

A roadmap to consolidate research and innovation in agricultural water management in Bosnia and Herzegovina

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ABSTRACT

Bosnia and Herzegovina (BiH) accumulates challenges in the areas of research and innovation (R&I), agricultural water management (AWM) and their intersection. In the decade 2012–2022, the BiH gross domestic product per capita in current US\$ increased by 6.2% annually. However, improvements are slowly arriving in R&I and AWM. In this period, relevant challenges to AWM have materialized, such as climate change effects or the need to implement an interconnected vision of ecosystem services. In the R&I arena, the societal demand for knowledge goods remains low, while the reforms of higher education and R&I funding systems have become urgent. This paper set out to elaborate a realistic and feasible policy roadmap to consolidate R&I in AWM in BiH. The methodology included an assessment of policies and sector performance, the analysis of stakeholder perceptions, the development of strategic directions and the design of a strategy. Desk research and stakeholder consultations (33 interviews, six workshops, 179 persons in total) were used to take stock of the current situation and expectations for the future. Stakeholders were divided into knowledge supply and knowledge demand, with five and six subcategories, respectively. Relations were established among the key enabling factors, the needs and the capacities of the involved stakeholders. The TOWS (Threats, Opportunities, Weaknesses and Strengths) matrix permitted to identify policy strategies. A Weaknesses – Opportunities, conservative or mini-maxi strategy was selected, owing to the relevance of system weaknesses (such as low investments, poor return of R&I to society or low R&I for AWM adaptation) and opportunities (such as the Green Agenda for the Western Balkans, Smart Specialization or regional partnerships). The policy roadmap was structured along three policy goals: strengthen R&I, strengthen AWM and identify / fund local R&I priorities for AWM. Policy goals included policy instruments promoting eco-efficient use of resources and sustainable development of rural areas.

1. Introduction

Bosnia and Herzegovina (BiH) has followed a path of economic development in the last two decades. According to the [World Bank \(2023\)](#), the Gross Domestic Product (GDP) per capita in current US\$ has

increased from 1603 in 2002 to 4688 in 2012 and to 7585 in 2022. This shocking increase in GDP is not translating at the same speed to all sectors of society. Improvements are slowly arriving in Agricultural Water Management (AWM) and Research and Innovation (R&I), the two basic target areas of this paper.

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Agriculture has always been important for BiH socio-economy. This sector needs to strengthen its attractiveness and viability, so that it can support the development of BiH rural areas (Bajramović, 2022; Vaško, 2022). Climate change is one of the key challenges this sector needs to tackle. According to the BiH National Adaptation Plan (Government of Bosnia and Herzegovina, 2021), drought and heat waves were observed in seven years of the 2011–2020 decade, reducing crop yields and intensifying the demand for water for irrigation. Srdić et al. (2023) reported a decreasing trend of the aridity index (precipitation / reference evapotranspiration ratio) and the recent appearance of semi-arid climatic zones at several locations of BiH. This implies a higher water demand in all sectors, while water availability decreases. Several studies (Stricevic et al., 2018; Trbic et al., 2021) reported future trends for climate change in BiH. They pointed out a foreseen decrease in precipitation accompanied by warmer winters, less snow and more summer days. These authors claimed for thematic research leading to planned and integrated adaptation of agriculture. For instance, drip irrigation and reduced tillage are effective land and water adaptation measures in the Mediterranean, with strong potential in BiH (Zurovec et al., 2015; Zagaria et al., 2023). Unfortunately, BiH shows a great mismatch between adaptation needs and their potential for implementation. The United Nations (2017) identified both progress in BiH water management and the need for policy reforms and coordinated investments in infrastructure. Gordon et al. (2010) recognized the capacity of agriculture to generate “provisioning ecosystem services”, but at the same time showed concern about its capacity to alter water quality and quantity. These authors proposed strategies to promote synergies between food production and other ecosystem services. Among them, improving the efficiency of agricultural water use and linking management practices in all types of water uses.

The low demand for R&I in BiH is related to the weaknesses of both universities and businesses (Joint Research Centre, 2011). Universities need to accelerate reforms to evolve from teaching institutions to multi-functional institutions in which research fuels teaching, transfer, entrepreneurship and policy support. Research policy in BiH is generic, and does not show support for specific thematic areas. The Joint Research Centre (2011) expressed the need for increasing R&I demand, strengthening cooperation between Academia and businesses, and facilitating knowledge transfer. The European Commission recommended a 2022–2028 strategy and action plan for scientific development, a smart specialization strategy, a roadmap for research infrastructure, increased R&I budget allocations (currently at 0.3% of GDP), stopping the intense brain drain and developing complete R&I statistics (European Commission, 2022). On the positive side, the EC recognized a very good increase in BiH publications and patents.

