulates groundwater within its national legislation, identifies key similarities and differences, and evaluates the implications for joint groundwater governance under DIKTAS II. The comparative review is organized into four critical dimensions: Groundwater Ownership and Use Rights, Licensing and Permitting Procedures, Pollution Control and Sanitary Protection Zones Together, these elements form the foundation for understanding legal asymmetries and operational gaps that influence the management of shared karst aquifers

2.3.1 Groundwater Ownership and Use Rights

Both Croatia and Bosnia and Herzegovina legally define water resources, including groundwater, as a public good, prohibiting private ownership of aquifers or water bodies. However, the scope and clarity of these provisions, as well as their practical implementation, vary significantly between the two countries.

In Croatia, the Water Act (Official Gazette Nos. 66/2019, 84/2021, 47/2023) establishes groundwater as part of the national water estate, managed in the public interest. Ownership rights over groundwater are excluded, and its use is regulated through a system of permits and concessions. Water abstraction for public supply, agriculture, and industry requires a Water Use Permit issued by Croatian Waters, while large-scale or economically significant uses - such as hydropower or mineral water exploitation - require a concession granted by the Ministry of Environmental Protection and Green Transition. These permits and concessions are time-bound (typically 12 years for permits and up to 40 years for concessions) and subject to compliance with environmental standards and monitoring obligations. The Water Act also integrates the polluter pays and cost recovery principles, requiring users to pay fees that reflect resource and environmental costs. Despite this robust legal

framework, enforcement challenges persist. Monitoring of abstraction volumes is uneven, particularly in rural areas, and illegal water use remains a concern.

In Bosnia and Herzegovina, groundwater is similarly defined as a public good under entity-level Water Laws - the Federation of BiH Water Law. These laws prohibit private ownership and regulate use through permits and, in some cases, concessions. However, the permitting system is fragmented across entities and cantons, resulting in overlapping competencies and procedural inconsistencies. In the Federation of BiH, water permits for smaller abstractions are issued by cantonal authorities, while larger uses fall under the jurisdiction of entity-level water agencies. In Republika Srpska, the Public Institution "Vode Srpske" manages permitting and monitoring. Concessions for hydropower and other major uses are governed by separate concession laws, adding another layer of complexity. While both entities recognize the polluter pays principle, cost recovery is only partially implemented, and water pricing structures do not systematically incorporate environmental costs. Monitoring obligations exist in law but are weakly enforced due to limited technical capacity and financial resources. Illegal abstractions and unregistered wells are common, particularly in rural and karst areas, where oversight is minimal.

A critical difference between the two countries lies in the integration of groundwater use rights with spatial planning and environmental protection. Croatia's legislation explicitly links water permits to compliance with sanitary protection zones and in BiH water permits take into account sanitary zones and source protection, though many zones have not yet been formally proclaimed or integrated into spatial plans, making the linkage with spatial planning and environmental protection less explicit and implementation less consistent. This gap exposes groundwater sources to uncontrolled land-use changes and pollution risks.

Both countries face shortcomings in operationalizing groundwater ownership and use rights in practice. In Croatia, the main issues include delayed spatial planning updates, insufficient monitoring of abstraction volumes, and weak enforcement of restrictions in sanitary zones. In BiH, the main challenges include the incomplete proclamation of sanitary protection zones, their limited integration into spatial plans, inconsistent enforcement of restrictions, and weak institutional coordination between water management and environmental authorities.".For the TBA Una, these shortcomings translate into risks of over-abstraction, contamination, and uncoordinated development on both sides of the border.

2.3.2 Licensing and Permitting Procedures

Licensing and permitting systems regulate abstraction, discharge, and other activities that may impact aquifer integrity. Both Croatia and Bosnia and Herzegovina legally require permits for groundwater use, yet their frameworks differ significantly in terms of structure, clarity, and enforcement, with implications for transboundary management in the Una TBA.

In Croatia, the Water Act establishes a two-tiered system: Water Use Permits for standard abstractions and Concessions for economically significant or large-scale uses. Croatian Waters issues permits for public water supply, irrigation, and industrial use below defined thresholds, typically valid for 12 years. Concessions, granted by the Ministry of Environmental Protection and Green Transition, apply to hydropower generation, mineral and geothermal water exploitation, and abstractions exceeding 10,000 m^3 annually, with durations of up to 40 years. Both instruments require compliance with environmental standards, monitoring obligations, and payment of water-related fees under the Water Management Financing Act. The permitting process is linked to spatial planning and sanitary protection zones, ensuring that hydrogeological studies inform decisions. However, practical

challenges persist: delays in processing applications, insufficient integration of vulnerability assessments, and weak monitoring of compliance. Illegal abstractions and underreporting of water volumes remain issues, particularly in rural karst areas where enforcement capacity is limited.

In Bosnia and Herzegovina, entity-level Water Laws govern permitting and the system is more fragmented. In the F BiH, water permits for smaller abstractions are issued by cantonal ministries, while larger uses fall under the jurisdiction of entity water agencies (AVP Sava and AVP Jadran). In Republika Srpska, the Public Institution "Vode Srpske" manages permits for all significant uses. Concessions for hydropower and other major activities are regulated by separate concession laws, adding complexity and procedural delays. While legal provisions require permits for abstraction and discharge, implementation is inconsistent. Monitoring obligations are weakly enforced, and many water sources remain with ought legally binding protection and unregistered. The lack of harmonized criteria for karst aquifers and vulnerability assessments further undermines the effectiveness of permitting decisions. Environmental impact assessments are formally required for projects with potential water-related impacts, but groundwater-specific methodologies are rarely applied, and cumulative effects are not systematically evaluated.

A key difference lies in the integration of permitting with broader governance instruments. Croatia's framework, despite operational gaps, demonstrates stronger linkage between permits, sanitary protection zones, and river basin management plans. Bosnia and Herzegovina lacks such systemic integration; permitting decisions often occur in isolation from spatial planning and sectoral strategies, increasing the risk of uncontrolled land-use changes and pollution near sensitive recharge zones. Both countries recognize the polluter pays principle, yet cost recovery mechanisms are more advanced in Croatia, where water pricing methodologies incorporate resource and environmental costs. In BiH, fee structures vary across entities and enforcement is sporadic.

For the Una TBA, For the Una TBA, these disparities create significant challenges for coordinated groundwater management. Croatia's permitting system offers a clearer legal basis but suffers from enforcement weaknesses, while in FBiH the permitting framework is marked by procedural complexity due to shared responsibilities and weak enforcement.

2.3.3 Pollution Control and Sanitary Protection Zones

Pollution control and the establishment of sanitary protection zones (SPZs) are essential components of groundwater governance, particularly in highly vulnerable karst systems such as the TBA Una. Both Croatia and Bosnia and Herzegovina have legal provisions addressing these issues, but their frameworks differ in technical detail, enforcement capacity, and practical implementation. For the TBA Una, which is entirely located within the Federation of BiH, the effectiveness of measures in this entity is of primary importance.

In Croatia, pollution control is embedded in the Water Act and supported by implementing regulations. Direct discharges of pollutants into groundwater are strictly prohibited, while indirect discharges - such as infiltration of treated wastewater - are permitted only under strict conditions and subject to risk assessments. The Regulation on Emission Limit Values for Wastewater sets pollutant thresholds and monitoring requirements in line with EU standards. However, gaps remain in regulating artificial aquifer recharge and assessing cumulative impacts on groundwater-dependent ecosystems. Enforcement of discharge restrictions is uneven, particularly in rural karst areas where illegal waste disposal and insufficient wastewater treatment persist. The River Basin Management Plan (RBMP) identifies these pressures as significant risks, calling for improved monitoring and remediation measures.

The Rulebook on Conditions for Establishing Sanitary Protection Zones mandates an inventory of potential pollution sources and prescribes protective measures, including prohibitions on waste disposal, hazardous construction, and certain agricultural activities. In theory, these measures are complemented by monitoring obligations and remediation programs. These provisions are critical for safeguarding springs and recharge areas in the Una basin In practice, however, implementation is uneven. Many municipalities delay incorporating SPZs into spatial plans, despite legal requirements, and enforcement of restrictions within zones is inconsistent. Remediation programs for legacy pollution sources are often incomplete or not implemented, leaving sensitive recharge areas exposed to contamination risks.

In BiH, pollution control is defined under the entities Water Laws and supported by environmental regulations. Groundwater protection measures are embedded in the entities Water Laws and regulations. The Water Laws (RS, FBiH) specify that direct discharge of wastewater into groundwater is prohibited. However, indirect discharge is allowed only under the conditions and in the manner determined by law and by-laws. There are corresponding Regulations on the conditions for discharging wastewater into public sewage systems and surface waters in RS ((Official Gazette of RS No. 44/01), as well as regulation Rulebook on the Conditions for Discharging Wastewater into the Environment and Public Sewage Systems ("Official Gazette of FBiH", 26/20, 96/20), defining technical and sanitary requirements for discharging wastewater, maximum allowable pollutant concentrations, monitoring and reporting requirements. However, monitoring of compliance and enforcement is weak, technical guidelines for risk assessment are underdeveloped, and illegal waste disposal and uncontrolled wastewater infiltration remain widespread, particularly in rural karst areas. The lack of systematic evaluation of impacts on groundwater-dependent ecosystems further undermines pollution control efforts.

The FBIH regulation on protection zones distinguishes karst environments and mandates vulnerability assessments, while RS applies uniform criteria without reflecting hydrogeological complexity. Karst-specific protective measures are explicitly defined in the FBH Regulation while RS applies general groundwater protection criteria. Enforcement is inconsistent, and many municipalities have not adopted formal decisions or integrated zones into spatial plans, despite legal obligations.

Environmental laws in both entities include provisions that prohibit or restrict the discharge of pollutants into groundwater, through environmental permitting and impact assessment mechanisms.

Artificial aquifer recharge can be legally addressed through provisions in the water laws of both entities but it is necessary to prepare a detailed Environmental Impact Assessment and obtain the appropriate permits from the competent authorities proving that it does not have adverse effect to water resources.

From a comparative perspective, Croatia shows stronger alignment with EU directives and provides more detailed technical standards for SPZs, yet it continues to face challenges in enforcing restrictions within zones and in incorporating SPZs into spatial plans. The FBIH, where the entire TBA Una is located, despite having regulations that acknowledge karst vulnerability, faces persistent challenges with the legal proclamation of many SPZs, their integration into spatial plans, and the implementation, monitoring, and inspection of sanitary protection zones. It also struggles with illegal waste disposal and inadequate wastewater treatment, which remain major threats to groundwater quality.

2.4 Identified Legal Gaps and Opportunities for Harmonization

The comparative review of legal frameworks governing groundwater in Croatia and Bosnia and Herzegovina reveals substantial asymmetries in regulatory maturity, operationalization, and integration with EU directives, which directly affect the governance of the TBA Una. While Croatia exhibits formal alignment with the Water Framework Directive (WFD) and Groundwater Directive (GWD), Bosnia and Herzegovina remains only partially compliant, with fragmented implementation across entities and cantons. These disparities create significant challenges for harmonized management and underscore the need for targeted legal and institutional convergence.

A primary gap in Bosnia and Herzegovina is absence of harmonised implementation of entities Laws, which results in inconsistent methodologies for groundwater status assessment, sanitary protection zone delineation, and pollution control. The Groundwater Directive is only partially transposed, leaving critical provisions - such as trend reversal, threshold value determination, and protection of groundwater-dependent ecosystems - either incomplete or absent. Monitoring obligations exist in law but are weakly enforced, and ecological indicators are rarely integrated into groundwater assessments. In contrast, Croatia has fully transposed both directives, established standardized monitoring protocols, and defined threshold values for pollutants, although gaps persist in regulating artificial recharge and cumulative impacts on karst ecosystems.

Both countries share deficiencies in the limited implementation of indirect wastewater discharge and artificial aquifer recharge. Croatia prohibits direct discharges and allows indirect discharges under strict conditions, yet lacks comprehensive technical guidelines for risk assessment and monitoring. Bosnia and Herzegovina's legal framework similarly prohibits direct discharges but provides no operational methodology for evaluating indirect infiltration risks, leaving karst aquifers vulnerable to contamination. Remediation measures for contaminated soil and groundwater are legally mandated in both jurisdictions but remain inconsistently implemented, particularly in rural and karst areas where enforcement capacity is limited.

Sanitary protection zones represent another critical area of divergence. Croatia applies detailed hydrogeological criteria for delineating zones, supported by (optional) vulnerability mapping and flow-time calculations, whereas Bosnia and Herzegovina lacks harmonized methodologies across entities. FBIH prescribes karst-specific criteria, including vulnerability assessments, while RS applies uniform standards that disregard hydrogeological complexity. In practice, both countries struggle with delayed incorporation of protection zones into spatial plans and incomplete enforcement of restrictions, exposing sensitive recharge areas to uncontrolled land-use changes.

Integration of groundwater considerations into spatial planning and sectoral policies remains insufficient in both countries. Croatia's Spatial Development Strategy and Natura 2000 provisions formally link groundwater protection with biodiversity conservation, yet operationalization is uneven, and cumulative impacts from tourism and infrastructure projects are rarely assessed comprehensively. Bosnia and Herzegovina faces even greater challenges: groundwater is marginally addressed in agriculture, energy, and tourism strategies, and vulnerability mapping is largely absent from planning instruments. Environmental impact assessments are legally required in both jurisdictions but lack standardized groundwater-specific methodologies, limiting their effectiveness in karst environments.

Economic instruments also reveal gaps. Croatia incorporates the polluter pays and cost recovery principles into its water legislation and tariff-setting methodologies, albeit with partial implementation and contested application at the local level. Bosnia and Herzegovina recognizes these

principles in law but has not integrated environmental costs into water pricing, resulting in inadequate financial resources for monitoring and enforcement. This shortfall is compounded by chronic underfunding of water agencies and inspectorates, which constrains compliance monitoring and remediation efforts.

Opportunities for harmonization are evident across several dimensions. First, both countries should adopt standardized methodologies for vulnerability mapping and risk assessment of indirect discharges, ensuring consistency with EU guidance documents. Second, Bosnia and Herzegovina requires accelerated transposition of the Groundwater Directive, including provisions for chemical status assessment, trend reversal, and ecological connectivity. Third, integration of groundwater considerations into spatial planning and sectoral strategies must move beyond declarative commitments toward enforceable measures, supported by technical guidelines and monitoring protocols. Fourth, economic instruments should be aligned to reflect environmental and resource costs, enabling sustainable financing of groundwater protection measures. Finally, it is necessary to include groundwater-specific obligations, harmonized sanitary zone criteria, joint monitoring programs, and data-sharing mechanisms, providing a robust legal foundation for transboundary cooperation under DIKTAS II.

In summary, Croatia offers a stronger regulatory and institutional baseline for groundwater governance, than Bosnia and Herzegovina which faces gaps that hinder effective implementation. Harmonization efforts should prioritize legal convergence, methodological standardization, and capacity building, ensuring that both countries meet identical standards and safeguard the ecological integrity of the TBA Una.

2.5 Summary Tables: Legal Framework Comparison – HR vs BiH (TBA Una)

Table 1 Summary table 2.3.1.-2.3.2.Groundwater ownership and use rights & Licensing and permitting procedures (HR vs BiH)

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
Legal status of groundwater	Public good; private ownership prohibited under Water Act	Public good; private ownership prohibited under Water Law	Public good; private ownership prohibited under Water Laws
Legal framework	Water Act (OG 66/2019, 84/2021, 47/2023); fully aligned with EU WFD & GWD	Water Law, WFD transposition almost completed; GWD up to 30%	Water Law, partial WFD transposition; GWD largely missing
Ownership & use rights	Groundwater cannot be privately owned; use regulated through permits and concessions	Groundwater cannot be privately owned; rights regulated through permits and concessions; decentralized governance	Same principle; rights regulated through permits and concessions; centralized at entity level
Permitting system	Two-tier: Water Use Permits (≤12 yrs) and Concessions (up to 40 yrs);	Decentralized: permitting system (cantonal and entity level) based on FBIH Water Law (usage,	Centralized: permitting system (entity level) based on RS Water Law (usage, discharge) Concessions regulated

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
	based on hydrogeological studies and compliance with environmental standards	discharge) Concessions regulated separately in accordance to FBIH Law on concessions and Cantonal Laws on concessions	separately in accordance of RS Law on concessions
Integration with spatial planning	Strong legal link; permits require compliance with sanitary protection zones and spatial plans	Legally required; implementation sporadic; many municipalities fail to establish zones	Legally required; implementation sporadic; many municipalities fail to establish zones
Polluter pays & Cost recovery	Embedded in law; fees reflect resource and environmental costs	Recognized in law but only partially implemented; fees do not reflect resource and environmental costs	Recognized in law but weak implementation; tariffs low; environmental costs not integrated
Monitoring obligations	Mandatory reporting of abstraction volumes; enforcement uneven in rural areas	Legally required measurements and reporting but weakly enforced	Legally required but weakly enforced; measuring sporadic

Table 2 Summmary Table 2.3.3-Pollution Control and Sanitary Protection Zones (HR vs BiH)

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
Legal framework	Water Act; Rulebook on SPZ; RBMP 2022–2027	Water Law; Regulation on SPZ; RBMP 2022–2027	Water Law; Regulation on SPZ; RBMP 2017–2021
Number of zones	4 zones (I–IV)	3–4 zones (zone IV: optional)	3 zones

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
Technical criteria for zone delineation	Hydrogeological study; karst-specific criteria; flow-time thresholds and apparent flow (AF) velocities: Zone II ≤ 1 day; V_{AF} ? 3.0 cm; Zone III 1 - 10 day; V_{AF}1.0 - 3.0 cm; Zone IV includes catchment beyond Zone III with flow through fracture-cavernous aquifers during high-water conditions (10–50 days depending on source type); exceptionally entire recharge area if apparent flow <1 cm/s.	Differ among entities; Detailed karst methodology; vulnerability mapping mandatory; flow-time thresholds (zone II – minimum 1 day; zone III – minimum 10 days)	Differ among entities Uniform criteria for all mediums; flow-time (7, 90, 180 days); minimum distances (50m, 250m, 200m)
Inventory of pollution sources	Mandatory in technical study	Mandatory in SPZ Program (Study)	Mandatory in SPZ Program (Study)
Protective measures – Zone I	Physical fencing; ban on all activities except maintenance	Physical fencing; ban on all activities except maintenance	Ban on construction, waste disposal, agriculture
Protective measures – Zone II	Ban on waste disposal, industry, agriculture (except ecological)	Ban on agriculture, waste disposal, hazardous construction	Ban on construction, waste disposal; agriculture partly allowed
Protective measures – Zone III	Ban on waste disposal, hazardous construction, and polluting facilities; agriculture allowed only under ecological standards; certain developments (e.g., waste management centers) permitted only with detailed hydrogeological study and strict protective conditions	Broader land-use restrictions; mandatory environmental impact assessments for new projects; agriculture and construction regulated; zone may include entire hydrogeological catchment; vulnerability mapping required	Outer zone: general restrictions on construction, excavation, and waste disposal; agriculture partly allowed; no karst-specific criteria (uniform approach)
Protective measures – Zone IV	Passive protection measures; includes catchment beyond Zone III; land-use control and spatial planning	Optional zone; applied in highly sensitive karst systems; passive measures (land-use control, planning); long-term monitoring and planning functions	Not defined (only three zones exist)
Monitoring within zones	Monitoring is mandatory in all zones but is primarily carried out at water abstraction points (springs and wells) used for public supply. It includes water	Monitoring is mandatory in all zones and defined in the Sanitary Protection Programme. Parameters include	Monitoring is included in the Sanitary Protection Programme; carried out at abstraction points and in Zone I, occasionally in Zones II and III. Parameters include chemical and