Pending reforms in R&I in AWM require a reorientation, “a shift in broader societal priorities that drives reform of AWM” (Seijger and Hellegers, 2023). These authors documented reorientations currently developing in 21 countries of the world. BiH appears as a candidate for a strong knowledge-based AWM reorientation to cope with a changing climate, intensify rural development, increase food security, and exploit synergies with the rest of ecosystem services. The Green Agenda for the Western Balkans (Regional Cooperation Council, 2020) and the Smart Specialization process (Smart Specialization Platform, 2023) can provide policy impulse and funds to support this reorientation.

The aim of this research is to elaborate a realistic and feasible roadmap to consolidate AWM R&I in BiH. Specific objectives include: 1) To assess the current R&I and AWM policies and sector performance; 2) To identify key local stakeholders and analyze their perceptions; 3) To develop strategic directions; and 4) To outline a policy roadmap, taking stock of the current situation and the needs for reorientation.

2. Materials and methods

2.1. Analysis of sector policies and performance

Bosnia and Herzegovina is divided in two Entities: the Republika

Srpska (RS), located in the north and east, and the Federation of Bosnia and Herzegovina (FBiH), located in the western and central areas. The territorial setup of the country is completed with the Brčko District (BD), a separate administrative unit. FBiH comprises 10 cantons with each canton having its own local administration. FBiH has 79 municipalities, while the RS administrative structure has 64 municipalities. Municipalities and towns with local self-governance are the lowest level of the political and territorial structure within BiH. The analysis of sector policies and performance was done in consideration of the administrative structure of BiH. Official documents and scientific literature were analyzed about BiH and its Entities in R&I, AWM, and the intersection between them. Information was summarized to produce a synthetic report highlighting progress and limitations.

2.2. Stakeholders' interviews, workshops and roadmap development

Stakeholders' interviews were designed to obtain individual, face-to-face information from persons representing specific groups of stakeholders. These were divided in two major groups representing knowledge supply and demand in the value chain (Fig. 1). This division can be seen as slightly artificial, since some actors (like advisory services or advanced farmers) actually could belong to both categories. However, this classification was useful to present R&I in terms of knowledge transactions by a group of actors. Knowledge supply and demand were divided in five and six types of stakeholders, respectively. Ten interviews characterized knowledge supply and 23 interviews characterized knowledge demand (Table 1). These 33 interviews were performed in May 2023.

Stakeholder selection was designed to obtain a comprehensive understanding of the challenges and opportunities within the sector. This was facilitated by the classification of stakeholders in eleven types. Geographic and gender representativity were sought. Regarding gender, 33% of the interviewed stakeholders were women. Their participation was 40% and 30% among the knowledge supply and demand groups, respectively.

A guide was produced to support the process and standardize the interviews. The document, included as [Supplementary Material](#) to this paper, presents – for each type of stakeholder – a list of enabling factors and questions to be addressed. Enabling factors are the qualities of each type of stakeholder that facilitate progress in R&I for AWM in BiH. Interviewees were requested to expand the questions as needed, reacting to the answers provided by the interviewees. As an example, Table 2 presents the interview material for Early Career Researchers in AWM. Notes taken during each interview were elaborated into 33 working documents.

Stakeholder workshops were designed to foster dialogue among different interest groups (Table 3). 179 persons participated in these workshops, which were organized in three modalities. General workshops (WG-01 in June 2021; WG-02 in June 2022) aimed at discussing the possibilities and requirements of irrigated agriculture and strengthening sustainable water management systems in BiH. Results were also used to design the guide for interviews. Water users' workshops were organized in May 2023 in connection with Water Users Associations (WUAs) in Bratunac (WU-BR) and Trebinje (WU-TR). These workshops gathered the directors and staff from WUAs, professionals from supporting companies, associated farmers and other stakeholders. Finally, wide discussion workshops were organized in Banja Luka (WD-BL) and Trebinje (WD-TR) in May 2023. The workshop in Banja Luka gathered a wide variety of stakeholders, while the workshop in Trebinje, programmed as an event in the AgroRes 2023 Symposium of Agricultural Sciences (<https://agrores.net/en/>), facilitated discussions by actors in knowledge supply from different countries in the Western Balkans and the rest of Europe. Participants in discussion workshops were presented with preliminary versions of some of the results reported in this paper, and had the chance to express their opinions on them.

The views expressed in interviews and workshops were summarized

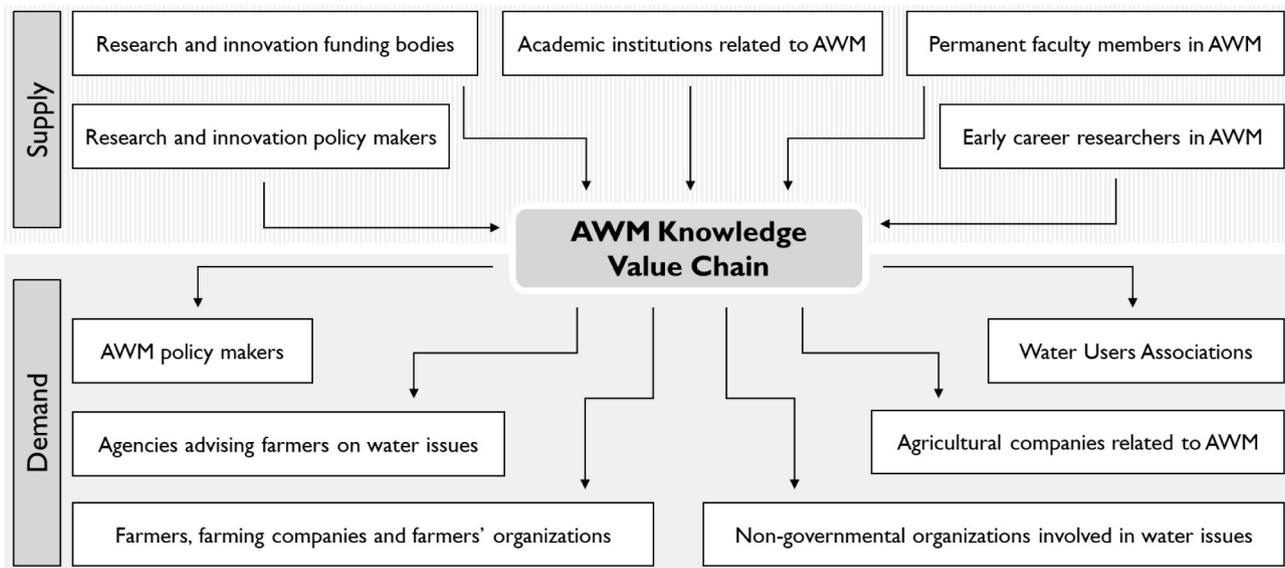


Fig. 1. Conceptual map of types of stakeholders in the Agricultural Water Management Knowledge Value Chain in BiH.

Table 1
Code, type of stakeholders and number of performed interviews.

Code	Type of stakeholders	# Interviews
Knowledge Supply 10		
Su1	R&I Policy Makers	1
Su2	R&I funding bodies	2
Su3	Academic Institutions related to AWM	1
Su4	Permanent Faculty in AWM	2
Su5	Early career researchers in AWM	4
Knowledge Demand 23		
De1	AWM policy makers	2
De2	Agencies advising farmers on water issues	1
De3	Farmers, farming companies and farmers' organizations involved in AWM	9
De4	Water Users Associations (WUAs)	7
De5	Agricultural companies (inputs, commercialization, transformation) related to AWM	2
De6	Non-governmental organizations involved in water issues	2
Interviews with all types of stakeholders		33

as perceptions from each type of stakeholder. This information was used to develop a SWOT (Strengths, Weaknesses, Opportunities and Threats) table. A TOWS matrix (Wehrich, 1982) was subsequently used to identify strategies leading to the development of the policy roadmap in four directions:

- WT, defensive or mini-mini, minimizing both weaknesses and threats;
- WO, conservative or min-maxi, minimizing weaknesses and maximizing opportunities;
- ST, competitive or maxi-mini, maximizing strengths and minimizing threats; and
- SO, offensive or maxi-maxi, maximizing both strengths and opportunities.

Strategies were prioritized considering their adequacy to the problem being analyzed. A roadmap was subsequently elaborated following a structure of Policy Goals and Policy Instruments (Håring et al., 2009).

Table 2
Interview material for Early Career Researchers in Agricultural Water Management.