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
	quality (physical-chemical and microbiological parameters) and, where relevant, quantity (spring discharge). Monitoring requirements are defined in the Decision on the Protection of Drinking Water Source and implemented by water utilities under the supervision of Croatian Waters and the Public Health Institute. In karst areas, continuous monitoring is emphasized due to high vulnerability	physical-chemical and microbiological indicators; frequency and number of points are determined by consumer numbers, risk level, and distance from the intake. Monitoring is performed by water utilities and controlled by cantonal inspectorates; methodology is not standardized between entity level	microbiological indicators; frequency is not clearly prescribed and depends on local conditions. There is no karst-specific methodology, and systematic monitoring of water quantity (spring discharge) is not implemented
Remediation	Prescribed in Rulebook & RBMP; often not implemented	Prescribed in Program; rare implementation	Prescribed in Program, rare implementation
Integration into spatial plans	Legally required; implementation occasionally slow	Legally required; many municipalities often non-compliant	Legally required; municipalities often non-compliant
Regulation of wastewater discharge	Direct discharge prohibited; indirect under strict conditions; MAR guidelines missing	Direct discharge prohibited; indirect under strict conditions; lacks technical guidance	Direct discharge prohibited; indirect under strict conditions; lacks technical guidance

Table 3 Key summary table 2.4a -. Identified Legal Gaps (HR vs BiH)

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
EU directive transposition	WFD and GWD fully transposed; minor gaps in operationalization (e.g., cumulative impact assessment)	WFD largely transposed (>90%); GWD only partially implemented (30%); lack provisions for trend reversal and ecological connectivity, and not established a WFD/GWD-compliant methodology for assessing chemical status or defining groundwater threshold values."	WFD partially transposed (~75%); GWD largely missing; lack provisions for trend reversal and ecological connectivity, and not established a WFD/GWD-compliant methodology for assessing chemical status or defining groundwater threshold values

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
Groundwater-dependent ecosystems (GWDE)	Legally recognized under Nature Protection Act and Natura 2000; weak integration into planning and monitoring	Not explicitly defined; addressed indirectly via environmental and nature protection laws; no operational criteria	Not explicitly defined; addressed indirectly via environmental and nature protection laws; no operational criteria
Sanitary protection zones (SPZ)	Detailed hydrogeological criteria exist; vulnerability mapping optional; enforcement uneven; delays in spatial plan integration	Karst-specific methodology legally required; vulnerability mapping mandatory; implementation sporadic; many municipalities lack formal decisions	Uniform criteria applied; ignores karst complexity; no vulnerability mapping; enforcement weak
Monitoring framework	Standardized methodology aligned with EU CIS guidance; integrated into RBMP; gaps in karst-specific monitoring and ecological indicators	Monitoring obligations exist through water Law and RBMP; gaps in karst-specific monitoring (focused on drinking water sources) and gap in ecological indicators, lack of standardized methodology among entities;	Monitoring obligations exist through water Law and RBMP; gaps in karst-specific monitoring (focused on drinking water sources) and gap in ecological indicators, lack of standardized methodology among entities;
Pollution control & Wastewater regulation	Direct discharge prohibited; indirect allowed under strict conditions; lacks technical guidelines for indirect wastewater discharge and risk assessment	Direct discharge prohibited; indirect allowed under strict conditions; lacks operational guidelines and monitoring protocols and risk assessment or technical guidance	Direct discharge prohibited; indirect allowed under strict conditions; lacks operational guidelines and monitoring protocols and risk assessment or technical guidance
Artificial recharge regulation	No comprehensive legal framework for MAR; absence of technical standards and risk assessment procedures	Legal basis exists in principle; no operational methodology or technical standards	Legal basis exists in principle; no operational methodology or technical standards
Integration of SPZ with spatial planning	Legally required; delays in incorporating SPZ into spatial plans; cumulative impacts rarely assessed	Legally required; many municipalities non-compliant; weak enforcement mechanisms	Legally required; many municipalities non-compliant
Economic instruments	Polluter pays and cost recovery principles embedded; partial implementation; contested locally	Recognized in law; distributed among Federal and cantonal levels and Environment fund; collected amount insufficient for water requirements; environmental/resource costs absent	Recognized in law; distributed among RS and municipal levels and Environment fund; collected amount insufficient for water requirements; environmental/resource costs absent

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
Remediation of contaminated sites	Legally mandated in RBMP and SPZ programs; implementation inconsistent; no dedicated law for remediation	Prescribed by legislations; weak enforcement; remediation rarely implemented	Prescribed by legislations; weak enforcement; remediation rarely implemented

Table 4 Key summary table 2.4.b -Identified Opportunities for Harmonization (HR vs BIH)

Legal dimension	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
EU directive compliance	Maintain full WFD/GWD alignment; introduce detailed guidance for cumulative impact assessment	Accelerate full GWD transposition; adopt provisions for chemical status, trend reversal, and ecological connectivity, develop methodology for threshold values and chemical status assessment	Accelerate full GWD transposition; adopt provisions for chemical status, trend reversal, and ecological connectivity, develop methodology for threshold values and chemical status assessment
Groundwater-dependent ecosystems (GWDE)	Operationalize Natura 2000 commitments; integrate GWDE criteria into RBMP and EIA procedures	Define GWDE explicitly in water Law; Introduce GWDE definition and protection measures; link to biodiversity strategies; integrate into RBMP and spatial planning	Define GWDE explicitly in water Law; Introduce GWDE definition and protection measures; link to biodiversity strategies integrate into RBMP and spatial planning
Sanitary protection zones (SPZ)	Harmonize SPZ delineation with vulnerability mapping as mandatory; strengthen enforcement and integration into spatial plans	Ensure full compliance with the legal requirement to identify all water abstraction springs and to establish all protection zones through systematic vulnerability mapping."	Revise SPZ regulation to include karst-specific criteria; introduce vulnerability mapping and risk-based zoning and uniform enforcement, identify all water abstraction springs and establish protection zones
Monitoring & Data systems	Expand karst-specific monitoring; integrate ecological indicators; improve interoperability of national databases	Start karst-specific monitoring; integrate ecological indicators; develop unified methodology for groundwater monitoring establish data platform used by both entities	Start karst-specific monitoring; integrate ecological indicators; develop unified methodology for groundwater monitoring establish data platform used by both entities
Pollution control & MAR regulation	Develop technical guidelines for Managed Aquifer Recharge (MAR) and indirect discharge risk assessment	Introduce detailed risk assessment procedures for indirect discharges; adopt MAR guidelines	Introduce detailed risk assessment procedures for indirect discharges; adopt MAR guidelines

Legal dimension	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)
Integration with spatial planning	Enforce mandatory inclusion of SPZ and vulnerability maps in all spatial plans; strengthen cross-sectoral coordination	Ensure SPZ integration into spatial plans; link groundwater protection to land-use decisions	Mandate SPZ and vulnerability mapping in spatial plans; introduce karst-specific planning criteria; Ensure SPZ integration into spatial plans; link groundwater protection to land-use decisions
Economic instruments	Improve implementation of polluter pays and cost recovery; align tariffs with environmental/resource costs	Revise fee system to reflect resource and environmental costs; harmonization among entities	Revise fee system to reflect resource and environmental costs, harmonization among entities
Remediation framework	Adopt dedicated by-law for remediation of contaminated groundwater; enforce SPZ remediation programs	Develop clear procedures for remediation under water and environmental laws; ensure funding mechanisms	Develop clear methodologies and procedures for remediation under water and environmental laws; ensure funding mechanisms

3. Institutioan arrangements

3.1 Institutional Roles and Capacities in Croatia and BiH

The main actors in groundwater governance and management in Croatia operate at multiple levels. At the national level, the Ministry of Environmental Protection and Green Transition (Directorate for Water Management and Sea Protection) and Croatian Waters are responsible for preparing legislation strategic planning, supervision, and implementation of water resource management policies.The Croatian Institute of Public Health – Andrija Štampar Institute and the network of county institutes regularly conduct analyses of drinking water quality. Thay have well-developed laboratory systems for water quality control, yet continuous investment in equipment and staff training remains necessary, particularly in karst and rural regions. Croatian Waters and new Water Institute Josip Juraj Strossmayer possess substantial technical expertise and long-standing experience in planning, monitoring, and managing water resources, though modernization and digitalization efforts are constrained by limited budgets. .In Croatia, central technical capacity is strong, but local level implementation is constrained, particularly in relation to agricultural practices and diffuse pollution. Downstream exposure to upstream pressures limits the effectiveness of national measures alone.

The following are the primary institutions at the UNA TBA territory:

- County and Municipal Governments (Plitvička Jezera, Rakovica, Korenica, Slunj): Responsible for local spatial planning, sanitation, and waste management. Capacities limited due to small population, reduced budgets, and dispersed settlements.
- Public Utilities: Operate small, decentralised water-supply systems; limited financial and technical capability.
- Inspectorate: Responsible for compliance control; presence in rural karst areas is inconsistent.

The state Ministry of Foreign Trade and Economic Relations in Bosnia and Herzegovina has jurisdiction on defining policy, and basic principles, coordinating activities, and harmonizing the plans of entity authorities and institutions at the international level, among others in the fields of agriculture, energy, environmental protection, development and use of natural resources (incl. water) and tourism. The key actors relevant for groundwater management are the entity ministries responsible for water management – the Ministry of Agriculture, Water Management and Forestry (MoAWMF) of the Federation of BiH and the Ministry of Agriculture, Forestry and Water Management of the Republika Srpska. Their tasks delegated to water management sectors includes inter alia the strategic planning and implementation of water-related legislation. MoAWMF is also responsible for the supervision of the performance of the water management agencies/institutions. The entities Water Agencies/ Institution (Agency for watershed area of Adriatic Sea (AVP Jadran) and Agency for watershed area of Sava River (AVP Sava) and Public Institution "Vode Srpske" in RS (PI Vode Srpske) are responsible for overall water management including monitoring, issuing water permits, and planning groundwater protection measures. Within Public Institution 'Vode Srpske', there operates a specialized department responsible for the Trebišnjica River. The entity water agencies/public institution have competent technical staff but, the number of qualified employees is significantly below the level required to meet the expected demands of implementing EU legislation and regulations, to which Bosnia and Herzegovina has committed through its candidate status. Financial resources for managing water resources are very limited, including groundwater monitoring or upgrading / modernisation of databases / Water information systems. Budget allocations have been consistently absent for many years so. Hydrometeorological Institutes focus on meteorological and hydrological activities including monitoring and processing data. The entities' Institutes of Public Health are responsible for monitoring drinking water quality. Entities Geological Institutes contribute by collecting, analysing, and interpreting hydrogeological data essential for assessing groundwater quantity and quality. Generally, in B&H institutional fragmentation reduces operational efficiency. Permitting and enforcement processes are not efficient, and coordination between water, energy, environment, and spatial planning sectors remains weak.

In the Federation of BiH, cantonal ministries play a role in implementing water legislation (issuing water permits for smaller water abstractions and inspections). Public water supply companies are responsible for the abstraction, treatment, and distribution of groundwater for drinking purposes and are also involved in the monitoring and protection of water sources within sanitary protection zones. Municipal utilities face lack of qualified technical staff, chronic under-financing and rely heavily on donor support or loans for capital investment and training. Overall, financial and human resources capacity constraints hinder the systematic integration of groundwater considerations into planning and decision-making (World Bank 2022b; UNESCO-IHP 2024).

Civil society organisations (CZZS, Aarhus Centres, WWF Adria) and research institutions (university in Mostar) influence policy through advocacy and studies.

The following are the primary institutions operating at the UNA TBA territory:

- Una-Sana Canton: Oversight of environment, forestry, communal services, and implementation of sectoral strategies.
- City of Bihać: Local authority for spatial planning, sanitation, wastewater management, and inspections.
- Bihać Water Utility: Key operational stakeholder; highly dependent on Klokot/Kostela springs. Strong incentive for protection but limited control over wider land use.

- NP Una Administration: Manages tourism, conservation, and infrastructure in protected areas; influential actor in areas overlapping recharge zones.
- NGOs and Community Groups: Active in environmental protection; influential in public awareness and reporting.

3.2. Enforcement Mechanisms and Institutional Capacities

Enforcement mechanisms and institutional capacities for groundwater governance in Croatia and Bosnia and Herzegovina exhibit significant structural and operational differences, with implications for the management of the TBA Una. Croatia demonstrates a more centralized and legally coherent system, whereas Bosnia and Herzegovina operates under a decentralised framework shaped by its constitutional arrangement and entity-level autonomy.

In Croatia, enforcement is anchored in the Water Act and supported by a comprehensive set of implementing regulations aligned with EU Water Framework Directive (WFD) and Groundwater Directive (GWD) requirements. Croatian Waters acts as the central implementing authority, complemented by the Ministry of Environmental Protection and Green Transition and the State Inspectorate. These institutions possess clear mandates for issuing permits, monitoring compliance, and imposing sanctions. Enforcement tools include administrative measures, financial penalties, and mandatory remediation programs, integrated into River Basin Management Plans (RBMPs). The system benefits from structured inspection protocols and a relatively stable financing mechanism under the Water Management Financing Act, which ensures cost recovery and supports compliance monitoring. However, operational challenges persist, particularly in rural and karst areas where illegal abstractions and delayed incorporation of sanitary protection zones into spatial plans undermine effectiveness.

Institutional capacity in Croatia is comparatively strong at the national level, with Croatian Waters and specialized institutes demonstrating technical expertise and experience in groundwater management. Financial sustainability is supported through water-related fees and EU funding streams, while human resources are reinforced by structured roles and certification systems. Nonetheless, local-level capacities remain uneven, and enforcement often relies on reactive rather than preventive measures.

In Bosnia and Herzegovina, enforcement is decentralized across entities, cantons, and municipalities, resulting in some cases in overlapping competencies and procedural inconsistencies. Entities' Water Laws provide the legal basis for compliance monitoring and sanctions, but implementation is hindered by chronic understaffing, limited budgets, and weak coordination. Entity water agencies (AVP Sava, AVP Jadran, and PI Vode Srpske) are responsible for permitting and monitoring, while inspectorates conduct inspections and impose penalties. However, enforcement is largely reactive, triggered by complaints or visible violations, and lacks systematic risk-based planning. Financial mechanisms for cost recovery exist in law but are inadequately operationalized; water tariffs fail to incorporate environmental and resource costs.

Institutional capacity constraints in BiH are acute. Technical expertise is concentrated within entity agencies, but staffing levels are insufficient to meet the demands of EU approximation and RBMP implementation. Cantonal and municipal authorities often lack qualified personnel and rely heavily on donor-funded projects for monitoring and infrastructure upgrades. Budgetary allocations for groundwater protection are minimal, and investment planning is sporadic. These limitations severely restrict the ability to enforce monitoring, sanitary protection zones, monitor abstraction volumes, and control pollution in karst areas.

Both countries share common weaknesses, including insufficient integration of groundwater considerations into spatial planning and sectoral policies, as well as gaps in regulating cumulative pressures from tourism, agriculture, and infrastructure development. However, Croatia's centralized structure and alignment with EU directives provide a stronger foundation for enforcement and institutional strengthening, whereas Bosnia and Herzegovina requires substantial changes to strengthen inter – entity joint planning and resource deficits.

For the Una TBA, these disparities translate into practical challenges for harmonized governance. Croatia's enforcement mechanisms, while imperfect, offer a basis for transboundary cooperation, but their effectiveness is limited by uneven local implementation. Bosnia and Herzegovina's decentralised system and weak institutional capacity pose greater risks, necessitating targeted capacity-building, standardized methodologies, and enhanced financing mechanisms

3.3. Cross-sectoral Coordination

At the national level In Croatia, collaboration between the Ministry of Environmental Protection and Green Transition, Croatian Waters, and the Croatian Institute of Public Health occurs regularly through the implementation of the Water Act and the River Basin Management Plan. However, horizontal coordination between sectors, particularly tourism, agriculture, and energy, remains mostly project-based rather than systematically institutionalized. Cooperation between public authorities and non-governmental organizations exists through campaigns and environmental projects but lacks formal mechanisms for participation in policy-making. Overall, inter-agency cooperation is functional but would benefit from stronger cross-sectoral integration and more

At the institutional level, Croatian Waters, the Croatian Institute of Public Health (CIPH), and the Croatian Meteorological and Hydrological Service (DHMZ) exchange data through formal reporting mechanisms under the Water Framework Directive (WFD) and through the national environmental information system. However, data exchange across sectors remains fragmented. The private sector and local utilities often rely on summary reports rather than direct access to raw datasets (e.g., continuous groundwater monitoring series or spatial data on karst aquifers). While inter-agency cooperation is supported by open data initiatives and formal agreements under NIPP and INSPIRE, structured and interoperable data sharing between public authorities, research institutions, and private operators is still limited.

There is no single national data platform integrating all groundwater and groundwater-dependent ecosystem (GWDE) datasets, particularly those relevant to karst regions: technical and organizational differences between institutions (e.g., metadata standards, GIS formats) hinder full interoperability; private entities, including consultants, utilities, and land users, face barriers in accessing detailed or real-time groundwater data.

The practical exchange of groundwater data across institutions and with private stakeholders remains limited, especially for detailed monitoring and karst-related datasets.

In BIH, the horizontal integration with sectors such as agriculture, energy, and spatial planning is modest. Legal mechanisms for cooperation exist in Water Laws and Environmental Laws, but coordination is not regular or systematic. Groundwater protection measures are rarely included in physical plans, irrigation, or land-use policies. Coordination between the water sector and other sectors - energy, agriculture, planning, health is irregular. It occurs mainly through donor-driven projects such as DIKTAS-2, GCF/UNDP, and World Bank initiatives. No permanent inter-sectoral platform exists to align groundwater management with socio-economic priorities.

Entity water laws reference cooperation between agencies for shared water bodies. In practice, joint planning across entities is not implemented. River basin management plans are prepared separately, despite basins spanning both entities. This division highlights the lack of integrated management.

In FBiH, water agencies provide online data. Available datasets include water levels, water quality, monitoring networks, groundwater cadastre, and GIS maps. These are interactive, regularly updated, and only partly downloadable. The Hydro Meteorological Institute publishes reports ranging from daily bulletins to annual analyses, using data from water agencies' monitoring stations and its own, yet deficiencies lie in the rather slow processing of data, with time lags of up to five years. Data sharing is carried out upon request rather than regularly through established protocols or systematic procedures, resulting in fragmented and inconsistent practice. In RS, water agencies and hydrometeorological institutes collect hydrological and quality data, but dissemination is irregular. Public access is limited to summary reports or project outputs. Raw data on groundwater levels, abstraction, or chemistry are rarely available online. RS maintains time series but does not publish open datasets.

Geological surveys in both entities hold archives on aquifers and karst morphology. Most remain analogue or unpublished. Some datasets have been digitized under donor projects, but continuity is uncertain after projects end.

No unified water information system exists in BIH. Data exchange across entities and sectors is limited. Knowledge-sharing frameworks remain fragmented, preventing integrated understanding of karst aquifers and groundwater-dependent ecosystems eventhou systematisation of data collection, monitoring, and decision-making is required for sustainable groundwater management.