Enabling factors	<ul style="list-style-type: none"> • Progressing in R&I career paths • Participating in groups valuing multidisciplinary approaches and diversity, respecting ethical codes • Acquiring capacities for competitive participation in international calls
Interview questions	<ul style="list-style-type: none"> • R&I importance and rewards <ul style="list-style-type: none"> o Are you hired by the University, or a grant, or other sources? o Is your contract for lecturing, R&I or both? o How much of your time do you devote to R&I? o Do you feel rewarded for your R&I? o Do you think your R&I will facilitate a career in Academia? o Do you think your R&I will facilitate a career in the private sector? • R&I training and support <ul style="list-style-type: none"> o Do you receive training for publishing papers? o How to accelerate the transition from research papers to societal development? o Do you make part of a group? What is its composition? • R&I in AWM <ul style="list-style-type: none"> o Do you participate in specific organizations for this topic (Department, Institute or group)? o How do you perceive this topic in the light of climate change, water pollution, renewable energies, food sovereignty, and digitalization? o What kind of interest do you perceive from public authorities? <ul style="list-style-type: none"> ■ Are they interested in cooperating with researchers for policy development or assessment? Are you? ■ How should they evolve to facilitate cooperation with you? o What kind of interest do you perceive from the private sector? <ul style="list-style-type: none"> ■ Are they interested in cooperating with researchers for problem-solving research? Are you? ■ How should they evolve to facilitate cooperation with you? o What kind of interest do you perceive in society? <ul style="list-style-type: none"> ■ How should society evolve to facilitate cooperation with you? o Where do you think you will be working in five years' time?

3. Results

3.1. R&I policy and performance in BiH

According to Mirascija (2010), R&I is not a direct responsibility of

Table 3

Workshops vs. types of attendants. Knowledge supply and demand are classified as Su1 to Su5 and De1 to De6, respectively, following the description in Table 1.

Workshop	Type of attendants											Attendants	
	Knowledge Supply					Knowledge Demand							
	Su1	Su2	Su3	Su4	Su5	De1	De2	De3	De4	De5	De6		
WG-01			X	X	X	X	X	X			X	X	31
WG-02	X	X	X	X	X	X	X	X			X	X	73
WU-BR								X	X				15
WU-TR								X	X		X		30
WD-BL	X	X	X	X	X	X	X				X	X	15
WD-TR			X	X	X								15
Stakeholders in all events													179

the national level of government in BiH, which holds representation and coordination responsibilities. R&I policy is decentralized to the two Entities (RS and FBiH), as well as to BD. Further, R&I policy in FBiH has been transferred to the ten cantons.

The BiH Ministry of Civil Affairs represents BiH in international R&I activities. In May 2009 the BiH Parliament approved the Framework Law on Higher Education (Government of Bosnia and Herzegovina, 2009a). A few months later, in December, a strategy for the development of science in BiH was adopted (Government of Bosnia and Herzegovina, 2009b). The strategy focused on the link between R&I and BiH development, public-private cooperation, international standards and statistics for R&I, participation in the European Research Area, reform of higher education for the promotion of R&I, cooperation with industry, access to electronic scientific databases and the improvement of research infrastructure. Regarding agricultural sciences, the Strategy recommended supporting R&I for rural development, innovations in agriculture and increasing the income of farms and rural communities. The strategy also called for developing additional knowledge on sustainable development, management policies, evaluation of the achieved development and competitiveness and institutional development. A new strategic document was approved for 2017–2022 (Government of Bosnia and Herzegovina, 2016), expressing continuity in policy objectives and updating the action plan.

The World Bank (2013) presented a comprehensive report on policies for AWM in BiH. It included an analysis of the situation of local R&I. The report called for an urgent empowerment of the knowledge base to foster competitiveness. The World Bank found that human resources for R&I were low (even for regional standards), the R&I funding structure was inadequate (with relative funding intensities by the government, the private sector and higher education system of 80%, 10% and 10%, respectively), scientists concentrated in just a few centers with limited mobility, scientific publications were scarce and had a moderate impact and R&I results showed incipient traits of commercialization. The population of researchers in the country was 443 per million inhabitants in 2021 (UNESCO, 2021). When this information was combined with the population reported by the Agency of Statistics of BiH, the total number of researchers was 1496 in 2021. The number of researchers decreased in the period 2015–2021 at a rate of 39 per year. The number of scientific publications per capita on Agri-Food in BiH is about 30% of that of the Western Balkans Economies (Matusiak et al., 2022). The World Bank (2013) established a set of priorities aiming at the identified problems, focusing on providing sufficient resources for policy implementation and impact evaluation, improving coordination among different government levels, and building statistical infrastructure to monitor R&I activities, facilitating progress tracking.

Deloitte (2013) presented a summary of BiH policy developments and a snapshot of the evolution of science in the country. The document claimed for women careers in science and measures to promote gender balance. Between 2006 and 2012 the number of University students grew in RS from 27 k to 47 k, and in FBiH from 63 k to 72 k. However, a strong decline in the population and more intensely in the students enrolled in education at all three levels has been recently reported by Mujčinović et al. (2020). The enrollment rate in BiH Universities

decreased in the period 2009–2019 (from 148.100 to 112.933, a reduction of 35.167 students or 24%). In the same period, population decreased from 3.491 to 3.416 million inhabitants (a reduction of 75,575 inhabitants, or 2.2%). On the positive side, BiH Universities have made relevant progress in the application of the European Credit Transfer System (ECTS) (European Commission, 2017). Regarding gender in Universities, women represented 63% of Degree, 63% of Master and 47% of Doctoral students completing their programme in 2022. In the same year, Women represented 43% of Faculty members and 58% of Teaching Assistants. (Agency for Statistics of Bosnia and Herzegovina, 2022).

The participation of BiH in the EU Framework Programme for R&I (The EU FP, currently Horizon Europe) has strongly increased (Mirascija, 2010). During the period 2014–2020, BiH obtained a net EU contribution of 8.72 M€, with 70 signed grants, 118 participations and a success rate of 12%. This represents doubling the participation indicators respect to the previous seven-year programme. In addition, BiH is a member of the COST, Erasmus+ and EUREKA European R&I programmes.

RS adopted a Strategy for Scientific and Technological Development for the period from 2017 to 2021 (Government of the Republika Srpska, 2017). About 43% of the R&I budget is dedicated to projects (basic, applied and experimental development). Grants are also allocated for mobility (about 4% of the budget). Additional R&I funds are allocated by other Ministries. According to Deloitte (2013), the total budget for R&I in RS was 13.4 M€ in 2011. A new draft of the RS Strategy document for the period 2023–2029 is currently in public consultation (Government of the Republika Srpska, 2023). The document pursues further harmonization with the legal acquis of the European Union and with the Berlin Process for the Western Balkans. The concept of Smart Specialization, the promotion of Open Science / Open Data, the alignment between education and the labor market and the pursuit of digitalization are relevant aspects of the new strategy.

FBiH embarked in the preparation of the 2016–2026 strategy for the development of science and research. One of its strategic priorities was to improve the quality of higher education, scientific work and databases. The document has not yet been adopted. FBiH R&I has been transferred to the Cantons, which adopt legislative acts, and administer funding (projects and mobility, for the most part), through the responsible Ministries. FBiH also annually provides funding through competitive grants. According to Deloitte (2013), the total R&I investment in FBiH ranged between 1.5 and 2.7 M€ in the period 2007–2013.

A large number of BiH University faculties can contribute to consolidate R&I in AWM. This can be illustrated by the number of faculties in four disciplines: 8 Faculties of Agriculture (7 public, 1 private), 9 Faculties of Civil Engineering (7 public, 2 private), 24 Faculties of Economy (10 public, 14 private) and 4 Faculties of Political Science (2 public and 2 private).

3.2. AWM policy and performance in BiH

BiH has a complex institutional framework for water management. Low coordination and cooperation between local institutions reduce the

outcome of the water sector. Responsibilities in water management are fragmented and distributed at the State level, the Entities and BD level, the Cantonal level (in FBiH) and the level of local administration (cities and municipalities in FBiH and RS). At the state level, the BiH Ministry of Foreign Trade and Economic Relations is responsible for coordinating activities and plans between the Entities and international institutions. The BiH Ministry of Communications and Transport is in charge of river and sea navigation. Water management is the responsibility of the Entity Ministries of Agriculture, Forestry and Water Management and the respective Water Agencies. However, water use, flood protection and climate change adaptation require active cooperation between the sectors of hydropower, agriculture, forestry, spatial planning and the environment.