3.4. Observations for the TBA Una

Institutional issues further add complexity to governance in both in both countries. Croatia benefits from centralized oversight by Croatian Waters and the Ministry of Environmental Protection and Green Transition, but resource constraints and uneven local capacities limit effective enforcement. Bosnia and Herzegovina relies on decentralized structures, with overlapping competencies among entities, cantons, and municipalities, resulting in slow decision-making and weak compliance monitoring. While both countries recognize the polluter pays and cost recovery principles, Croatia's application of these principles is partial and often contested, and Bosnia and Herzegovina lacks harmonized fee structures and systematic integration of environmental costs into water pricing.

3.5. Summary Tables on institutional arrangements and coordination

Table 5 Summary Table 3.1- Key Institutions and their roles (HR vs BiH)

Institutional Level t	Croatia (HR)	Bosna I Hercegovina (BIH
National Ministries	Ministry of Environmental Protection and Green Transition (Directorate for Water Management and Sea Protection). Defines legislation, strategic planning, supervision.	State Ministry of Foreign Trade and Economic Relations (MoFTER). Coordinates policy, principles, and harmonization of entity plans at international level.
Central Water Institutions	Croatian Waters – main technical body for implementation, supervision, permits, monitoring.	**FBiH:** Ministry of Agriculture, Water Management and Forestry; Agencies for Adriatic (AVP Jadran) and Sava (AVP Sava). **RS:** Ministry of Agriculture, Forestry and Water Management; Public Institution "Vode Srpske". Define legislation, strategic planning, supervision at entity level
Institutional Level t	**Croatia (HR)**	**Bosna I Hercegovina (BIH**
Specialized Institutes	Croatian Institute of Public Health; Water Institute Josip Juraj Strossmayer; Andrija Štampar Institute; county public health institutes (drinking water quality). DHMZ (hydrology, meteorology).	Entities Geological Institutes (Sarajevo, Zvornik) – hydrogeological data. Entities Hydrometeorological Institutes –monitoring and processing hydrology, meteorology. Entities Institutes of Public Health – drinking water quality monitoring. Universities (Sarajevo, Tuzla, Mostar, Banja Luka) – research and policy input.
Regional / Local Authorities	County public institutions and municipal utilities (e.g., Lička vode, Dubrovnik, Split, Rijeka). Manage water supply, wastewater, sanitary zones.	Cantonal Ministries in FBIH -Defines legislation, strategic planning, supervision at Cantonal level including specialised institutes for health, spatial planning etc Municipal utilities – abstraction, treatment, distribution of groundwater. Local governments – spatial planning, sanitation, waste management.
Civil Society / NGOs	Green Action, Croatian Water Pollution Control Society, WWF Adria, ZMAG, Rotary Croatia. Awareness, advocacy, projects.	Center for environment protection (CZZS), Aarhus Centres, WWF Adria, local NGOs- Advocacy, awareness, reporting.
UNA TBA – Croatia	County/Municipal Governments (Plitvička Jezera, Rakovica, Korenica, Slunj). Public utilities – small decentralized systems. Environmental Inspectorate – compliance control (limited presence).	Una-Sana Canton – oversight of environment, forestry, communal services. Cantonal ministries (FBiH) – permits for abstractions significant for cantonal level, inspections. City of Bihać – spatial planning, sanitation, wastewater, inspections. Bihać Water Utility – dependent on Klokot/Kostela springs, limited land-use control. Una Administration – tourism, conservation, infrastructure in recharge zones. NGOs/community groups – awareness, reporting.

Table 6- Summary Table 3.2- Institutional Capacities and Enforcement Mechanisms (HR vs BiH)

spect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	**Republika Srpska (RS)and**
Institutional structure	Centralized: Croatian Waters (implementation), Ministry of Environmental Protection and Green Transition (policy), State Inspectorate (control)	Decentralized : Entity Ministry for Agriculture, Water and Forestry; Entity Water Agencies (AVP Sava, AVP Jadran), Hydro meteoritical Institute, Geology	Centralized: Entity Ministry for Agriculture, Forestry and Water PI "Vode Srpske"; Hydro meteoritical Institute, Geology Institute municipal utilities

spect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
		Institute Cantonal ministries; municipal utilities,	
Mandates & Competencies	Clear mandates for permitting, compliance monitoring, and sanctions; integrated into RBMPs	Entity and Cantonal level institutions: Planning, permitting monitoring Overlapping competencies among entity and cantonal level, weak coordination municipalities implement local measures	Entity level: Planning, permitting monitoring; municipalities implement local measures; limited coordination
Regulatory authorities (permits, concessions)	Croatian Waters (permits); Ministry of Environmental Protection and Green Transition (concessions)	Water Agencies (AVP Sava, AVP Jadran) – permits for water resources of federal importance; cantonal authorities for permits of local significance; FBIH Government based on FBIH Concession Commissions' proposal in accordance to FBIH Law on concessions and Cantonal Governments based on Cantonal Concession Commissions' proposal	PI "Vode Srpske" for permits (Permits) RS Government based on RS Concession Commission proposal in accordance to RS Law on concessions (Concessions)
Inspection & Compliance monitoring	Structured inspection protocols; proactive and risk-based in theory; enforcement supported by financing mechanisms	Reactive inspections; triggered by complaints; no systematic risk-based planning; understaffed; monitoring mandated but sporadic implementation for GW	Reactive inspections; limited coverage; monitoring focused on drinking water sources, monitoring mandated but weak implementation for GW
Sanctioning tools	Administrative measures, financial penalties, mandatory remediation programs; cost recovery embedded in law	Cost recovery embedded in law, sanctions legally defined but weakly applied; enforcement often delayed	Cost recovery embedded in law, sanctions legally defined but weakly applied; enforcement often delayed
Financial mechanisms for enforcement	Stable financing via Water Management Financing Act; water-related fees support monitoring and compliance	Fee structures exist but insufficient for financing water sector needs; environmental/resource costs not integrated; chronic underfunding	Fee structures exist but insufficient for financing water sector needs; environmental/resource costs not integrated; chronic underfunding

spect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
Technical capacity	Strong at national level; EU-funded modernization; karst-specific expertise available	Adequate at entity level, limited technical capacity at lower administrative levels; outdated equipment;	Adequate at entity level, limited technical capacity at lower administrative levels; outdated equipment;
Human resources	Adequate at central level; structured roles and certification systems; local-level capacity uneven	Acute shortages at entity and cantonal levels; no systematic training	Shortages at entity and municipal levels; training sporadic
Enforcement & Institutional capacity for sanitary protection zones	Centralized enforcement by Croatian Waters**,** Ministry and Inspectorate; monitoring relatively strong mandatory but uneven	Enforcement at all levels weak; monitoring minimal; many municipalities lack formal decisions on SPZ	**Centralized at entity level;** Enforcement weak; monitoring minimal

Table 7 . Summary table 3.3-Cross-sectoral Coordination and Opportunities for Harmonization (HR vs BiH)

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
National-level coordination	Strong at national level; weak horizontal integration with sectors (agriculture, tourism, energy); local enforcement uneven Regular collaboration between Ministry of Environmental Protection, Croatian Waters, and Public Health Institute under Water Act and RBMP. Horizontal coordination with tourism, agriculture, energy mostly project-based, not institutionalized. NGOs involved via campaigns, but no formal policy-making role.	MoFTER responsible for coordination and harmonization of entities activities. Slow and often inefficient coordination. Coordinated planning across entities not implemented, RBMP prepared separately withought cooperation, despite shared basins	
Institutional-level coordination	Croatian Waters, CIPH, and DHMZ exchange data via WFD reporting and national environmental information system. Supported by NIPP and INSPIRE.	Highly fragmented; overlapping competencies among entities, cantons, municipalities Legal mechanisms exist in Water and Environmental	Centralized at entity level; Horizontal integration with agriculture, energy, spatial planning minimal and occurs mainly through donor driven projects

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
		Laws, but coordination irregular. Horizontal integration with agriculture, energy, spatial planning modest. Cooperation mainly donor-driven (DIKTAS-2, GCF/UNDP, World Bank). No permanent inter-sectoral platform. Entity water Law reference cooperative planning for shared basins, but not implemented.	Entity water Laws reference cooperative planning for shared basins, but not implemented.
Data sharing – public authorities	Formal reporting mechanisms exist. Fragmentation across sectors persists. No single national platform integrating all GW/GWDE datasets. Metadata and GIS differences hinder interoperability.	Data exchange across entities limited. Knowledge sharing across entities limited preventing integrated understanding of karst aquifers and groundwater dependent ecosystems Water Agencies provide online datasets (levels, quality, cadastre, GIS maps), partly downloadable. Geological surveys hold analogue archives, digitization limited.	Data exchange across entities limited. Knowledge sharing across entities limited preventing integrated understanding of karst aquifers and groundwater dependent ecosystems PI collect hydrological and quality data, dissemination irregular, raw datasets rarely accessible.
Data sharing – private sector & stakeholders	Private sector and utilities rely on summary reports, not raw datasets. Barriers to accessing detailed or real-time GW data.	Public access limited to some interactive datasets available. Private stakeholders face barriers.	Public access limited to summary reports only. Private stakeholders face barriers.
Unified information system	Absent. No integrated national platform for GW/GWDE, especially karst.	Absent. No unified WIS across entities. Fragmented knowledge-sharing frameworks prevent integrated understanding of karst aquifers and GWDE.	
Opportunities for Harmonization	Strengthen horizontal integration with agriculture, tourism, and energy sectors; formalize inter-sectoral platforms	Propose changes to establish clear division of responsibilities and avoid overlapping between entities and cantons responsibilities Establish formal systematic inter-entity coordination, planning and data sharing mechanism	Improve coordination between PI Vode Srpske and other sectors Establish formal systematic inter-entity coordination, planning and data sharing mechanism

4. Policy and Planning Framework – TBA Una (Croatia and BiH)

4.1 National Water Strategies and River Basin Management Plans

The Croatian Water Management Strategy of 2008 highlights the importance of protecting groundwater, particularly in karst regions where aquifers are highly vulnerable to pollution and essential for drinking water supply. The document follows European directives and the precautionary principle, stressing the need to reduce pollution from point and diffuse sources and to strengthen monitoring systems. Pursuant to the objectives set forth in Strategy delineation and establishment of sanitary protection zones around well fields and springs and appropriate protective measures will need to be undertaken. It highlights the need for tailored technical solutions and stricter measures in karst areas due to rapid groundwater flow and limited natural filtration. The strategy also foresees harmonization of monitoring networks, adoption of new technical standards, implementation of automated data collection and transmission systems. A key component is the integration of water quality indicators into national databases and the establishment of regular reporting mechanisms, such as annual water status reports and six-year river basin management plans Although it recognizes the hydrogeological complexity of karst, it does not explicitly define measures for groundwater-dependent ecosystems, but However, it does propose the adaptation of monitoring programs to protected and sensitive zones, which implicitly includes karst systems.

The Croatian National Development Strategy until 2030 integrates environmental sustainability and resource protection across several strategic goals, yet it does not explicitly address groundwater or groundwater-dependent ecosystems. While it emphasizes ecological transition, climate neutrality, and sustainable resource management, groundwater remains outside the focus, with no concrete measures for its protection.

The Croatian River Basin Management Plan until 2027 provides the most detailed framework for groundwater. Aquifers are delineated according to hydrogeological criteria, and both quantitative and chemical status are assessed. The plan is aligned with the EU Groundwater Directive, prohibits direct discharges into groundwater, and addresses the vulnerability of coastal aquifers to salinization in karst regions. Groundwater-dependent ecosystems are explicitly considered, and monitoring programs are expanded to detect changes in groundwater levels and quality, especially near sensitive habitats. Attention is given to karst, with precise measures and monitoring protocols incorporating statistical trend analyses and background levels of sulphates, chlorides, and electrical conductivity. The plan acknowledges the unique dynamics of the Dinaric karst - rapid flows, short residence times, and episodic turbidity - and introduces an environmental connectivity test to ensure that groundwater abstraction does not negatively affect surface waters or terrestrial ecosystems. It also establishes the Surface Water Test, which evaluates groundwater chemical status in relation to its impact on connected surface waters. Integrated monitoring is achieved through harmonized sampling protocols, shared parameters, and coordinated stations, while common protection goals combine chemical and quantitative criteria for groundwater with ecological and chemical criteria for surface waters, fully aligned with the EU Water Framework Directive.

In conclusion, Croatian documents show varying degrees of inclusion of groundwater. The Water Management Strategy provides a strong framework for karst aquifers and monitoring, the National Development Strategy largely overlooks groundwater, while the River Basin Management Plan offers the most comprehensive and integrated approach, with special emphasis on karst, monitoring, and connectivity tests between groundwater and surface waters.

Water Management Strategy of FBiH (2022–2032) sets high-level objectives such as protecting water quality and ensuring good status of water bodies, ensuring sustainable use of resources, safeguarding drinking water, managing risks from extreme events, and adapting to climate change. It identifies measures to align water management with EU directives. It establishes the intensification of cooperation between the water sector and other sectors as a priority for ensuring the protection and sustainable use of water resources. However, it is noted that situation with groundwater monitoring is complex, since in the Sava River Basin there is not enough stations, and at the existing stations quality monitoring was only initiated in 2020. In the Adriatic Sea Basin, quantitative monitoring has not been established at all karst springs used for water supply. Strategy does not define groundwater-dependent ecosystems (GWDE), nor does it propose ecological criteria for their protection. It recognizes that karst covers a significant part of the territory, particularly within the Adriatic basin, but leaves it insufficiently addressed. For a significant number of water springs in FBIH, including karst springs, protection zone studies have not been prepared in accordance with the current valid Regulation. Implementation of measures for drinking water protection zones are mostly insufficient or absent.

RS Water Management Strategy (2014–2025) also highlights groundwater as strategically important, proposing monitoring improvements, protection of infiltration zones, and creation of a centralized groundwater database. It includes measures to strengthen inspection and control of wastewater discharges into subsurface systems. Yet, like the FBiH strategy, it does not define GWDE or provide specific measures for their protection. References to EU directives are present, but concrete compliance measures for groundwater and karst aquifers are absent. Ecological modelling and site-specific protection of sensitive aquifers, particularly karst systems, are not included. Based on information from "Environmental strategy and Action Plan for RS 2023-2033" (ESAP), groundwater monitoring has been focused on checking the quality of groundwater used for water supply, while systematic monitoring requires significantly greater financial investments than currently available, both in infrastructure and on an annual basis for ongoing activities. For the groundwater body groups (GWBGs), a risk assessment was carried out regarding the non-attainment of environmental protection objectives due to quantitative and qualitative pressures. The existing legislation related to the establishment of sanitary protection zones around drinking water sources has not been fully implemented.

River Basin Management Plans (RBMPs) prepared in both entities provide more detailed elaboration on groundwater. In FBiH, the third cycle of RBMPs for Sava river basin and Adriatic river basin (2027–2032) are under preparation, while in RS the second cycle of RBMPs for Sava river basin and Adriatic river basin are ongoing.

All RBMPs define and delineate groundwater bodies and include monitoring, but implementation varies. In FBiH, the Sava RBMP initiated systematic quantitative groundwater monitoring for certain GWBs in 2019, and qualitative monitoring in 2020, while monitoring in the karst area, which represents the largest part of the Adriatic Sea river basin in the FBIH, is carried out by measuring flow at major springs or at immediately associated downstream watercourses. Both RS RBMPs mention groundwater monitoring, but they do not comprehensively assess chemical and quantitative status. Across all RBMPs, coverage needs expansion, data quality improvement, and integration of ecological considerations, particularly in karst areas.

The BiH RBMPs reflect principles of the EU Water Framework Directive and partially align with the Groundwater Directive. They address pollution from point and diffuse sources, over-abstraction, and pressures on drinking water sources. Karst aquifers are acknowledged as highly vulnerable due to

rapid flow and limited natural filtration. However, GWDE are not explicitly defined, and no targeted measures for karst systems are provided beyond general monitoring and pollution control. Ecological connectivity tests or modelling tools to assess impacts on surface water or terrestrial ecosystems dependent on groundwater are absent.

Entity-specific challenges are noted. In FBiH, urban wastewater, industrial discharges, dumping sites and utilization of water potential – non-compliance with provisions on releasing the environmental flow at small hydropower plants, are identified as major pressures. Cumulative impacts from tourism in coastal karst zones and diffuse agricultural pollution are not comprehensively addressed. In the Sava River Basin exist over 200 springs and in the Adriatic Sea Basin over 70 springs. For a significant number of drinking water springs in the Federation of Bosnia and Herzegovina, protection zone studies have not been prepared, or were prepared under earlier regulations and have not been harmonized with the currently valid Regulation. In RS, the RBMPs highlights nitrate contamination and abstraction stress, sets threshold values and background concentrations for pollutants, and identifies protected zones around drinking water sources.

4.2. Integration of Groundwater into Relevant Sectoral Policies and Planning Instruments

Groundwater management in Croatia is formally anchored in the Water Act and the River Basin Management Plan (RBMP) until 2027, which establish vertical coordination between national, regional, and local levels. These instruments define strategic objectives for monitoring, source protection, and compliance with EU directives. They represent the most developed planning tools for groundwater, ensuring systematic integration into water resource governance.

The Water Management Strategy of Croatia (2008) is formally presented as a framework for coordinating sectoral strategies, including those related to agriculture, environment, tourism, traffic, and energy. It is partially harmonized with these sectors, with alignment most evident in strategic documents such as the Agriculture Strategy of the Republic of Croatia until 2030 and the Spatial Development Strategy of the Republic of Croatia.

Beyond the water sector, integration into other planning instruments remains partial.

The Agriculture Strategy of the Republic of Croatia until 2030 is focused on sustainable water use in agricultural production. It promotes improved access to irrigation and increased efficiency in water use, particularly in karst areas where groundwater is the main source. However, sustainability criteria for groundwater abstraction are not systematically included, leaving risks of over-abstraction and nitrate pollution. The strategy supports environmentally friendly practices and encourages the transition to organic farming, which indirectly contributes to reducing groundwater pollution from agrochemicals. Strategy addresses irrigation and pollution control in line with the EU Nitrates Directive.

Croatian Spatial planning laws recognize water protection zones and sanitary areas, yet groundwater vulnerability is not consistently mapped or embedded into broader land-use decisions. Croatian Spatial Development Strategy promotes integrated land use planning that considers hydrogeological characteristics. It recognizes groundwater as a strategic natural resource and emphasizes its protection within the broader framework of sustainable spatial planning. It highlights that nearly 90% of water used for public supply is abstracted from aquifers, supports the delineation of sanitary protection zones around springs, yet underscoring the importance of safeguarding groundwater reserves, especially in karst regions. However, while groundwater is acknowledged as critical, the

strategy does not provide operational mechanisms for its protection across all sectors, relying instead on alignment with environmental legislation and planning instruments

The Sustainable Tourism Development Strategy of the Republic of Croatia until 2030 emphasizes the importance of preserving natural resources as part of its broader environmental goals. It emphasizes water supply and wastewater infrastructure in coastal areas, reflecting seasonal demands. Tourism strategies recognise negative impacts of tourism on the environment and promotes sustainable spatial planning and infrastructure development to mitigate risks, particularly in ecologically sensitive areas such as karst terrains. It highlights the value of karst landscapes and natural resources but lack operational mechanisms for aquifer protection or water-balance monitoring.

Transport Development Strategy of the Republic of Croatia (2017–2030) emphasizes the need for environmentally responsible planning and implementation of transport infrastructure, particularly in karst. It mandates Environmental Impact Assessments (SEIA) for all major projects, ensuring that groundwater protection is integrated into transport development.