Hydrographically, BiH belongs to two major basins: The Black Sea basin (76% of the country, discharging to the Sava River Basin) and the Adriatic Sea basin (24%) (Marić et al., 2017). The mean annual precipitation for BiH amounts to 1250 mm. Precipitation is neither spatially nor temporally evenly distributed. Severe droughts have caused enormous damage to BiH agriculture in recent years (Marić et al., 2017). Climate change is increasing the pressure on agricultural production, particularly during the summer months, when a reduction of precipitation is expected along with an increase in air temperature (Stricević et al., 2018). Adaptation measures include the anticipation of the sowing / planting date of spring-summer crops and the introduction of irrigation, though their implementation level is very variable. BiH currently uses about 29% of its water potential. The United Nations (2017), in their report on the environmental performance of BiH, advocated for environmental assessment of new water resources projects for agriculture.

The BiH government operates on the principles of promoting integrated water management, preventing degradation, achieving sustainable water use, ensuring fair access to water, promoting social and economic development, ensuring protection from water, fostering public participation and fulfilling international obligations (Hadžić and Imamović, 2020; Marić et al., 2017). A decentralized system has been implemented for RS, FBiH and BD. The effective coordination of these water management systems at national and transboundary river basin levels remains a key challenge (Hadžić and Imamović, 2020). Water laws and Strategies have been approved in FBiH and RS, incorporating the European Nitrates Directive (European Commission, 1991) and the Water Framework Directive (European Commission, 2000), among others.

The FBiH Water Law (Government of the Federation of Bosnia and Herzegovina, 2006) required a large number of by-laws. While most of them have already been adopted, a number of them are in different degrees of progress. FBiH river basins are managed by Water Agencies. The Agency responsible for the Black Sea Basin is located in Sarajevo, while the Agency responsible for the Adriatic Sea Basin is located in Mostar. The Water Management Strategy of FBiH (Government of the Federation of Bosnia and Herzegovina, 2012) focused on agricultural pollution, particularly in the Sava River Basin. The document requested R&I actions to characterize spatial units about the use of agricultural land and the impact of these activities on water quality under various hydrologic conditions. The FBiH government is expected to issue methodological regulations and parameter thresholds for the classification of surface and groundwater bodies.

The RS Water Law (Government of the Republika Srpska, 2006) blends knowledge of the local water sector, as well as the modern European view of water management (Government of the Republika Srpska, 2016). The Law prescribes an integrated approach to water management, defines responsibilities, introduces a river basin management approach, and aligns with the 'user/polluter pays' principle. The public institution Vode Srpske is the water management authority, formed as a river basin organization with sectors for the management of the Sava and Trebišnjica rivers. Surface water quality is measured annually since 2000. Groundwater status classification is done by

monitoring the quantitative and chemical status of groundwater, following the European Water Framework Directive. RS is currently implementing its strategy for integrated water management (2015–2024), in alignment with EU directives in the field of water management (Government of the Republika Srpska, 2016).

Climate change requires policy reorientations in the field of AWM. Iglesias and Garrote (2015) evaluated a set of adaptation measures, rating them according to a benefit-to-effort ratio. Cost-effective measures to improve resilience and adaptive capacity included improved monitoring and early warning and improved coordination planning. To respond to changes in water availability, these authors identified improving water use efficiency and the construction of small-scale reservoirs. These measures are compatible with the current situation in BiH. However, water quality as related to agriculture is a bigger challenge, requiring additional measures like the optimization of inorganic and organic fertilization. These measures are listed in the RS Environmental Strategy (Government of the Republika Srpska, 2022).

The total agricultural area in BiH is 2.2 M ha (1.6 M ha of cultivable land and 0.6 M ha of pastures). The annual Gross Value Added (GVA) for agriculture, forestry and fishing is about 870 M€, with a growth trend (Predić et al., 2018). Agriculture has a greater significance for RS than for FBiH: The GVA for agriculture in 2015 was 9.3% in RS and 4.6% in FBiH, while employment in agriculture was 29.1% in RS and 17.9% in FBiH. According to the World Bank (2020), the contribution of agriculture to BiH GDP has been falling over time, from around 15% in 2001 to 7% in 2013. At the same time, local production has been increasingly able to satisfy local food demand: while in 2001 the value of food imports was fifteen times the level of food exports, in 2012 the ratio fell to four. Unfortunately, this ratio did not improve in 2019, when agri-food exports amounted to 435 M€ and imports amounted to 1652 M€ (Martinovska Stojcheska et al., 2021). BiH agriculture relies on small-scale agricultural production, with growing difficulties to apply new technologies (Vaško, 2022).