The Energy Development Strategy of the Republic of Croatia until 2030 with an outlook to 2050, together with the Revised National Energy and Climate Plan (NECP), promotes sustainable energy development but only indirectly addresses groundwater protection. It recognizes the strategic role of hydropower and calls for alignment with bilateral agreements for transboundary projects. Energy planning emphasizes hydropower development, but groundwater is considered only indirectly, mainly in relation to dam stability rather than aquifer dynamics.

The health sector provides the most direct planning link to groundwater through regular drinking water quality monitoring conducted by national and county public health institutes. This ensures public safety but does not extend to broader aquifer protection.

Environmental strategies include groundwater within general objectives of resource protection, yet they omit specific indicators for groundwater-dependent ecosystems (GWDE).

The National Development Strategy of the Republic of Croatia until 2030 emphasizes green and digital transitions, climate neutrality, and sustainable resource management, particularly under Strategic Goal 8: "Ecological and energy transition for climate neutrality" and Strategic Goal 9: "Food self-sufficiency and development of the bioeconomy". It acknowledges the importance of integrated planning and cross-sectoral coordination

Overall, Croatia demonstrates strong integration of groundwater within water-sector planning instruments, but cross-sectoral incorporation remains fragmented. Groundwater is acknowledged in agriculture, energy, tourism, spatial planning, and health, yet often without explicit safeguards or measurable targets. Strengthening inter-sectoral coordination, embedding groundwater sustainability criteria into sectoral policies, and expanding public awareness are essential steps to achieve comprehensive integration of groundwater into national planning instruments.

Groundwater planning in Bosnia and Herzegovina is primarily framed through the River Basin Management Plans (RBMPs) prepared in both entities. These plans delineate groundwater bodies and establish monitoring, but implementation varies. Coverage of GW chemical and quantitative status remains weak and ecological considerations -particularly for vulnerable karst areas - are limited. Although RBMPs reflect EU Water Framework Directive principles and partially align with the Groundwater Directive, they do not explicitly define groundwater-dependent ecosystems (GWDE) or include targeted legal instruments for their protection. Karst aquifers are acknowledged as vulnerable,

but measures remain general, focusing on pollution control and source protection without ecological modelling or connectivity tests.

Entities Agricultural Development Strategies (2021–2027) promote irrigation expansion without groundwater-sustainability criteria, risking over-abstraction in semi-arid karst zones such as Popovo Polje. FBIH Agricultural Strategy emphasizes the importance of Green Agenda and related Action Plan for medium-term strategic planning of agricultural development in FBiH, in the context of climate change. Agricultural policies include nutrient and pesticide management, but irrigation subsidies and fertilizer-use policies are not linked to groundwater-quality monitoring, raising risks of over-abstraction and nitrate pollution.

Spatial planning strategies recognize karst landscapes as valuable assets but lack mechanisms for aquifer protection or water balance monitoring. It addresses groundwater mainly through source-protection zones, often unenforced. Groundwater vulnerability is not consistently mapped or embedded into land-use decisions.

Tourism strategies in karst regions (Trebinje, Mostar, Livno) adopt sustainability principles but lack hydrogeological data or water-balance monitoring. Tourism strategies recognize karst landscapes as valuable assets but lack mechanisms for aquifer protection or water-balance monitoring. FBIH tourism strategy highlights that legislation in FBiH includes specific environmental requirements, but coordination among relevant actors is lacking. Achievement of sustainable tourism requires efficient use of water and energy, use of recycled products in accommodation facilities, and introduction of environmentally friendly labels.

Transport-infrastructure policy considers hydrological impacts only through project-level EIAs, not strategy.

Energy strategies recognize groundwater / karstic and groundwater dependent ecosystems (GWDE), yet without measurable targets or budgetary commitments. Energy planning considers groundwater only in context of hydropower licensing and in relation to dam seepage rather than aquifer dynamics.

Public health regulations focus narrowly on drinking water quality at the source, without extending to aquifer protection.

In Environmental strategies groundwater / karstic and groundwater dependent ecosystems (GWDE) are mentioned, but without measurable targets or budgetary commitments. Entities Environmental Protection Strategies and Action Plans – ESAP (RS 2022; FBiH 2023) introduce integrated resource-management principles. Thay aim to reduce pollution and protect natural resources but omit specific groundwater indicators and do not mainstream GWDE.

Overall, sectoral alignment is moderate, constrained by administrative fragmentation and the absence of a unified national framework linking water, agriculture, environment, and spatial planning. Bosnia and Herzegovina acknowledges the importance of groundwater but does not systematically integrate it into sectoral planning instruments. RBMPs provide the most structured framework yet remain limited in scope and ecological depth. Other sectors - agriculture, energy, tourism, spatial planning, and health - address groundwater only indirectly, often through project-based initiatives or donor-driven programs.

In BIH's both entities FBIH and RS, horizontal integration between water policies and agriculture, energy, and spatial planning remains limited. Groundwater protection measures are rarely incorporated into physical plans, irrigation, or land use policies. Strengthening cross-sectoral

coordination, embedding groundwater sustainability criteria into sectoral policies and developing targeted instruments for karst and GWDE are essential steps toward effective integration of groundwater in sectoral planning frameworks.

4.3 Comparative Analysis of Policy Coherence and Implementation

4.3.1 Alignment with EU WFD and GWD

The Water Management Strategy of Croatia aligns closely with WFD and GWD. It adopts the WFD goal of "good status" for all waters, integrating ecological and chemical criteria. It emphasizes sustainable use via integrated river basin management, applies the "polluter pays" principle, and introduces water pricing and cost recovery (Art. 9 WFD). Groundwater protection is ensured through monitoring, delineation of protection zones, and control of hazardous substances (GWD). The strategy supports cross-sectoral coordination, public participation, monitoring, reporting, and adaptive management. It mirrors WFD's long-term planning with dual 15-year investment cycles to 2038, prioritizes aquifer protection, and strengthens institutional capacity for groundwater monitoring. Integration into spatial planning, environment, agriculture, energy, and tourism reflects WFD's call for embedding water policy in broader frameworks.

National methodology in RBMP 2027 defines background concentrations and threshold values tailored to karst hydrogeology, using BRIDGE project and CIS Guidance No. 18. Classification tests include saline intrusion, surface water interaction, and terrestrial ecosystem impacts, as outlined in CIS Guidance. Precautionary principle is explicitly applied in threshold setting, especially for drinking water zones and sensitive ecosystems. Monitoring in karst includes specific parameters (nitrates, chlorides, ammonium, EC, phosphates) as indicators of anthropogenic impact.

The framework for drinking water abstraction in Croatian shows ambiguity. The Water Act and RBMP recognize sanitary protection zones, but not full designation of groundwater bodies as required by WFD. Protection relies on sanitary zones, leaving the relationship with groundwater bodies undefined. Chemical status assessment includes the DWPA test, checking thresholds and pollutant trends. Strategic groundwater reserves are designated under WMS as protected areas but not fully integrated into the WFD concept. Overall, Croatia emphasizes sanitary zones but falls short of fully aligning with WFD's requirement to designate entire groundwater bodies for drinking water abstraction.

Transposition of the WFD in BiH is uneven: FBiH has achieved about 95%, RS about 75%. Both entity Water Laws include WFD principles such as integrated basin management, groundwater status assessment, pollution prevention, and ecological flow. The GWD transposition is weak, below 30%, with no dedicated regulation; only partial implementation of chemical status, pollution prevention, trend reversal, and threshold values.

In FBiH, the Water Law reflects WFD objectives. The Rulebook on Monitoring of Surface and Groundwater defines parameters and frequency for chemical and quantitative monitoring. The Rulebook on Classification of Water Bodies sets criteria for status assessment and threshold values, partly aligned with GWD. In RS, the Water Law also incorporates WFD principles. The Rulebook on Monitoring of Water Quality establishes sampling and reporting procedures, while the Rulebook on Classification of Water Bodies defines groundwater status categories and threshold values, again partial GWD alignment.

GWDEs are not defined in water laws. In FBiH, the Environmental Protection Law requires EIAs to consider wetlands and springs. In RS, sensitive ecosystems are addressed in permitting, but GWDEs are not explicitly integrated. The FBiH Water Strategy (2022–2032) aligns with the WFD through water

quality protection, basin planning, pollution control, and monitoring, but lacks ecological criteria for groundwater and omits GWDEs. Economic instruments are mentioned but not applied. The RS Water Strategy (2014–2025) supports WFD goals of pollution reduction and monitoring, but lacks methodological definition of ecological status, classification of water bodies, and GWDE protection. Basin planning and economic tools are underdeveloped. The RS Environmental Protection Strategy (2022–2032) conceptually reflects WFD principles but lacks implementation instruments.

Groundwater quality standards and thresholds are only partly developed. A national methodology exists, incorporating karst characteristics, but full GWD requirements are not met. Standards cover chemical status and EU pollutant limits, with some national provisions, but monitoring and published criteria remain incomplete.

Drinking water abstraction areas are defined through sanitary protection zones in both entities, not through designation of entire groundwater bodies as required by WFD. FBiH defines zones in three or four levels based on vulnerability; RS applies zones around abstraction points with hydrogeological assessments. Neither entity links zones to groundwater body boundaries nor assesses chemical status across whole bodies. Strategic reserves are not formally defined. Reliance on sanitary zones creates a gap with WFD's framework for protected areas.

4.3.2 Transboundary Planning in the Context of Natura 2000 and Nature Protection for TBA Una

In addition to RBMPs that define water resource management, relevant transboundary planning instruments include also those regulating nature protection.

Croatian Natura 2000 network was established by the Regulation on Ecological Network (2013). It preserves or restores favourable conditions for more than 1,000 endangered species and about 230 habitat types. Croatia's network covers 36.67% of land and 16.39% of the sea.

For Bosnia and Herzegovina, an analysis of the distribution of habitat types and species listed in these directives was carried out in BIH, through the IPA project "Support to the Implementation of the Birds and Habitats Directives in BiH (2012–2015)". A total of 70 different habitat types and 208 species were recorded, including 109 bird species. A database in standard formats was also created (UNECE 2018). A draft plan for the Natura 2000 ecological network in BiH was prepared. In total, 122 areas were proposed, covering 956,776 ha, about 20% of the state territory (Milanović and Golob, 2015). The project represents one step toward establishing the ecological network of FBiH which requires further multiple activities.

Alongside harmonization of sectoral regulations with EU law, identification of other ecologically significant areas (water protection zones, hunting and fishing areas, etc.) is also necessary, and their inclusion in the ecological network of the FBIH. To align with EU nature protection standards, it is necessary to include protected areas and other ecologically significant sites in a common ecological network, as prescribed by the Law on Nature Protection of the FBIH.

The results of the IPA project were integrated into the Spatial Plan of RS. Article 25 of the RS Nature Protection Law requires a regulation to establish the ecological network, define management and financing, and identify EU ecological areas for Natura 2000. Ecological network of RS is not yet established. Article 100 of the Law states international ecological areas will be defined upon BiH's accession to the EU.

For Croatia and BIH, international collaboration in the water sector constitutes the foundation of transboundary planning. Republic of Croatia and BIH are a contracting party to many international conventions and protocols.

4.4. Summary Tables: Policy and Planning Comparison – HR vs BiH

Table 8 Summary Table 4.1 -National Water Strategies and River Basin Management Plans

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
Water Management Strategy	2008. Strong focus on groundwater protection, especially karst. Precautionary principle. Sanitary zones required. Harmonization of monitoring networks, automated data collection. No explicit GWDE measures.	**(2022–2032):** General objectives aligned with EU directives. Groundwater monitoring weak (Sava basin started 2019/2020; Adriatic basin lacks quantitative monitoring). Karst insufficiently addressed. Protection zones mostly absent or outdated. No GWDE defined.	Groundwater proposes monitoring improvements and database. No GWDE defined. Weak compliance with EU directives. Sanitary zones not fully implemented.
River Basin Management Plans (RBMPs)			
General characteristic	Most detailed planning framework. Aquifers delineated by hydrogeology. Quantitative and chemical status assessed. Aligned with WFD/GWD. Explicit GWDE consideration. Special measures for karst (trend analyses, background levels, connectivity tests). Integrated monitoring and reporting.	Most detailed planning framework Third cycle RBMPs (2027–2032) under preparation. Partially aligned with WFD. GW bodies monitoring started 2019–2020 only in FBIH Sava river basin .. GWDE not considered.	S Most detailed planning framework Second cycle RBMPs ongoing. Partially aligned with WFD. Monitoring mentioned but not comprehensive. GWDE not defined, karst measures general only., GW bodies monitoring not present.
Karst Aquifers in RBMP	Recognized as highly vulnerable. Tailored technical solutions, stricter measures. Connectivity tests between groundwater and surface waters.	Elaborated and Recognized as significant but insufficiently addressed. Monitoring gaps, lack of ecological modelling.. No connectivity tests. Karst monitoring limited to spring flows- only in FBIH Sava River basin started systematic GW monitoring.	
Sanitary Protection Zones in RBMP	Framework established. Required around well fields and springs. Not included the whole water body.	Elaborated - many springs lack updated protection zone studies. Not encompass the whole water body	Required around well fields and springs. Not encompass the whole water body Many springs lack updated protection zone studies.
Monitoring & Data	Harmonized networks, automated systems, national databases, annual reports.	Started systematic GW bodies monitoring in 2019 and 2020 in the Sava RB. In Adriatic RB monitoring limited to supply sources. No annual reports.	Monitoring limited to supply sources. Infrastructure and funding insufficient. No database.. No annual reports
Groundwater-Dependent Ecosystems (GWDE)	Not explicitly defined in the strategies but implicitly included in	Not defined in RBMPs. No ecological criteria or targeted measures.	

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
	monitoring programs. Explicitly considered in RBMP.		

Table 9 Summary Table 4.2 Groundwater integration in Relevant Sectoral Policies and Planning Instruments

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
Water Management Strategy and RBMP	Framework for coordinating agriculture, environment, tourism, traffic, energy. Strong focus on groundwater, karst protection, sanitary zones, monitoring. Clear objectives for monitoring, source protection, EU compliance. Karst aquifers addressed with specific measures. GWDE considered.	General objectives aligned with EU directives. Groundwater monitoring weak, karst insufficiently addressed, protection zones mostly not designed or implemented. Based on water Laws, RBMPs in both entities delineate GW bodies, but monitoring weak. Karst acknowledged but measures general. GWDE not defined. Implementation of RBM fragmented between entities.	
Agriculture Strategy	Strategy promotes sustainable water use irrigation efficiency, pollution control (Nitrates Directive). Sustainability criteria for abstraction not systematic. Organic farming indirectly reduces pollution. Recognizes groundwater as main source in karst.	Strategies promote irrigation expansion without GW safeguards. Fertilizer/pesticide use not linked to GW monitoring. Risk of over-abstraction and nitrate pollution. Promote irrigation expansion without groundwater sustainability criteria. Risk of over-abstraction in karst (e.g., Popovo Polje). FBiH emphasizes Green Agenda but lacks groundwater safeguards.	
Spatial Development Strategy	Recognizes groundwater as strategic resource. Nearly 90% of public supply from aquifers. Recognizes sanitary zones and aquifers. Promotes integrated land use planning. Vulnerability mapping incomplete; no operational mechanisms.	Spatial planning strategies recognize karst landscapes but lack aquifer protection mechanisms. Vulnerability not mapped. Water source zones often unenforced. Source zones, often not included	
Tourism Strategy	Preserves natural resources. Focus on water supply and wastewater infrastructure in coastal areas. Seasonal demand considered. Strategy until 2030 highlights karst landscapes. Promotes sustainable planning and infrastructure. No operational aquifer protection or water-balance monitoring.	Tourism strategies highlight karst as asset. Sustainable tourism goals mention efficient water use but no aquifer protection Tourism strategies in karst regions adopt sustainability principles. Lack hydrogeological data and water-balance monitoring. GW protection absent. FBiH includes environmental requirements but lacks coordination	
Energy Strategy	Recognizes hydropower. Calls for alignment with bilateral agreements on transboundary projects. Hydropower emphasized. GW considered indirectly (dam stability). NECP promotes sustainability but no direct GW protection.	Energy strategies mention groundwater and GWDE but without measurable targets or budgets. GW only in hydropower licensing, focused on seepage. No aquifer dynamics considered. No measurable targets for GW protection.	
National Development Strategy	Integrates sustainability, climate neutrality, resource management. Emphasizes	No equivalent national strategy	

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
	cross-sectoral coordination. Groundwater not explicitly addressed.		
Transport Strategy	Emphasizes environmentally responsible planning, especially in karst areas SEIA mandated for major projects. GW protection integrated into project assessments.	Transport policies consider hydrological impacts only through project-level EIAs, not strategic planning. Transport policies consider hydrological impacts only through project-level EIAs, not strategic planning. Hydrological impacts considered only via project-level EIAs. No strategic GW integration.	
Health	Direct link: drinking water quality monitoring by public health institutes. Ensures safety but not aquifer protection.	Focus on drinking water quality at source. No broader aquifer protection.	
Environmental Protection Strategies (ESAP)	Integrated resource management principles. Groundwater indirectly included via WFD/GWD alignment. Include GW in general resource protection. No specific GWDE indicators. ESAPs mention integrated resource management. GW indicators absent. GWDE not mainstreamed.	Introduce integrated resource management but lack of groundwater indicators. GWDE mentioned but no measurable targets **Entities' ESAPs (Environmental Strategies and Action Plans) mention integrated resource management. GW indicators absent. GWDE not mainstreamed.** .	

Table 10 Summary Table 4.3.1 Alignment with EU WFD and GWD

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
Transposition of WFD	Fully transposed into national law. Annex II & V implemented. Strong compliance.	FBiH ~95% transposed,	~75%. principles included but gaps remain.
Transposition of GWD	Fully transposed. Annex I implemented. Standards operationalized.	Weak (<30%). No dedicated regulation. Partial implementation only.	
Water Act / Legal Basis	Provides full legal basis for GW standards, pollutant thresholds, monitoring.	Sanitary zones recognized. GW bodies not fully designated as required by WFD. Strategic reserves defined but not fully integrated.	Entity Water Laws include WFD principles. Rulebook not aligned with GWD
Groundwater Quality Standards	Regulation defines chemical status, risks, thresholds. National methodology tailored to karst. Precautionary principle applied.	Methodology exists but incomplete. Standards partly developed. Monitoring and published criteria insufficient.	

Aspect	Croatia (HR)	Bosna I Hercegovina (BIH)	
		Federation of BiH (FBiH)	Republika Srpska (RS)and
Monitoring & Classification	Systematic monitoring. RBMP defines background concentrations, saline intrusion, connectivity tests. Karst-specific parameters included.	FBiH started systematic monitoring only in 2019–2020.	Monitoring limited. No ecological connectivity tests.
Groundwater-Dependent Ecosystems (GWDE)	Considered in RBMP. Not explicitly defined in strategy but implicitly included.	Not defined in water laws or strategies. Environmental laws mention wetlands/springs but no systematic integration.	
River Basin Management Plans (RBMPs)	Fully aligned with WFD/GWD. Integrated monitoring, ecological and chemical criteria. Special focus on karst.	Reflect WFD principles, partial GWD alignment. GW bodies delineated but monitoring starts in 2019 only in FBIH Sava Reiver Basin . Karst measures general only.	
Drinking Water Abstraction	Sanitary zones recognized. GW bodies not fully designated as required by WFD. Strategic reserves defined but not fully integrated.	Sanitary zones recognized but not implemented in many localities. GW bodies not fully designated as required by WFD. Strategic reserves not defined. No linkage to chemical status.	
Economic Instruments	"Polluter pays" principle, water pricing, cost recovery applied.	Mentioned in strategies but not operationalized.	
Cross-Sectoral Integration	Water policy embedded in spatial planning, agriculture, tourism, energy. Public participation and adaptive management included.	Weak. Horizontal integration modest. GW rarely incorporated into agriculture, energy, or spatial planning. Coordination in and between entities missing.	

Table 11 Summary Table 4.3.2-Transboundary Planning Instruments for TBA Una

Transboundary Instrument	Croatia (HR)	Bosnia and Herzegovina (BiH)
Natura 2000 / Ecological Network	Established by Regulation on Ecological Network (2013). Covers 36.67% of land and 16.39% of sea. Protects >1,000 species and ~230 habitat types. Fully operational.	IPA project (2012–2015) identified 70 habitat types and 208 species (109 birds). Draft plan prepared: 122 areas, 956,776 ha (~20% territory). FBiH requires further activities; RS ecological network not yet established. Full implementation pending EU accession.
International Conventions (Water Sector)	Party to: Water (Helsinki) Convention (1992), Protocol on Water and Health, Danube Convention (1994, ratified 1996), Framework Agreement on Sava River Basin (2002, ratified 2003), Barcelona Convention (1976, revised 1995), Athens Protocol (1980, revised 1995), Convention on Transboundary Effects of Industrial Accidents (1992). Active in Adriatic Ionian Initiative (2000). Member of Joint Commission for Adriatic Waters (1977). Operational roles: Ministry of Environmental Protection, Croatian Waters, DHMZ, Sava Commission.	Contracting party to same frameworks: Helsinki Convention, Danube Convention, Framework Agreement on Sava River Basin, Barcelona Convention and protocols. Member of Adriatic Ionian Initiative and ISRBC (2006). Implementation responsibility divided between state (MoFTER) and entity institutions. Coordination weak due to limited institutional capacity and entity fragmentation.

5. Socio-economic Indicators and Pressures – TBA Una

5.1 Demographic Characteristics and Settlement Structure of the TBA Una

Demographic patterns within the Transboundary Aquifer (TBA) Una play a key role in shaping groundwater pressures, infrastructure demands, and governance challenges. Population size,

settlement structure and demographic trends determine both the scale and nature of water use, sanitation practices, and the capacity of local communities and institutions to manage groundwater-related risks. The TBA Una is characterized by strong contrasts between the Croatian and Bosnia and Herzegovina (BiH) sides, reflecting different settlement patterns, demographic trajectories and socio-institutional contexts.

At this stage, demographic estimates are based on official census data and expert judgement. Figures represent indicative orders of magnitude rather than GIS-verified population counts.

5.1.1 Croatia

The Croatian part of the TBA Una is characterized by very low population density and a dispersed rural settlement pattern typical of the Lika karst region. Settlements are small, spatially fragmented and largely rural, with no major urban centers located within the aquifer area. The permanent population within the Croatian part of the TBA is estimated at approximately 9,500 inhabitants.

Population density is typically below 10 inhabitants per km², reflecting long-term processes of depopulation and rural decline. Census data indicate a population decrease of nearly 20% between 2011 and 2021, accompanied by a pronounced ageing trend. The ageing index exceeds national averages, indicating a high proportion of elderly residents and a shrinking working-age population.

Economically, local livelihoods combine subsistence or semi-subsistence agriculture with seasonal tourism-related activities. Agricultural production is generally small scale and low intensity, while tourism is concentrated around protected areas, particularly the Plitvice Lakes National Park, one of the most visited national parks in Croatia, attracting over 1.4 million visitors annually. Although Plitvice Lakes lies partially outside the surface-water catchment of the Una, its hydrogeological connection to the wider karst system creates indirect but significant seasonal pressures on groundwater resources.

Water supply and sanitation in Croatian TBA settlements rely predominantly on household-level solutions, including private wells, small communal systems and septic tanks. Limited institutional capacity at local level constrains systematic monitoring, enforcement and maintenance. As a result, groundwater pressures are generally low in continuous terms but structurally vulnerable due to diffuse pollution risks and limited adaptive capacity.

5.1.2 Bosnia and Herzegovina

On the BiH side, the TBA Una includes both rural settlements and suburban areas associated with the City of Bihać. Settlement density is higher than on the Croatian side, and demographic structures are more diverse. The permanent population residing within the BiH part of the TBA is estimated at approximately 10,000 inhabitants.

Unlike Croatia, the BiH part of the TBA includes functionally urbanized zones where groundwater abstraction and sanitation pressures are more continuous. The presence of the City of Bihać in close proximity to the aquifer recharge and discharge zones introduces a larger number of stakeholders, including public utilities, municipal authorities, tourism operators and protected area management bodies.

Una National Park represents a key spatial and socio-economic feature. Tourism-related activities associated with the park generate strong seasonal population fluctuations and several hundred thousand visitors annually in peak years, particularly during summer months, increasing water demand and wastewater generation in groundwater-vulnerable karst terrain. While rural settlements

rely largely on decentralized sanitation systems, suburban areas are more closely linked to centralized water-supply and wastewater infrastructure, creating concentrated pressure points within the TBA.

Overall, demographic pressures on the BiH side are more continuous and institutionally complex than in Croatia, reflecting higher population density, stronger dependence on groundwater for public supply and more intensive tourism development.

5.1.3 Transboundary Synthesis

From a cross-border perspective, the Una TBA shows a clear population imbalance. The Croatian side is characterized by a very low permanent population (approximately 9,500 inhabitants), highly dispersed settlements and limited local institutional capacity. Groundwater pressures are generally low in absolute terms but structurally sensitive due to ageing populations, decentralized sanitation and weak monitoring.

In contrast, the BiH side hosts a slightly larger permanent population (around 10,000 inhabitants within the TBA) and is functionally linked to the wider urban system of Bihać. This results in higher continuous pressure on groundwater resources, stronger institutional involvement and a higher level of dependency on a small number of karst springs for drinking-water supply.

Seasonal dynamics further amplify transboundary interdependence. Tourism related population peaks affect both sides of the border, with upstream land-use and sanitation practices in Croatia influencing downstream groundwater quality and water security in BiH. While pressures originate from different demographic and institutional contexts, their impacts are shared across the aquifer system.

These demographic characteristics provide the foundation for understanding sectoral groundwater use, pressure hotspots and vulnerability patterns addressed in subsequent sections of this chapter.

5.2 Groundwater Use by Sector (Drinking Water, Agriculture, Industry, Tourism)

Groundwater use within the TBA Una reflects the needs of distinct user groups whose activities generate both continuous and seasonal pressures on the aquifers. Sectoral water demand patterns differ markedly between Croatia and Bosnia and Herzegovina (BiH), driven by contrasting settlement structures, levels of institutional organization and economic activities. Across both countries, groundwater represents the dominant source of drinking water, while other uses are generally limited in scale but locally significant due to the high vulnerability of karst systems.

5.2.1 Drinking Water Supply

Croatia

In the Croatian part of the TBA Una, drinking-water supply is predominantly decentralized. Households rely on private wells, small communal systems and locally managed spring abstractions. Oversight, monitoring and maintenance are limited, reflecting the small size and limited capacity of local authorities and utilities. As a result, abstraction volumes are generally low, but risks related to water quality are elevated due to diffuse sanitation pressures and the absence of systematic control.

The lack of centralized infrastructure reduces continuous quantitative pressure on the aquifer but increases vulnerability to contamination events, particularly during periods of increased seasonal use associated with tourism.

Bosnia and Herzegovina

In BiH, groundwater use for drinking-water supply is more centralized and institutionally structured. The dominant user is the public water utility of the City of Bihać (JP "Vodovod" d.o.o. Bihać), which abstracts groundwater primarily from the Klokot and Kostela karst springs, supported by additional sources within the wider TBA area.

Although the permanent population residing within the BiH part of the TBA Una is approximately 10,000, groundwater abstracted from these karst springs supplies drinking water to the entire urban water-supply system of the City of Bihać, serving approximately 24,000 registered users (households and legal entities). This creates a pronounced asymmetry between resident population within the aquifer area and the scale of service-area demand dependent on the same groundwater system.

This dependence significantly elevates the strategic importance of groundwater protection in the BiH part of the TBA, as any deterioration in water quality or quantity would directly affect a much larger population beyond the immediate aquifer boundaries.

5.2.2 Agriculture

Across the TBA Una, agricultural water use is generally low in quantitative terms. Farming is predominantly small-scale, with limited irrigation and modest abstraction volumes. Livestock rearing is present on both sides of the border, particularly in rural settlements.

The primary concern related to agriculture is not water abstraction but diffuse pollution, including manure storage, livestock access to karst features and inadequate separation between agricultural activities and vulnerable recharge zones. These pressures are spatially dispersed and difficult to regulate, particularly in areas dominated by household-level land management.

While agricultural demand does not constitute a major quantitative stress on groundwater resources, its qualitative impacts are relevant due to the sensitivity of karst aquifers and the limited monitoring of diffuse sources.

5.2.3 Industry

Industrial groundwater use within the TBA Una is limited. On the Croatian side, there are no significant industrial abstractions within the aquifer area. In BiH, industrial activities consist mainly of small manufacturing and service enterprises whose groundwater use is minor compared to drinking-water supply.

Despite low abstraction volumes, industrial and service-sector wastewater management practices may still pose localized risks where pre-treatment and discharge controls are inadequate. Overall, however, industry does not represent a dominant driver of groundwater pressure in the TBA Una.

5.2.4 Tourism

Tourism represents the most dynamic and seasonally variable source of groundwater pressure across the TBA Una. On both sides of the border, tourism activities are closely linked to protected natural areas and river-based recreation, operating predominantly in highly vulnerable karst environments.

In Croatia, tourism pressure is strongly influenced by the Plitvice Lakes National Park and associated accommodation facilities in adjacent areas. Seasonal peaks lead to short-term increases in water demand and wastewater generation, often managed through decentralized sanitation systems.

In BiH, tourism pressure is concentrated within Una National Park and associated destinations such as Martin Brod and Kulen Vakuf. Stakeholders include park management, rafting operators,

accommodation providers and food-service establishments. Seasonal influxes of visitors significantly increase demand on water-supply and sanitation systems, amplifying contamination risks in sensitive recharge and discharge zones.

Tourism-related groundwater pressures are therefore seasonal but synchronized across the border, reinforcing the need for coordinated management approaches and harmonized environmental standards.

5.2.5 Transboundary Synthesis

Sectoral groundwater use in the TBA Una is characterized by a combination of low baseline abstraction and high vulnerability to qualitative pressures. Croatia exhibits low continuous demand but relies heavily on decentralized systems with limited oversight. BiH combines higher continuous abstraction for public supply with strong dependence on a small number of karst springs serving a large urban population.

Across both countries, tourism introduces pronounced seasonal peaks in water demand and wastewater generation, often exceeding the management capacity of local sanitation systems. Although absolute abstraction volumes remain modest, the interaction between sectoral use patterns and karst hydrogeology creates elevated risks of contamination and supply disruption.

These sectoral dynamics underpin the identification of pressure hotspots and vulnerability patterns discussed in subsequent sections.

5.3 Environmental Pressures Affecting Groundwater in the TBA Una

Groundwater pressures within the TBA Una arise primarily from human activities interacting with a highly vulnerable karst environment. Due to the intrinsic characteristics of karst aquifers, rapid infiltration, limited natural attenuation and strong hydraulic connectivity, even relatively low-intensity activities can generate disproportionate impacts on groundwater quality and security. Environmental pressures in the TBA Una are therefore driven less by absolute abstraction volumes and more by land use, sanitation practices and seasonal concentration of activities.

5.3.1 Domestic Sanitation and Wastewater

In both Croatia and Bosnia and Herzegovina, domestic sanitation represents the most widespread and structurally significant source of groundwater pressure. Large parts of the TBA rely on decentralized wastewater systems, primarily septic tanks, often lacking adequate design, maintenance or monitoring.

On the Croatian side, small and dispersed rural settlements depend almost exclusively on household-level sanitation. Limited institutional capacity and ageing populations constrain regular inspection and upgrading of systems, increasing the risk of leakage and diffuse contamination. Although population density is low, the cumulative impact of poorly managed septic systems poses a persistent qualitative pressure on groundwater.

In BiH, decentralized sanitation is also common in rural and suburban areas within the TBA. In settlements adjacent to Bihać and within the Una National Park, increased population density and seasonal tourism intensify wastewater generation. Where centralized wastewater infrastructure is absent or incomplete, untreated or partially treated effluents may infiltrate directly into vulnerable karst zones.

Overall, domestic sanitation constitutes a high-risk, diffuse pressure across the TBA Una, affecting both recharge and discharge areas.

5.3.2 Solid Waste and Illegal Dumping

Solid waste mismanagement represents an additional pressure on groundwater, particularly in rural and remote areas. Illegal dumping sites have been identified in proximity to karst features such as dolines, sinkholes and losing streams, where contaminants can rapidly enter the groundwater system.

Waste collection services are uneven, especially in sparsely populated Croatian areas and in rural parts of the BiH TBA. Seasonal increases in waste generation associated with tourism further strain existing services. Although individual dumping sites may be small, their location in highly sensitive karst environments amplifies potential impacts on groundwater quality.

5.3.3 Agriculture and Livestock Activities

Agricultural pressures within the TBA Una are generally low in terms of water abstraction but relevant with respect to diffuse pollution. Small scale livestock farming is present on both sides of the border, with manure storage and animal access to karst features constituting the primary risk pathways.

The absence of buffer zones, inadequate manure management practices and limited awareness of karst vulnerability increase the likelihood of nutrient and microbiological contamination. These pressures are spatially dispersed and difficult to regulate, particularly in areas dominated by household-level land management.

5.3.4 Tourism-Related Pressures

Tourism introduces the most pronounced seasonal pressures on groundwater within the TBA Una. Activities are concentrated in protected areas and river corridors, where environmental sensitivity is highest.

In Croatia, tourism pressure is strongly influenced by visitor flows linked to the Plitvice Lakes National Park and surrounding accommodation zones. Seasonal peaks lead to temporary surges in water use and wastewater production, often managed through decentralized systems with limited treatment capacity.

In BiH, tourism pressure is concentrated within Una National Park and associated destinations. Rafting operations, accommodation facilities, food services and recreational infrastructure generate synchronized seasonal loads on water supply and sanitation systems. The proximity of these activities to karst springs and recharge zones heightens contamination risks during peak periods.

5.3.5 Infrastructure Limitations and Monitoring Gaps

Across the TBA Una, limited wastewater infrastructure and insufficient monitoring capacity exacerbate environmental pressures. Decentralized systems dominate, while inspection, enforcement and data collection are constrained by institutional fragmentation, limited budgets and dispersed settlements.

Monitoring of groundwater quality and sanitation performance is uneven and not harmonized across the border. As a result, early detection of contamination events is challenging, and response mechanisms are often reactive rather than preventive.

5.3.6 Transboundary Synthesis

Environmental pressures in the TBA Una are asymmetric in origin but transboundary in impact. On the Croatian side, pressures stem primarily from decentralized household sanitation, ageing infrastructure and seasonal tourism, combined with limited local capacity for oversight. In BiH, pressures are driven by higher continuous demand, stronger dependence on groundwater for public supply and concentrated tourism activities within sensitive karst zones.

Despite differing socio-economic contexts, the shared karst aquifer system transmits pressures across the border. Diffuse upstream pressures in Croatia can affect downstream water quality and supply security in BiH, while seasonal tourism peaks generate synchronized risks on both sides.

These environmental pressures form the basis for identifying groundwater hotspots and assessing vulnerability and risk in the following sections.

5.4 Hotspots and Areas of Elevated Groundwater Pressure

Within the TBA Una, groundwater pressures are not evenly distributed but tend to concentrate in specific areas where human activities, infrastructure limitations and karst vulnerability intersect. The hotspots are identified functionally, based on combinations of land use, population dynamics, sanitation practices and hydrogeological sensitivity.

These hotspot areas represent zones where relatively modest pressures can generate disproportionate risks for groundwater quality and supply security.

5.4.1 Suburban Zones and Public Water Supply Catchments (BiH)

Suburban areas surrounding the City of Bihać constitute a primary hotspot of groundwater pressure. These zones combine relatively higher population density, incomplete wastewater infrastructure and proximity to locally sensitive karst pathways that may connect to major springs.

Decentralized sanitation systems in suburban settlements, together with expanding residential development, increase the likelihood of untreated wastewater infiltration into recharge zones. Given that these springs supply drinking water to the wider Bihać urban system, pressures originating in relatively small areas within the TBA have amplified downstream consequences.

This hotspot is characterized by high strategic importance and high vulnerability, despite moderate resident population levels within the aquifer area itself.

5.4.2 Tourism Nodes in Protected Areas

Tourism related hotspots are concentrated within and around protected areas, notably Una National Park in BiH and tourism corridors associated with the Plitvice Lakes National Park on the Croatian side.

These areas experience pronounced seasonal population surges, resulting in temporary but intense increases in water demand, wastewater generation and solid waste production. Tourism infrastructure often relies on decentralized sanitation systems, while activities are near karst features, springs and river corridors.

Although tourism pressure is seasonal, its synchronization across the border and concentration in environmentally sensitive zones elevate the risk of contamination events during peak periods.

5.4.3 Rural Settlements with Decentralized Sanitation (Croatia and BiH)

Dispersed rural settlements across both sides of the TBA represent a widespread but less visible category of hotspot. These areas are characterized by:

- reliance on septic tanks and household-level wastewater management,
- limited inspection and maintenance,
- ageing populations and declining local capacity.

While individual settlements generate low absolute pressures, their cumulative impact across the karst landscape constitutes a persistent diffuse risk. In Croatia, this hotspot type is amplified by very low institutional capacity at municipal level, while in BiH it overlaps with areas of agricultural activity and seasonal tourism spillover.

5.4.4 Agriculture–Karst Interaction Zones

Hotspots also emerge where small-scale agricultural and livestock activities intersect with highly vulnerable karst features. Manure storage, livestock access to sinkholes and inadequate separation between agricultural activities and recharge zones create localized contamination pathways.

These hotspots are difficult to delineate precisely without spatial analysis but are functionally identifiable through land-use patterns and observed practices. Their significance lies in the persistence of diffuse pollution rather than in episodic events.

5.4.5 Waste Disposal and Informal Dumping Sites

Areas affected by illegal dumping and inadequate waste management constitute additional localized hotspots. Dumping sites located near dolines, losing streams and riverbanks pose a direct risk of contaminant transport into the groundwater system.

Seasonal increases in waste generation associated with tourism intensify this pressure, particularly where waste-collection services are insufficient or inconsistent.

5.4.6 Transboundary Interpretation of Hotspots

Hotspots within the TBA Una are asymmetric in form but interconnected in impact. Croatian hotspots are dominated by diffuse, decentralized pressures linked to rural sanitation and seasonal tourism, combined with limited local oversight. BiH hotspots are more closely associated with public water-supply catchments, suburban development and concentrated tourism activities.

Despite these differences, the shared karst aquifer system transmits risks across the border. Pressures originating upstream or in recharge areas can affect downstream water quality and supply security, underscoring the transboundary nature of hotspot dynamics.