Until 1992, irrigation systems in BiH covered a total of 19,570 ha: 12,600 ha in the Sava River Basin and 6970 ha in the Adriatic Sea River Basin (Marić et al., 2017). Despite these large figures, many systems were not completely functioning. An assessment of the status of these 20th century structures is largely pending (Sagardoy, J. A., consultant of the World Bank, personal communication). The World Bank has been providing loans for irrigation development and rehabilitation in BiH during the 21st century. The Small-Scale Commercial Agricultural Development Project was completed in 2010, improving irrigation structures in 35 areas covering 4100 ha and creating 37 Water Users Associations (WUA). The World Bank (2020) completed an additional Irrigation Development Project (IDP), with an investment of 47 M US\$. Several challenges were identified during the conception of the project, including land fragmentation, with little production surplus for the market; difficulties in establishing WUAs and collecting water use fees; and institutional and regulatory issues with respect to water charges, advisory services, lack of funding for on-farm improvements, and market limitations.

J. A. Sagardoy (personal communication) compiled information on the status of irrigation in BiH. In his view, by 2020, the World Bank had provided funds for irrigation rehabilitation projects adding up to 2500 ha in RS and 2300 ha in FBiH (4800 ha in BiH). He showed concern for the lack of statistics on irrigation practice, reproducing figures used in the country: approximately 30,000 ha of individual irrigation systems and about 2000 greenhouses using irrigation. Regarding the governance of irrigated areas, different models are in use in the country. Among them, cooperatives, WUAs and public/private companies. These new irrigated areas developed in the 21st century are starting to recover irrigation costs and are taking steps towards effective operation and maintenance.

At the interface between R&I and AWM policies, the Agricultural Knowledge and Innovation Systems (AKIS) have set out to transform European agriculture. Vaško (2022) and Bajramović (2022) presented

AKIS reports and action plans for RS and FBiH, respectively. These reports are based on SWOT analyses, institutional mapping, roadmaps (objectives, milestones, deliverables, resources needed and timeline) and action plans. The documents call for applied R&I and reforms in the agricultural education systems as means to develop a technology-rich agricultural sector.

3.3. Stakeholders perceptions

3.3.1. *Su1, R&I policy makers*

The BiH Government analyses the investments performed in R&I and evaluates the development of capacities. Entities elaborate their policies using research documents among other inputs. Entities (and cantons in FBiH) fund R&I which is relevant to their priorities. AWM is not a specific priority in BiH, but eligible applications are generally funded.

Entrepreneurial thinking among researchers can accelerate the societal impact of research funds. Collaboration between researchers and industry is sought to impulse problem-solving research, complementing curiosity-driven research. Specific programmes have been designed to meet this goal, but the number of applications has not been high. R&I impact is analyzed using indicators and programme statistics.

3.3.2. *Su2, R&I funding bodies*

Administrative problems arise in R&I funding due to the contrast between annual Ministries budgets and the need for multiannual investments. R&I funding agencies are a standard solution for transparency issues and multiannual funding, but such agencies have not been implemented. Calls are published about annually, with funds granted for the current year, and the execution period can be reduced to six months. BiH funding is seen by some researchers as seed grants to incentive application to international calls. Funding organizations focus on different programs: infrastructure, human resources or other direct costs. Funding organizations in BiH (Entities and/or Cantons) can only fund their own researchers, without chances for coordinating efforts within BiH or in the Western Balkans. Some bilateral mobility actions are an exception to this rule.

Electronic portals are used by most funding organizations. Proposal evaluation is based on peer review, with some internationalization (expatriates are often recruited as evaluators due to their knowledge of the local language and the R&I system). The quality of a proposal is considered more important than its adequacy to priorities. Success rates are usually very high for projects and human resources calls. Funds per proposal are often adjusted to obtain these high success ratios. At the end of project execution, the financial aspects are reviewed. However, the outcome is typically not evaluated, or is evaluated through outcome-based indicators.

Funding programs for human resources focus on the doctoral phase, seeking internationalization of early career researchers (attending seminars, congresses). International programs for young research careers and mobility schemes are very appreciated by young BiH researchers (this is the case of EU FP, COST, Fulbright, Erasmus+, Mevlana or CEEPUS).

Pushing societal development is a clear priority in BiH, but funding is much more applied to curiosity-driven research than to problem-solving research. To accelerate societal impact, institutions are aware of the need to deepen the understanding of societal problems, promote interdisciplinary approaches, foster public-private partnerships, and focus on entrepreneurs.