Identification of these hotspot categories provides the basis for assessing water-demand stress, vulnerability and risk in the following sections.

5.5 Water Demand and Infrastructure Stress

Water demand within the TBA Una is shaped by a combination of demographic patterns, sectoral water use and infrastructure capacity. Although the permanent population residing within the aquifer area is relatively small, groundwater demand and associated infrastructure stress are amplified by

functional dependencies that extend beyond the immediate TBA boundaries, particularly in the BiH part of the aquifer.

Infrastructure-related pressures are therefore not solely a function of resident population size but of the scale, organization and vulnerability of water-supply and sanitation systems connected to the aquifer.

5.5.1 Drinking-Water Demand and Supply Systems

In Croatia, drinking-water demand within the TBA Una remains low in absolute terms due to sparse population and limited economic activity. Water-supply systems are predominantly small-scale and decentralized, serving individual settlements or groups of households. Infrastructure capacity is generally modest, and system resilience is constrained by limited maintenance resources and institutional oversight.

In Bosnia and Herzegovina, groundwater demand is more structurally significant. Although the permanent population within the BiH part of the TBA Una is approximately 10,000, the karst springs Klokot, Kostela and associated sources supply drinking water to the entire urban water-supply system of the City of Bihać, serving approximately 24,000 registered users. This creates a substantial disparity between resident population within the aquifer and the scale of demand placed on groundwater resources.

As a result, water-supply reliability in BiH is highly sensitive to changes in groundwater quality and quantity within the TBA, elevating infrastructure stress despite moderate abstraction volumes relative to aquifer capacity.

5.5.2 Sanitation Infrastructure and Wastewater Management

Sanitation infrastructure represents a critical stress factor across the TBA Una. In both countries, decentralized wastewater systems dominate large parts of the aquifer area, particularly in rural and suburban settlements.

In Croatia, reliance on septic tanks and small communal systems is nearly universal within the TBA. Inspection, maintenance and upgrading of these systems are limited by small municipal capacities and ageing populations. Infrastructure stress manifests not as system overload but as chronic vulnerability to diffuse contamination.

In BiH, sanitation infrastructure is more heterogeneous. Suburban zones around Bihać and settlements within Una National Park generate higher wastewater loads, particularly during tourism peaks. Where centralized wastewater treatment is absent or incomplete, infrastructure stress increases the likelihood of untreated discharges entering sensitive karst pathways.

5.5.3 Seasonal Demand Peaks and System Stress

Tourism introduces pronounced seasonal fluctuations in water demand and wastewater generation on both sides of the border. These peaks often exceed the design assumptions of local infrastructure, particularly decentralized sanitation systems.

In Croatia, seasonal tourism linked to the Plitvice Lakes National Park corridor leads to short-term increases in demand that stress household-level and small communal systems. In BiH, tourism concentrated within Una National Park and associated destinations generates synchronized peaks affecting water supply, sanitation and waste-management services.

Seasonal demand peaks amplify existing infrastructure weaknesses and increase the probability of contamination events during periods of highest use.

5.5.4 Infrastructure Capacity, Resilience and Operational Constraints

Across the TBA Una, infrastructure resilience is constrained by limited financial resources, fragmented responsibilities and insufficient monitoring. Preventive maintenance and system upgrades are often deferred, while emergency response mechanisms remain largely reactive.

In BiH, the concentration of water-supply dependence on a small number of karst springs increases systemic risk. Any disruption to groundwater quality at these sources would have immediate consequences for a large service population. In Croatia, while dependence is more dispersed, limited institutional capacity reduces the ability to detect and address infrastructure failures promptly.

5.5.5 Transboundary Synthesis

Infrastructure stress within the TBA Una reflects asymmetric but interconnected demand patterns. Croatia exhibits low continuous demand but structurally fragile, decentralized infrastructure. BiH combines moderate abstraction volumes with high strategic dependence on groundwater for public supply, creating elevated systemic risk.

Seasonal tourism synchronizes demand peaks across the border, further stressing infrastructure systems in highly vulnerable karst environments. These dynamics underscore the importance of coordinated infrastructure planning, information exchange and demand management across the TBA.

The interaction between water demand and infrastructure stress provides a critical input for assessing socio-economic vulnerability and groundwater risk in the following section.

5.6 Socio-economic Vulnerability and Groundwater Risk

Socio-economic vulnerability within the TBA Una reflects the interaction between environmental pressures, infrastructure capacity and the ability of institutions and communities to prevent, absorb and respond to groundwater-related risks. In a karst aquifer system characterized by rapid hydraulic connectivity and limited natural attenuation, vulnerability is shaped less by absolute pressure levels and more by exposure, dependency and response capacity.

Groundwater risk in the TBA Una therefore emerges where high vulnerability coincides with persistent or episodic pressures affecting water quality and supply security.

5.6.1 Key Drivers of Socio-economic Vulnerability

Several interrelated factors contribute to elevated vulnerability across the TBA Una:

- *Dependence on groundwater for drinking-water supply*, particularly in BiH, where a small number of karst springs serve a large urban population.
- *Decentralized sanitation systems*, widespread across both countries, creating diffuse and difficult-to-control contamination pathways.
- *Seasonal tourism pressure*, generating synchronized peaks in water demand and wastewater generation.
- *Limited institutional and operational capacity*, especially at local and municipal levels.

- *Demographic decline and ageing*, particularly in rural settlements, reducing community capacity for maintenance, monitoring and response.

These drivers act cumulatively, increasing the sensitivity of the aquifer system to both chronic and episodic stressors.

5.6.2 Exposure and Sensitivity

Exposure within the TBA Una varies spatially and functionally. Areas overlapping with public water-supply catchments, tourism nodes and suburban settlements exhibit higher exposure due to the concentration of activities and infrastructure.

Sensitivity is uniformly high due to karst hydrogeology. Rapid infiltration, short residence times and limited filtration capacity mean that even small contamination events can propagate quickly through the aquifer system. As a result, the margin for errors in land-use and sanitation practices is low across the entire TBA.

5.6.3 Adaptive and Response Capacity

Adaptive capacity differs between the two countries:

- Croatia benefits from strong national-level technical competence in water management but faces weak local implementation capacity within the TBA due to small, resource-constrained municipalities and dispersed settlements.
- Bosnia and Herzegovina exhibits stronger incentives for groundwater protection due to direct dependency on public water-supply sources, but governance is fragmented across multiple institutional levels, complicating coordination and enforcement.

Across both sides, monitoring coverage and data harmonization remain limited, constraining early warning and preventive action.

5.6.4 Overall Risk Characterization

Groundwater risk in the TBA Una is characterized by moderate to high vulnerability combined with low to moderate pressures, resulting in a high sensitivity system with low tolerance for failure.

The most significant risks relate to:

- contamination of drinking-water sources supplying the City of Bihać,
- cumulative diffuse pollution from decentralized sanitation,
- contamination events during peak tourism periods,
- delayed detection and response due to monitoring gaps.

While catastrophic events are not frequent, the consequences of even localized contamination can be severe due to the scale of dependency and limited redundancy in water-supply systems.

5.6.5 Transboundary Risk Perspective

Risk within the TBA Una is inherently transboundary. Pressures originating in upstream recharge areas, particularly in Croatia, can affect downstream water quality and supply security in BiH. Conversely, local management failures in BiH can exacerbate vulnerability at key springs serving large populations.

Institutional asymmetries further shape risk distribution: Croatia's diffuse pressures intersect with BiH's concentrated dependency, creating a governance challenge where responsibility and impact are spatially separated.

Effective risk reduction therefore depends on coordinated transboundary action, shared monitoring and aligned preventive measures.

5.6.6 Implications for Joint Action Plan Development

The vulnerability and risk profile of the TBA Una highlights the need for:

- prioritization of sanitation improvements in high-risk areas,
- targeted management of tourism-related pressures,
- strengthening monitoring and early-warning systems,
- enhanced institutional coordination and stakeholder engagement across the border.

These implications inform the identification of priority actions and strategic responses in subsequent Joint Action Plan development.

5.7 Synthesis of Socio-economic Pressures, Vulnerability and Risk (Summary)

The socio-economic analysis of the TBA Una demonstrates that groundwater pressures and risks are shaped less by absolute population size or abstraction volumes and more by structural vulnerability, dependency patterns and governance capacity. Although the permanent population within the aquifer area is relatively small on both sides of the border, groundwater plays a strategic role in drinking-water supply, tourism and local livelihoods, particularly in Bosnia and Herzegovina.

Decentralized sanitation systems, seasonal tourism peaks and limited monitoring capacity represent the dominant drivers of groundwater vulnerability across the TBA. These pressures interact with highly sensitive karst hydrogeology, resulting in a system with low tolerance for failure. Institutional asymmetries further amplify risk, as diffuse upstream pressures intersect with concentrated downstream dependency.

Overall, the TBA Una can be characterized as a highly sensitive transboundary aquifer with moderate pressures but elevated socio-economic vulnerability, requiring coordinated preventive action rather than reactive response.

Table 12 Summary of Socio-economic Indicators and Risk Levels in the TBA Una

Indicator Category	Key Indicator	Croatia	Bosnia and Herzegovina	Transboundary Relevance
Demography	Permanent population pressure	Low	Moderate	Seasonal dynamics shared
Settlement structure	Degree of decentralization	High	Moderate	Diffuse pressure pathways
Drinking-water dependence	Reliance on groundwater for public supply	Moderate	High	Downstream dependency

Indicator Category	Key Indicator	Croatia	Bosnia and Herzegovina	Transboundary Relevance
Service-area demand	Population served beyond TBA	Low	High	Asymmetric impact
Sanitation	Reliance on septic systems	High	High	Shared contamination risk
Tourism pressure	Seasonal demand peaks	High (seasonal)	High (seasonal)	Synchronized peaks
Infrastructure resilience	Capacity to absorb demand peaks	Low–Moderate	Moderate	System fragility
Monitoring & control	Coverage and harmonization	Moderate	Low–Moderate	Limited early warning
Institutional capacity (including inclusiveness and stakeholder coordination)	Local implementation strength	Low	Moderate	Governance imbalance
Overall vulnerability	Combined socio-economic vulnerability	Moderate	High	High systemic sensitivity
Groundwater risk	Likelihood of quality/supply disruption	Moderate	High	Transboundary consequences

Note: Qualitative ratings (Low / Moderate / High) are based on the integrated assessment presented in Sections 5.1–5.6 and reflect relative conditions rather than quantified thresholds.

5.8 Gender Considerations in Groundwater Use and Vulnerability

Gender dynamics represent an important but often overlooked dimension of groundwater vulnerability in the TBA Una. Across both Croatia and Bosnia and Herzegovina, women play a central role in household water use, sanitation management and coping with service disruptions, while decision-making power over water infrastructure, land use and investments remains predominantly male-dominated. This structural mismatch increases socio-economic vulnerability in karst environments where household-level practices directly influence groundwater quality.

In small rural settlements, particularly in the Croatian part of the TBA and in rural areas of the Una-Sana region, women bear primary responsibility for everyday water-related tasks, including managing water supply interruptions, maintaining hygiene standards and responding to contamination risks. During droughts, floods or infrastructure failures, these responsibilities intensify, increasing unpaid care burdens and reducing adaptive capacity at household level.

In agriculture, gendered land ownership and access to resources further shape groundwater vulnerability. In Bosnia and Herzegovina, women represent a significant share of the agricultural workforce but control a limited proportion of land and farms, restricting their access to irrigation investments, subsidies and climate-resilient technologies. This limits both household resilience and the effectiveness of groundwater protection measures in rural karst zones.

Despite these constraints, women demonstrate high environmental awareness and play a key role in sustaining water-dependent livelihoods and tourism services. Their limited participation in formal

water governance structures therefore represents a missed opportunity for strengthening groundwater protection and risk communication across the TBA Una.

5.9 Stakeholder Landscape and Engagement Dynamics

Groundwater pressures in the TBA Una are shaped by a diverse and asymmetric stakeholder landscape. On the Croatian side, groundwater use and sanitation practices are dominated by individual households, small farmers and seasonal tourism operators operating with limited institutional oversight. Local governance structures are resource constrained, resulting in decentralized decision making and diffuse pressure pathways that are difficult to manage collectively.

In contrast, the Bosnia and Herzegovina side of the TBA features a more complex and concentrated stakeholder structure. The public water utility of the City of Bihać represents a dominant actor due to its reliance on the Klokot and Kostela springs for urban water supply. Additional stakeholders include municipal authorities, Una National Park management, tourism operators, rural communities and environmental NGOs, creating a dense network of actors directly affected by groundwater quality and availability.

This imbalance creates a cross-border governance challenge: diffuse upstream pressures generated by numerous small actors intersect with concentrated downstream dependency borne by a limited number of institutions and a large service population. While incentives for groundwater protection are strong on the BiH side, fragmented mandates and limited cross-border coordination constrain effective risk management.

Stakeholder engagement mechanisms across the TBA Una remain largely informal and unevenly developed. Public awareness of karst groundwater vulnerability is particularly limited among rural households and tourism operators relying on decentralized sanitation systems. Strengthening stakeholder coordination and communication therefore represents a critical enabling condition for reducing socio-economic vulnerability and managing groundwater risk at transboundary scale.

6 Transboundary Cooperation – TBA Una

6.1. Integrating Groundwater Provisions through the Update of the Bilateral Agreement between Croatia and Bosnia and Herzegovina

Bilateral agreement concluded between Croatia and Bosnia and Herzegovina (1996) outlines joint responsibilities for managing shared river basins, including the TBA Una. The agreement lacks specific provisions on groundwater, including monitoring, data exchange, and aquifer management, offering instead a general framework for cooperation in areas such as overall water management, pollution prevention and infrastructure. The lack of measures for aquifer management, groundwater monitoring and systematic data exchange reduces its practical value for achieving DIKTAS II objectives.

Updating this agreement to include explicit references to groundwater, harmonized monitoring protocols, and alignment with DIKTAS Rulebook, particularly regarding sanitary protection zones, would significantly strengthen transboundary governance. Such revisions should also introduce joint technical guidelines and institutional mechanisms to operationalize cooperation, ensuring that both countries meet EU standards and regional sustainability goals.

On the basis of the signed bilateral Agreement, an inter-state Working Group was established tasked to prepare a draft Regulation on the determination of sanitary protection zones for water sources in

the border area of BiH and Croatia. According to available information, the Regulation has been drafted some years ago, but it cannot enter into force until an international Agreement is signed on the proclamation of sanitary protection zones for water sources used for public water supply, where the zones extend into the territory of the other state (Agency for the Adriatic Sea River Basin, 2021).

6.2 Stakeholder Engagement and Public Awareness

This section evaluates engagement mechanisms, communication pathways, and awareness levels among key stakeholder groups influencing groundwater conditions in TBA Una.

Table 13 Stakeholder Engagement and Public Awareness

Key Stakeholder Groups	Engagement Gaps	Stakeholder Dynamics and Sensitivities
Public Water Utilities (HR & BiH): Technically capable institutions with limited public communication on groundwater risks. Municipal Governments: Responsible for local service provision; engagement generally administrative rather than participatory. Rural Communities: Low awareness of karst vulnerability; limited access to guidance on sanitation, waste management, and land-use impacts. Tourism Operators: High seasonal impact; variable awareness of environmental responsibilities; limited environmental training. Agricultural Users: Small-scale stakeholders with diffuse pollution potential; limited involvement in groundwater protection planning. NP Una Administration and Plitvice-adjacent tourism areas: Hold established outreach channels but lack harmonised groundwater-specific messaging. Environmental NGOs: Active in BiH and serve as potential partners for awareness and monitoring. Schools and youth groups: Underutilised but important long-term awareness stakeholders.	No formal cross-border stakeholder engagement platform. Public information on groundwater vulnerability, especially karst pathways, is limited. Rural households lack structured guidance on septic maintenance and waste disposal. Tourism operators are not systematically trained in environmental standards. Utilities do not routinely disseminate monitoring data or risk alerts to the public. Municipal messaging and engagement practices are inconsistent across the TBA.	Upstream–downstream perception gaps: Croatian users contribute diffuse pressures; BiH users face downstream impacts. Economic–environmental trade-offs in tourism. Fragmentation of mandates, particularly in BiH, complicates communication channels and dilutes accountability. Full implementation pending EU accession.

6.3. Opportunities for Strengthening Cooperation

Cooperation opportunities across the TBA Una can be organised into four strategic pillars. Each pillar consolidates actions that address the institutional asymmetries, capacity gaps and stakeholder pressures identified in the previous sections.

PILLAR 1: JOINT MONITORING AND INFORMATION EXCHANGE

- Establish a harmonised groundwater monitoring network across both countries.
- Develop a shared digital platform for spring discharge, microbiology, rainfall and chemical data.
- Conduct annual joint interpretation workshops.

Outcome: Common evidence base for decision-making and early-warning capability.

PILLAR 2: COORDINATED RISK MANAGEMENT AND PROTECTION MEASURES

- Introduce aligned protocols for pollution response and emergency communication between water utilities and authorities.
- Map and prioritise high-risk zones jointly.
- Develop cross border guidance for sewerage management and rural sanitation improvements.

Outcome: Reduced vulnerability of sensitive recharge areas and faster response to incidents.

PILLAR 3: SUSTAINABLE TOURISM AND LAND-USE COORDINATION

- Agree on shared environmental guidelines for tourism operators in both countries.
- Coordinate public awareness messaging through NP Una and NP Plitvice visitor centres.
- Promote eco-sanitation solutions for tourist hotspots.

Outcome: Harmonised seasonal pressure management and stronger visitor stewardship.

PILLAR 4: INSTITUTIONAL DIALOGUE AND COMMUNITY ENGAGEMENT

- Establish a permanent Croatia - BiH groundwater group.
- Facilitate structured participation of municipalities, NGOs and local communities.
- Promote cross-border training and exchange for inspectors, utilities and park authorities.

Outcome: Stable institutional cooperation, improved accountability and stronger bottom-up support.

7. Recommendations and Measures – TBA Una

7.1 Legal Harmonization Measures

As a first step, Croatia (HR) and Bosnia and Herzegovina (BiH) are encouraged to consider an addendum to the 1996 Agreement on Water Management Relations, based on guidelines to be elaborated in the Joint Action Program (JAP) for the TBA Una under the DIKTAS II project. These guidelines should set out a shared hydrogeological description of the TBA Una, including indicative aquifer boundaries and linkages with groundwater-dependent ecosystems, offering a common reference frame for subsequent technical and administrative cooperation. They may also describe joint commitments - rather than strict obligations - for mutual recognition of sanitary protection zones extending across the border, harmonized approaches to groundwater and groundwater-dependent ecosystem monitoring, reciprocal incident notification and early-warning communication, and regular information exchange through a bilateral data interface initiated under the Multilateral Agreement on establishing the Consultation and Information Exchange Body (CIE) proposed in DIKTAS II.

Sanitary protection zones (SPZ) appear to be the most immediate field for technical alignment in a karst setting. A common four-zone model for karst sources should be introduced as a recommended standard, anchored in hydrogeological investigation, residence-time thresholds, and explicit vulnerability mapping. Where an SPZ extends across the border, mutual recognition - implemented via local spatial plans and reflected in project permitting - should support coherent land-use management. To increase clarity for operators and communities, a uniform typology of prohibited, conditional, and generally compatible activities by zone should be developed, with tourism, waste infrastructure, and agriculture treated explicitly. Activities considered conditional should be assessed

through groundwater-specific environmental impact procedures drawing on tracer tests or equivalent karst research tools. Integration of approved SPZs into spatial planning should follow explicit timelines and confer immediate relevance on officially adopted technical background documents, such as maps, enhancing certainty for investors and authorities alike.

Convergence in permitting and discharge control should complement these spatial measures. BiH is encouraged to align procedural thresholds and documentation with Croatia's two-tier system (permits and concessions), while maintaining flexibility to reflect entity arrangements. Application content, public participation windows, validity periods, renewal conditions, and minimum monitoring plans should be harmonized through parallel by-laws and shared templates. For indirect discharges, joint technical guidance should offer a common risk-assessment framework, including source-pathway-receptor analysis, preventive design features, parameter lists, limit/threshold values, and trend assessment tests, while recognizing that national laws already preclude direct discharges. Recognizing climate variability, a shared framework for managed aquifer recharge in karst could be developed incrementally, covering site selection, source water quality, pre-treatment, hydraulic testing, operational monitoring, and cessation criteria, enabling pilots under controlled conditions.

Monitoring and information-management improvements should be anchored in a joint monitoring program, agreed at technical level in the JAP for the TBA Una, harmonizing station networks, parameters, and sampling frequencies and promoting quality assurance and inter-laboratory comparability. Attention should be given to continuous or high-frequency monitoring at key springs used for public supply, supplemented by surveillance monitoring points in upstream recharge zones and seasonal microbiological sampling during high-risk periods. A shared digital platform using EU standards and INSPIRE-compatible metadata should support near-real-time data exchange, routine trend analysis, and publication of validated summaries, with tiered access for authorities, utilities, and the wider public. Early-warning and incident communication should be codified through concise protocols specifying competent contacts, timelines for alerts and follow-up reports, and options for temporary abstraction curtailment or emergency supply measures when thresholds are exceeded.

Economic instruments could offer another avenue for convergence. Both parties are encouraged to explore alignment of abstraction and discharge fees so that tariffs progressively reflect resource and environmental costs, with revenues earmarked for monitoring, SPZ implementation, decentralized sanitation upgrades in sensitive areas, and remediation. Where a contamination event demonstrably produces cross-border impacts, the parties should activate cooperative cost-sharing arrangements endorsed by the bilateral commission and, where feasible, access EU, GEF, or regional funding premised on harmonized frameworks.

Enforcement and compliance assurance should be strengthened through aligned, risk-based inspection planning that considers karst vulnerability, proximity to recharge features, and seasonal tourism intensity. Transboundary compliance reviews - carried out annually - should focus on a practical checklist: progress with SPZ integration into spatial plans, permitting practice at sensitive locations, monitoring coverage and data quality, and handling of incidents. Where legacy contamination or new releases are identified, parallel guidelines on contaminated-site investigation and groundwater remediation in karst should provide a shared roadmap for site characterization, containment options, monitored natural attenuation, and verification sampling, bringing greater predictability to remedial action irrespective of jurisdiction.

Cross-sectoral integration should add resilience. Spatial planning statutes should incorporate explicit cross-references so that approved SPZ and vulnerability layers have direct planning relevance in

zoning, building permits, and strategic environmental assessments. Tourism licensing in sensitive zones should include groundwater-specific performance conditions for accommodation and recreational facilities, including sanitation design, peak-season load management, and waste handling. Agricultural measures, aligned with the Nitrates Directive, should be promoted in outer protection zones, supported by incentives for organic and low-input farming practices. Energy and hydropower licensing should incorporate ecological-flow safeguards and connectivity tests to avoid adverse effects on groundwater-dependent ecosystems. Public-health regulations should emphasize routine disclosure of drinking-water quality and participation of water utilities in joint monitoring arrangements, improving risk communication.

Harmonized public-participation rules for permits and SPZ decisions, access to technical studies, and clear timelines for comments should raise legitimacy and reduce disputes. Annual groundwater status notes, SPZ maps, and monitoring summaries should be published in a user-friendly format.

A sequenced implementation pathway is recommended as the most pragmatic way to operationalize legal harmonization measures. In an initial phase, HR and BiH should focus on the addendum to the 1996 Contract based on JAP guidelines covering SPZ alignment, monitoring, early-warning templates, and remediation measures. A second phase should address spatial-plan integration, convergence of permitting and discharge guidance, use of the shared data platform, and the first cycle of cooperative reviews. A third phase should explore alignment of economic instruments, complete cross-sectoral legal insertions, and publish a joint five-year compliance and status report consolidating lessons learned and proposing refinements.

7.2 Policy Integration and Planning Improvements

Groundwater governance in the TBA Una should be more strongly integrated into all planning instruments that affect the area. River Basin Management Plans already provide a solid technical basis, but their principles are not consistently reflected in spatial, tourism, agriculture, energy, and transport planning relevant to the TBA Una. Each of these plans should explicitly reference groundwater vulnerability and incorporate measures aligned with basin objectives to ensure coherent decision-making across sectors.

Spatial planning is a critical entry point for integration. Sanitary protection zones and vulnerability maps should be incorporated into municipal and cantonal spatial plans covering the TBA Una. This would give these zones direct planning relevance and prevent incompatible land-use decisions. Early advisory input from water authorities during plan preparation is recommended to avoid conflicts and ensure development proposals respect hydrogeological constraints.

Tourism planning for the TBA Una should address seasonal pressures on karst aquifers and include groundwater-specific conditions for accommodation facilities, camping sites, and recreational infrastructure within sensitive zones. These conditions should cover sanitation standards, wastewater disposal, and peak-season load management. Local development programs are encouraged to prioritize upgrading septic systems and introducing cluster solutions in rural settlements located in recharge areas. Linking these measures to tourism and rural development funding would accelerate implementation and reduce contamination risks.

Agricultural planning in the TBA Una should integrate groundwater sustainability criteria into irrigation and nutrient-management programs. Public support for irrigation projects should be linked to compatibility with groundwater status objectives defined in river basin plans. Nutrient-management plans and buffer practices adapted to karst features should be promoted in recharge zones, while

organic or low-input farming should be incentivized in outer sanitary zones. These measures would reduce diffuse pollution risks and align agricultural development with resource protection.

Energy and transport planning for the TBA Una should incorporate groundwater considerations at the strategic level. Hydropower and infrastructure planning should require environmental assessments that address karst pathways, seepage risks, and construction-phase water protection. Connectivity tests and ecological flow safeguards referenced in water-sector documents should inform project screening without creating new legal obligations. This approach ensures groundwater risks are considered early in decision-making for projects affecting the TBA Una.

Data integration is essential for evidence-based planning. Authorities responsible for tourism, agriculture, and public health in the TBA Una should share relevant datasets - such as spring discharge, water quality, and seasonal demand peaks - through a bilateral data interface initiated under the Multilateral Agreement on establishing the CIE, linked to river basin monitoring systems. This would improve trend analysis and enable planning reports to include groundwater indicators. Water-sector plans should also incorporate sectoral data to refine hotspot identification and intervention priorities.

Financial instruments should reinforce policy integration. Planning documents for EU-funded programs and national development schemes should highlight priority investments that reduce groundwater risk in the TBA Una, such as sanitation upgrades in vulnerable areas, leakage control for karst springs, and monitoring infrastructure. These priorities should be reflected in eligibility criteria and scoring systems for project selection, ensuring that public finance supports measures with the highest protective value.

Transparency and participation should be strengthened for all planning processes affecting the TBA Una. Sanitary zone maps, vulnerability layers, and monitoring summaries should be published in accessible formats. Public consultations on spatial and sectoral plans should invite groundwater-related comments, and authorities should provide reasoned responses based on river basin evidence. Where plans have potential transboundary impacts, notification and technical input from the counterpart administration should be encouraged through existing cooperation schemes set by the 1996 Contract on Water Management Relations or the Multilateral Agreement on establishing the CIE proposed by DIKTAS II.

Implementation should follow a phased approach tailored to the TBA Una. In the first phase, planning documents should include direct references to river basin objectives and add clear requirements for assessing groundwater risks. The second cycle should integrate sanitary zones into spatial and tourism plans, link financial incentives to risk-reduction outcomes, and formalize advisory roles for water authorities. In the third cycle, planning instruments should incorporate monitoring results, refine ecological connectivity tests, and adopt shared indicators for evaluating progress.

7.3 Socio-economic Measures for Sustainable Groundwater Use

Socio-economic measures in the TBA Una should address human drivers of groundwater pressure, strengthen local capacity, and promote practices that safeguard the aquifer's long-term sustainability. These measures target communities, service providers, tourism operators, and local authorities on both sides of the border.

The most urgent priority is to improve rural sanitation. Decentralized septic systems dominate across the TBA Una and represent the highest contamination risk. Vulnerable villages and tourism clusters should be prioritized for upgrades based on proximity to springs and recharge zones. Municipalities are encouraged to provide guidance on maintenance and leak prevention, while simple inspection

programs and registers of on-site systems should help prevent failures. In peri-urban Bihać, where loads are concentrated, cluster systems or small sewer extensions should be considered to protect the Klokot and Kostela springs.

Tourism-related pressures require targeted management. Seasonal peaks in Una National Park and the Plitvice corridor often exceed local sanitation capacity. Tourism operators should adopt EU standards for water efficiency, wastewater storage or pre-treatment, and safe waste handling. Visitor centres and tourism boards should disseminate groundwater protection messages, while seasonal coordination meetings between municipalities, park authorities, and utilities should ensure readiness and rapid response during peak months.

Waste management also requires targeted attention, particularly in environmentally sensitive zones. Illegal dumpsites located near springs, dolines, losing streams and other vulnerable karst features should be systematically removed, while seasonal waste-collection services should be reinforced during periods of increased tourism activity. NGOs, national park authorities and local community groups can play an important role in monitoring waste hotspots and supporting early identification of emerging risks.

Drinking-water security for Bihać should be strengthened through proactive measures. The city's dependence on Klokot and Kostela springs makes leakage control, pressure management, and contingency planning essential. Seasonal demand management campaigns and early-warning protocols for turbidity or microbiological exceedances should reduce systemic risk and protect public health.

Agricultural practices should be adapted to karst vulnerability. Although abstraction is low, diffuse pollution from livestock and manure remains a concern. Buffer zones around karst features, seasonal restrictions on manure spreading, and farmer training should reduce contamination risks. Incentives for low-input or organic farming in outer sanitary protection zones should align agriculture with groundwater protection goals.

Monitoring and data sharing should be strengthened. Authorities should integrate key datasets - spring discharge, turbidity events, seasonal visitor numbers, sanitation upgrades - into a shared platform based on the Multilateral Agreement on establishing the CIE and linked to river basin monitoring. Annual summaries and joint interpretation workshops should improve transparency and support evidence-based decisions.

Infrastructure improvements should be achieved through targeted micro-investments. Municipal programs are encouraged to co-finance sealed tanks, improved pre-treatment units, and shared cluster systems for high-risk settlements. Fast-track permits and standardized design templates should reduce costs and accelerate adoption.

Economic incentives should accelerate adoption of protective practices. Municipalities and park authorities may consider rebates or fee reductions for households and tourism operators investing in sanitation upgrades or water-saving measures. Tourism fees or concession revenues should be earmarked for groundwater protection projects.

Financing should prioritize high-risk areas. EU and national programs, municipal budgets, and park revenues should focus on projects that demonstrably reduce groundwater risk, such as septic upgrades in recharge zones, leakage control, and installation of continuous monitors at key springs. Implementation should follow short, repeatable cycles: initial steps include publishing guidance and

piloting incentives, followed by expanded monitoring and infrastructure upgrades. Each cycle should remain voluntary and emphasize learning from joint data and local experience.

Raising public awareness is essential. Information campaigns on karst vulnerability, safe sanitation and appropriate waste disposal should improve community understanding and behaviour. Schools, youth groups and local associations can contribute to long-term environmental education, while establishing a community stewardship network should strengthen local participation in monitoring and protection.

Communication between utilities and communities should be strengthened. Public water utilities should regularly share accessible updates on groundwater status and potential risks, while structured dialogue platforms involving utilities, municipalities and community representatives should help align expectations, improve transparency and foster collaborative problem solving.

By focusing on sanitation, tourism management, waste control, drinking-water resilience, agricultural buffers, micro-investments, monitoring, incentives, community engagement and coordination, groundwater and groundwater-dependent ecosystem risk can be progressively reduced.

7.4 Monitoring and Data Management Enhancements

Strengthening monitoring and data management in the TBA Una is essential for effective bilateral groundwater governance. Current monitoring on both sides is uneven in scope, methodology, and frequency, limiting the ability to assess groundwater status and respond to risks. A harmonized and targeted approach should be adopted, tailored to the hydrogeological characteristics of the Una aquifer.

Monitoring should be based on a detailed conceptual model of the TBA Una, with attention to recharge zones, major springs, flow paths, and groundwater-dependent ecosystems. The current focus on drinking water sources should expand to include representative points that capture system dynamics. Parameters should cover discharge, nutrients, microbiological indicators, and selected hazardous substances, with sampling frequencies adapted to rapid karst responses.

To ensure comparability, Croatia and Bosnia and Herzegovina should adopt harmonized methodologies as outlined in the Joint Action Program (JAP) under DIKTAS II. This includes common protocols for sampling, analysis, data validation, and reporting. Automatic sensors at key springs are recommended to improve early detection of contamination and seasonal changes.

Sanitary protection zones should be monitored and managed consistently based on shared criteria. A vulnerability-based approach should guide delineation and monitoring, ensuring comparable principles rather than identical national systems. Minimum monitoring requirements for each zone should inform land-use decisions, permitting, and risk mitigation. Where exceedances occur, both countries must coordinate responses, especially in zones crossing the border or affecting shared springs.

Data management is equally critical. An interoperable data-sharing mechanism, aligned with the Multilateral Agreement on establishing the Consultation and Information Exchange Body (CIE), should enable timely exchange of results and joint interpretation. Data should follow standardized formats with clear metadata and validation procedures. Regular bilateral reviews and annual joint reports should strengthen trust and ensure consistent interpretation.

Monitoring and data management improvements should support a joint indicator framework for governance performance, including coverage, data quality, reporting frequency, and integration into

planning processes. Indicators should be simple, measurable, and aligned with DIKTAS II requirements to track progress and identify priorities.

Risk-based and early-warning approaches should be introduced gradually. Automatic monitoring stations combined with meteorological and hydrological data would allow rapid detection of contamination and support proactive management, especially for springs supplying drinking water and areas with high tourism pressure.

Capacity building is essential. Both countries should invest in training on karst hydrogeology, monitoring design, data interpretation, and information systems. Joint field exercises should align practices and strengthen cooperation. Adequate staffing, equipment, and funding are necessary for sustainability.

Finally, transparency and stakeholder engagement should be integral. Monitoring results, protection zone maps, and risk assessments should be accessible to communities, utilities, and park administrations. Clear communication should support informed decisions and build public trust. Citizen observations can complement formal monitoring, especially in remote areas.

7.5 Transboundary Cooperation and Governance Mechanisms

The protection of groundwater and groundwater-dependent ecosystems in the TBA Una depends on stable, structured cross-border cooperation. Effective governance requires clear institutional coordination, harmonized monitoring, and inclusive stakeholder participation.

A permanent coordination mechanism between the two countries should provide a platform for regular dialogue, joint review of monitoring results, and coordinated responses to groundwater risks. Harmonizing monitoring practices and creating a shared data-exchange system should improve transparency and establish a common evidence base for decision-making.

Sanitation and wastewater management remain critical challenges. Both sides should agree on minimum technical standards for on-site systems and small cluster solutions suitable for rural karst settings, and apply them through targeted local programs. Priority areas should be identified based on monitoring and field inspections, focusing on settlements and facilities within protection zones or recharge corridors. For each area, municipalities should prepare time-bound improvement plans covering inspections, repairs of leaking tanks, installation of sealed storage or pre-treatment units, and small sewer extensions where needed. The coordination group should review these plans, monitor progress, and provide cross-border technical advice.

Tourism pressures should be managed through shared environmental guidelines, particularly for NP Una and Plitvice areas. Park administrations and tourism boards should adopt identical groundwater-focused requirements for accommodation, camping, and rafting operations, including seasonal load management, water-saving practices, and safe wastewater handling. Pre-season meetings should confirm operator readiness and contingency arrangements. Visitor centres should deliver consistent groundwater protection messages using the same materials on both sides. Monitoring results from the tourist season should be jointly reviewed to adjust measures for the following year.

Rapid communication during emergencies is essential. A joint notification protocol should define contacts, alert thresholds, and response steps for contamination events or sudden changes in spring conditions. It should cover microbiological exceedances, turbidity spikes, chemical detections, and discharge anomalies, and specify immediate actions such as abstraction curtailment, source switching,

or boil-water notices. After each incident, a short bilateral report should document causes, responses, and corrective measures.

Stakeholder engagement should be structured and regular. Municipalities, NGOs, community groups, water utilities, and park administrations should participate in coordination sessions to review monitoring results, sanitation upgrades, and tourism measures. The coordination group should publish simple summaries of groundwater conditions and maintain an online page with maps of protection zones, monitoring stations, and contact details for reporting issues. Citizen reports of illegal dumping or unusual spring turbidity should be registered through a simple form and reviewed by inspectors.

7.6 Indicator Framework for Joint Action Program

7.6.1 Proposed Indicators for Implementation Monitoring

The indicator framework for the Una TBA Joint Action Program (JAP) is designed to turn governance principles into measurable signals of progress. Indicators will be grouped into four categories: Institutional, Legal & Fiscal, Technical, and Policy Planning. This structure follows the approach set out in the "Global Framework for Action on Groundwater Governance", the final output of the FAO/UNESCO/IAH/World Bank/GEF "Groundwater Governance Project", which highlights that effective governance depends on strong institutions, clear legal and financial tools, sound technical measures, and planning based on evidence. Organizing indicators in this way ensures that monitoring covers not only activities but also the conditions and mechanisms that make long-term cooperation possible. It also aligns with the governance performance indicators presented in the Framework's annex, creating a link between global standards and the Una-specific program.

Institutional indicators will show whether the arrangements and capacities needed for joint aquifer management are in place and functioning. They will track the work of the Joint Water Management Commission, the frequency and quality of stakeholder meetings, and whether decisions reflect stakeholder input. These indicators will confirm if cooperation is moving from informal coordination to structured and transparent processes. As part of the TBA Una JAP, they will demonstrate whether joint mechanisms are operating effectively, whether stakeholder engagement is inclusive, and whether capacity for monitoring and conflict resolution is being strengthened.

Legal & Fiscal indicators will measure whether laws, regulations, and financial tools are applied and support sustainable groundwater use. They will include licensing of wells and discharges, inspection and compliance rates, sanctions for violations, and cost-recovery mechanisms. These indicators will show if legal frameworks are harmonized across borders, if permits and sanctions are reducing risks, and if financial incentives are shifting behaviour toward efficiency and protection.

Technical indicators will assess the performance of measures that directly affect the aquifer and related ecosystems. They will track adoption of water-saving technologies, recharge volumes, groundwater level trends, and water quality changes. These indicators will confirm whether technical actions are achieving intended results, such as stabilizing flows and protecting vulnerable areas, and whether monitoring systems are fully operational and integrated across both countries.

Policy Planning indicators will verify that governance principles and technical evidence are being translated into actionable plans and review processes. They will measure whether operational plans are adopted and funded, targets for quantity and quality are defined, communication strategies are implemented, and conflict resolution mechanisms work. These indicators will ensure that progress is

monitored against clear objectives and that plans are updated based on results and changing conditions.

Together, these four groups will provide a complete picture of implementation. Institutional indicators confirm governance structures; Legal & Fiscal indicators track compliance and incentives; Technical indicators measure physical and chemical responses; and Policy Planning indicators ensure actions are planned, financed, and reviewed. Applied across Chapters 8 to 12 of the TBA Una JAP, this framework will show what has been achieved and whether the foundations for effective transboundary groundwater governance are in place. It will allow the Una JAP to report progress, identify gaps, and adapt measures based on evidence and stakeholder input.

7.6.2 Alignment with SAP and DIKTAS II Objectives

The proposed indicator framework for the Una TBA Joint Action Program (JAP) aligns closely with both the Strategic Action Program (SAP) objectives and the DIKTAS II project goals. SAP defines five long-term objectives: (1) ensuring sufficient groundwater quantity, (2) maintaining and improving groundwater quality, (3) protecting groundwater-dependent ecosystems (GDEs), (4) supporting equitable allocation of resources, and (5) raising awareness and building capacity. DIKTAS II operationalizes these through five components and six outcomes, focusing on governance, monitoring, harmonization of protection measures, and stakeholder engagement.

Institutional indicators directly support SAP Objective E (capacity building) and DIKTAS II Component 1 (multi-country cooperation). By tracking the establishment and functioning of joint bodies, expert groups, and stakeholder platforms, these indicators measure progress toward institutionalization of cooperation and conflict resolution mechanisms, which are essential for implementing SAP's vision of coordinated management.

Legal & Fiscal indicators correspond to SAP Objectives B and D and DIKTAS II Component 2 (institutional strengthening). Harmonization of sanitary protection zone criteria, enforcement of groundwater protection laws, and cost-recovery mechanisms are central to SAP's call for equitable and sustainable use. These indicators will demonstrate whether national frameworks are converging toward common standards and whether economic instruments are applied to discourage pollution and over-abstraction, in line with DIKTAS II outputs on legal harmonization and policy reform.

Technical indicators are fully aligned with SAP Objective A (groundwater quantity) and Objective B (quality), as well as DIKTAS II Component 3 (monitoring). They measure the implementation of modern multi-purpose monitoring networks, managed aquifer recharge, and remediation measures. These indicators provide evidence of progress toward SAP's priority action on joint monitoring and DIKTAS II's outcome of real-time data sharing and adaptive management.

Policy Planning indicators reinforce SAP Objective C (ecosystem protection) and DIKTAS II Components 4 and 5 (focus on vulnerable areas and awareness raising). By assessing adoption of operational plans, target-setting, and review cycles, these indicators ensure that technical and governance measures are embedded in actionable plans/strategies. They also support DIKTAS II's emphasis on communication, gender mainstreaming, and stakeholder involvement, creating transparency and accountability in implementation.

It should be emphasized that proposed indicator framework is a mechanism to operationalize SAP's strategic vision and DIKTAS II's adaptive management approach. It provides measurable benchmarks for governance, compliance, technical performance, and planning, ensuring that the JAP for Una TBA

contributes to regional objectives for sustainable groundwater management and transboundary cooperation.

7.6.3. Recommended Measures

Table 14 Summary Table7.6.3: Recommended Measures

Category	Measure	Purpose	Expected outcome
Legal harmonization measures (6.1)	Addendum to 1996 Agreement including groundwater; harmonized SPZ criteria and mutual recognition; joint karst vulnerability methodology; alignment of BiH legislation with WFD/GWD; legal basis for joint monitoring, early-warning and data exchange	Establish a coherent bilateral legal framework for Una TBA groundwater	Consistent SPZ protection; reduced legal discrepancies; formalized joint monitoring and notification duties
Policy integration & planning improvements (6.2)	Integrate SPZs and vulnerability maps into all spatial/sectoral plans; embed JAP measures in tourism, agriculture, energy and transport planning; harmonize RBMP methodologies; introduce groundwater-specific EIA/SEA criteria	Ensure groundwater protection is embedded across all planning instruments	Reduced land-use conflicts; sectoral policies aligned with karst vulnerability; improved cumulative-impact assessment
Socio-economic measures for sustainable use (6.3)	Improve wastewater treatment; regulate decentralized sanitation; strengthen nutrient-management controls; address illegal waste disposal; enhance Bihać drinking-water security; manage tourism pressures	Reduce socio-economic pressures on vulnerable karst aquifers	Lower contamination risks; improved spring protection; reduced diffuse pollution; greater resilience of water supply
Monitoring & data management enhancements (6.4)	Harmonized bilateral monitoring network; standardized protocols; expanded monitoring in recharge zones; GDE indicators; automatic stations at key springs; interoperable data-sharing; joint annual reporting	Provide a shared evidence base for groundwater status and risks	Comparable datasets; early detection of contamination; transparent data exchange; monitoring aligned with JAP
Transboundary cooperation & governance (6.5)	Permanent bilateral coordination mechanism; joint emergency protocols; strengthened SPZ enforcement capacity; structured stakeholder engagement;	Move from ad hoc to institutionalized cooperation	Faster coordinated response; improved enforcement; enhanced technical capacity; regular joint decision-making

Category	Measure	Purpose	Expected outcome
	targeted training in karst hydrogeology		
Implementation monitoring indicators (6.6.1)	Four-pillar indicator framework (Institutional, Legal & Fiscal, Technical, Policy & Planning) to track JAP implementation and governance performance	Enable structured, adaptive monitoring of progress	Transparent tracking of reforms; early identification of gaps; evidence-based adjustment of measures

8. Conclusions

8.1 Key Findings from the Comparative Analyses

The comparison between Croatia and Bosnia and Herzegovina shows differences in how groundwater is managed. Generally, Croatia provides a stronger regulatory baseline, but operational enforcement should be improved further, while BiH faces systemic fragmentation and under resourcing. Croatia has a centralized, EU-aligned framework, with fully transposed WFD and GWD and detailed River Basin Management Plans. Bosnia and Herzegovina, by contrast, relies on fragmented entity laws, only partially aligned with EU directives.

Sanitary protection zones (SPZ) in Croatia are defined by clear hydrogeological criteria, time thresholds, and vulnerability mapping, but often delayed in spatial plan integration, while in BiH many municipalities have not prepared or updated SPZ studies. Sanitary protection zones differ between entities: FBiH applies karst-specific criteria, while RS uses uniform standards that overlook hydrogeological complexity. Croatia enforces sanitary zones centrally with uneven monitoring, while in BiH enforcement is fragmented or weak.

Monitoring remains a critical weakness. Croatia has expanded monitoring programs to include chemical and quantitative status, with specific protocols for karst aquifers and connectivity tests between groundwater and surface waters. Yet, data exchange remains fragmented and lacks a unified platform for systematic integration into planning and sectoral policies. In BiH, monitoring in karst is focused mainly on drinking water sources, with limited coverage of karst systems and no systematic ecological indicators.

Both Croatia and BiH prohibit direct discharges into groundwater. Croatia applies stricter conditions for indirect discharges but lacks MAR guidelines, while both entities in BiH allow indirect discharges under conditions but does not provide technical guidance Karst aquifers, recognized as highly vulnerable due to rapid flows and limited filtration, are addressed in Croatian RBMPs with tailored measures, but in BiH remain under-assessed and insufficiently integrated into planning instruments.

In Croatia, inspections follow structured, risk-based protocols and enforcement is stably financed through water-related fees while in BiH inspections are reactive, fee structures are fragmented and low. Croatia embeds water policy across spatial planning, agriculture, tourism, and energy with public participation, while in BiH coordination is fragmented, inter-entity cooperation weak, and groundwater rarely integrated into other sectors.

Both countries lack full integration of groundwater into agriculture, tourism, and energy strategies. 1996 bilateral agreement does not explicitly address groundwater, leaving cooperation without operational mechanisms.

Given the current divergent situation between Croatia and Bosnia and Herzegovina, the following measures are required to establish a coherent framework for joint management of the Una transboundary aquifer.

Joint legal harmonization is essential including:

- An addendum to the 1996 Water Management Contract should be elaborated to include a shared hydrogeological reference for the Una aquifer, mutual recognition of cross-border sanitary protection zone(s), harmonized monitoring, reciprocal incident notification, and regular data exchange through a bilateral platform.
- Harmonisation regarding sanitary protection zones, including introduced four-zone model for karst sources based on hydrogeological investigation and vulnerability mapping. Cross-border zones must be mutually recognized and integrated into spatial plans, with clear rules for activities to ensure coherent land-use management.
- Permitting and discharge control procedures need to be harmonized based on Croatia system using shared templates and joint technical guidance. BIH and Croatia should also develop a common framework for managed aquifer recharge in karst, enabling coordinated pilot projects under controlled conditions.
- Establishment of joint monitoring program with harmonized networks, parameters, and sampling, supported by continuous monitoring at key springs and seasonal checks in recharge zones. Digital platform for real-time data exchange and codify early-warning protocols should be available to ensure rapid communication and coordinated emergency measures.

Both countries should:

- ✓ align abstraction and discharge fees to reflect environmental costs and establish cooperative cost-sharing for cross-border impacts.
- ✓ strengthen enforcement through aligned, risk-based inspections and annual transboundary compliance reviews.
- ✓ adopt shared guidelines for contaminated-site investigation and groundwater remediation in karst to ensure predictable and coordinated action.
- ✓ harmonize public-participation rules with clear timelines and access to studies should strengthen legitimacy. Annual groundwater notes, SPZ maps, and monitoring summaries must be published in a transparent, user-friendly format.

Groundwater governance in the TBA Una must be integrated into all relevant planning instruments. Both countries shall ensure that River Basin Management Plan objectives are explicitly referenced in spatial, tourism, agriculture, energy, and transport planning, so that groundwater vulnerability is consistently addressed across sectors.

Cross sectoral integration is essential to strengthen resilience, ensure coherent land use management, and protect groundwater dependent ecosystems. Spatial planning should ensure that SPZ and

vulnerability layers have direct planning relevance in zoning, building permits, and strategic environmental assessments: Tourism, agriculture, energy, hydropower, and public health regulations should adapt their licensing, operational standards, and compliance measures to reflect these planning requirements.

Financial instruments must prioritize investments that reduce groundwater risk, including sanitation upgrades, leakage control, and monitoring infrastructure. Eligibility criteria and scoring systems shall reflect these priorities to ensure public finance supports protective measures.

Socio-economic measures are critical. Rural sanitation must be upgraded, tourism pressures managed, waste controlled, and drinking-water security reinforced. Agriculture should adopt practices compatible with karst vulnerability, while economic incentives and targeted financing should focus on high-risk areas. Public awareness and community engagement are essential to strengthen stewardship.

Monitoring and data management must be harmonized and expanded. A shared conceptual model, common protocols, and interoperable data exchange will provide a reliable evidence base. Automatic monitoring, risk-based approaches, and capacity building will improve early detection and response. Transparency must be ensured through accessible results and public communication.

Cross-border cooperation must be stable and structured. A permanent coordination mechanism should oversee dialogue, monitoring, and joint responses. Shared standards for sanitation, harmonized tourism requirements, rapid emergency communication, and inclusive stakeholder engagement will ensure resilience.

8.2 Strategic Priorities for Groundwater Governance in TBA Una

Groundwater in the TBA Una is a vital karst resource, highly vulnerable to contamination and essential for drinking water, ecosystems, and socioeconomic development. Strategic priorities should be established jointly by Bosnia and Herzegovina and Croatia, aligned with EU legislation, national River Basin Management Plans, and bilateral agreements. The following four priorities define the strategic focus for Bosnia and Herzegovina and Croatia in safeguarding this shared aquifer:

1. Groundwater Governance and Legal Alignment between Croatia and Bosnia and Herzegovina

   This priority emphasizes harmonized legal and institutional frameworks, mutual recognition of sanitary protection zones, and strengthened roles for the Joint Water Management Commission. It ensures that governance reflects socio economic realities, institutional capacities, and future demand projections, while the adapted bilateral Water Management Agreement between Bosnia and Herzegovina and Croatia provides the binding foundation for transboundary coordination and long-term sustainability.

2. Resource Assessment, Monitoring, and Risk Evaluation

   This priority establishes a harmonized methodology for assessing groundwater reserves, supported by aquifer characterization and vulnerability mapping. It also includes harmonized monitoring networks, shared data platforms, and standardized criteria for evaluating groundwater and ecosystem status, providing the scientific basis for sustainable and equitable use.

3. Protection and Remediation

This priority highlights preventive measures such as vulnerability and risk mapping, harmonized sanitary protection zones, and land use controls to safeguard drinking water sources. It also addresses contamination risks, including microbiological and PCB pollution, through targeted remediation and coordinated transboundary oversight.

4. Implementation, Transparency, and Adaptive Management

   This priority defines performance indicators, reporting procedures, and review cycles to ensure transparency and stakeholder involvement. It promotes adaptive management of the Joint Action Program, linking financial instruments and community participation to long term sustainability.

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9.2 Stakeholders and mandates

Table 15 8.2 Stakeholder Lists and Institutional Maps

CROATIA			
Stakeholder group	**Key Actors**	**Mandates / Roles**	**Relevance to Groundwater**
National Authorities	Ministry of Economy and Sustainable Development (MESD); Ministry of Agriculture	Water policy, groundwater protection, sanitation standards	High – sets regulatory framework
Water Management Institutions	Hrvatske Vode	Monitoring, abstraction permits, enforcement, protection zones	Very High – core technical authority
County Governments	Lika-Senj County, Karlovac County	Environmental management, spatial planning	Medium – decisions affect recharge zones
Municipalities	Plitvička Jezera, Rakovica, Korenica, Slunj	Local planning, sanitation, waste management, inspections	High (local) – septic & land-use control

CROATIA			
Stakeholder group	**Key Actors**	**Mandates / Roles**	**Relevance to Groundwater**
Public Utilities	Local water-supply utilities	Operate small systems dependent on springs and wells	Medium – ensure safe supply
Waste Management Operators	Municipal service providers	Waste collection & disposal	Medium – prevent illegal dumping
Tourism & Protected Areas	Plitvice Lakes NP (influence), tourism boards	Manage tourism flows, environmental messaging	Medium–High – seasonal pressure
Tourism Private Sector	Guesthouses, campsites, restaurants	Water use, wastewater handling	Medium – seasonal demand & pollution
Agriculture Stakeholders	Small farmers, livestock owners	Local food production, manure storage	Medium – diffuse pollution
Civil Society	Environmental NGOs, community groups	Awareness, reporting, advocacy	Medium – support monitoring
Local Communities	Rural settlements within TBA	Daily sanitation practices, land use	High – household-level impacts

BOSNIA AND HERZEGOVINA			
Stakeholder group	**Key Actors**	**Mandates / Roles**	**Relevance to Groundwater**
Entity Authorities	FBiH Ministry of Agriculture, Water Management and Forestry	Water governance, regulation, permitting	High – defines policy & oversight
Cantonal Authorities	Una-Sana Canton	Environment, forestry, communal services	High – strong operational influence
Municipal Authorities	City of Bihać	Spatial planning, sanitation, inspections	High – manages urban/peri-urban pressure

BOSNIA AND HERZEGOVINA			
Stakeholder group	**Key Actors**	**Mandates / Roles**	**Relevance to Groundwater**
Water Utilities	Vodovod Bihać	Abstraction from Klokot/Kostela, supply operations	Very High – critical dependency on springs
Waste & Sanitation Services	JKP utilities	Waste collection, wastewater operations	High – influence water quality
Protected Area Authorities	Una National Park	Tourism management, conservation, infrastructure	High – concentrated seasonal use
Tourism Private Sector	Rafting operators, lodges, guesthouses	Seasonal water use, wastewater loads	Medium–High – pressure in summer
Agriculture Stakeholders	Small farmers, livestock households	Livestock watering, manure management	Medium – diffuse pollution risk
Civil Society & NGOs	Environmental NGOs, youth groups	Monitoring, awareness, advocacy	Medium – strong in Bihać region
Local Communities	NP Una villages, peri-urban Bihać	Everyday sanitation & land-use behaviour	High – directly affect recharge zones
Research & Academia	Universities, hydrologists	Data, studies, vulnerability assessments	Medium – evidence base
International Actors	UNESCO, GEF, EU	Funding, technical support, governance frameworks	High – strategic cooperation role

CROSS-BORDER COORDINATION ROLES – TBA UNA				
Actor / Institution	**Country**	**Mandate in National System**	**Role in Cross-Border Cooperation**	**Priority Coordination Functions**
Hrvatske Vode (Croatian Waters)	Croatia	Groundwater monitoring, abstraction control, protection zones, WFD/GWD compliance	Core technical counterpart to BiH institutions	Joint monitoring design Data harmonization

CROSS-BORDER COORDINATION ROLES – TBA UNA				
Actor / Institution	**Country**	**Mandate in National System**	**Role in Cross-Border Cooperation**	**Priority Coordination Functions**
				Early warning & incident communication
Bihać Water Utility (Vodovod Bihać)	BiH	Abstraction from Klokot/Kostela, water-supply operations	Key downstream actor; highly dependent on aquifer status	Sharing operational data Participating in joint risk assessments Coordinating emergency response
Ministry of Economy and Sustainable Development (MESD)	Croatia	National water/waste/environment policy	Strategic-level coordination, legislative alignment	Legal harmonisation Transboundary agreements Strategic guidance
FBiH Ministry of Agriculture, Water Management and Forestry	BiH	Entity-level water governance & permitting	Strategic-level coordination and regulatory alignment	Joint policy discussions Harmonising standards Coordinating permits affecting transboundary zones
Una-Sana Canton Government	BiH	Environment, forestry, communal services	Operational coordination with Croatian counties	Coordinated land-use planning Tourism pressure management Joint hotspot mapping
County Authorities (Lika-Senj, Karlovac)	Croatia	Spatial planning, environmental oversight	Operational partner to Una-Sana Canton	Land-use coordination Sanitation priorities Joint awareness initiatives
Municipalities (Bihać, Plitvička Jezera, Rakovica, Korenica, Slunj)	HR & BiH	Local planning, wastewater, inspections	Local-level actors directly implementing measures	Coordinated sanitation improvements Rural engagement Reporting local incidents

CROSS-BORDER COORDINATION ROLES – TBA UNA				
Actor / Institution	**Country**	**Mandate in National System**	**Role in Cross-Border Cooperation**	**Priority Coordination Functions**
Una National Park Administration	BiH	Protected area management, tourism control	Key actor for tourism-related coordination with Croatia	Harmonised visitor messaging Joint environmental guidelines Seasonal monitoring
Plitvice Lakes NP (influence zone)	Croatia	Tourism management, biodiversity protection	Influences visitor flows into TBA Una	Joint communication campaigns Shared sustainability standards
NGOs and Civil Society Networks	HR & BiH	Advocacy, community mobilisation, monitoring	Neutral facilitators supporting trust-building	Reporting hotspots Participatory monitoring Public awareness
Tourism Operators (rafting, lodges, campsites)	HR & BiH	Service provision, seasonal water use	Require harmonised environmental practices	Adoption of cross-border guidelines Data on seasonal loads
Research & Academic Institutions	HR & BiH	Hydrology, karst research, data analysis	Provide evidence base for bilateral decisions	Joint studies Methodology alignment Technical training
UNESCO / DIKTAS II Partners	International	Coordination of project activities, facilitation	Catalytic role in formalising cooperation frameworks	Supporting creation of permanent coordination group Providing tools, guidance, and reporting mechanisms