Gender balance is often adequate in BiH R&I teams. However, evaluation committees are typically more populated by men. This could affect gender equality in the result. Gender equality will help a transition in R&I and public administration values in BiH.

Projects on AWM are very rare in all BiH funding organizations. Some funding organizations have not received one for years. Entity Ministries of Agriculture, Forestry and Water Management fund applied research projects, focusing on direct solutions to the sector. This may

apply to the practical problems related to building irrigation systems.

3.3.3. *Su3, academic institutions related to AWM*

University employees are requested to perform R&I activities, involving students from all three study cycles. Researchers are rewarded by obtaining and executing projects: they obtain salary rises, materials, equipment, study stays or training. Researchers can increase their salaries using part of the project costs dedicated to person-months. R&I products lead to progress in academic careers. Some Faculties recruit a few members specializing in research, employing them on a fixed-term basis. R&I on AWM requires multidisciplinary efforts in the Universities and other public and private institutions.

Funds for R&I are mainly provided by Ministries responsible for Science or Agriculture, by International agencies (mainly the EU FP) and by private sources (a small amount). Universities offer courses on proposal preparation and paper publishing. Project management offices with limited staff are often available at the central services of the Universities, with some support by the Faculties.

3.3.4. *Su4, permanent faculty in AWM*

A common time balance scheme between R&I and lecturing in BiH is 30 – 70%, respectively, but a small part of the Faculty members (10–15%) does extra R&I activities. The lecturing effort is quite variable (from 4 to 20 h/week), and it is not directly linked to R&I dedication. Faculties are organized in Departments for lecturing and often in Institutes for R&I. The largest Universities (Sarajevo and Banja Luka) have several thematic Institutes, while smaller Universities may have one Institute or may not have specific structures for research. Some Institutes are not affiliated to Universities. BiH Faculty members can get indirectly paid for R&I (following promotion) and/or on the occasion of publications, particularly in high-impact journals. Researchers often focus on preparing high-impact papers in English, and fail to communicate with local stakeholders. The intensification of research for societal development should be accelerated by institutional support and strengthening ties with the economy. Increasing public-private cooperation is a key issue at the moment.

National R&I funding is not sufficient: one international project may have a larger budget than one of the BiH Entities. International projects are therefore the best and most common option for R&I funding. Private financing is very rare. Administrative regulations complicate the execution of project budgets. Legal requirements often make project implementation complicated and slow. Training on preparing proposals and publishing papers should be more advanced and hands-on. Project management offices would be more effective at the Faculties than at the central services of the Universities.

There may be less than a dozen researchers in AWM in BiH. Local opportunities for food security are linked to water availability and its management. On the other hand, flooding is a problem in some areas of BiH. The country needs to take important steps towards digitalization. Access to public data is difficult even for public Universities (for instance, climate data or soil maps).

New irrigation developments are proving very effective for crop production. In some areas, rainfed agriculture is declining and shifting to irrigation. Farmers need to be trained in modern / smart irrigation and fertilization techniques to increase productivity, reduce the waste of resources and control pollution. Management is a critical word for future projects, since management is weak in BiH at all levels. Due to climate change, early warning systems for drought and flood-risk management should be among top priorities. Research activities are limited to a small number of young, motivated doctoral students and postdocs. Researchers need economic incentives in recognition of the impact they create. Farmers and researchers need to be more connected. Producers need to be more proactive, less subsidy-oriented and more capable to verbalize their R&I needs.

3.3.5. *Su5, early career researchers in AWM*

The most common position for early career researchers is that of a University Teaching Assistant (TA). They are frequently engaged in various Faculties and even various Universities at the time. TA contracts are full-time, and include lecturing (frequently, practicum) and other academic activities. R&I dedication is about 20–30% of their time. The lecturing commitment is between 10 and 20 h a week. University careers often take a long time to develop. Long career development periods often start with the doctoral phase, frequently exceeding the standard duration. Most TAs do not feel sufficiently rewarded for their R&I activities, and family conciliation is always an issue. They need R&I products to reach Assistant Professorship. Personal satisfaction would increase with salary rises responding to R&I accomplishments and a clear definition of their duties. TAs claim more time for field research and more independence. Young researchers can also be hired at Institutes, where R&I is part of their duties (about 40%) and they can interact with farmers. These researchers do not feel personally rewarded either and believe that R&I funds are insufficient and that maintaining a research profile is very difficult, due to the high number of concurrent tasks.

Early career researchers believe they have capacities to address societal problems and support policy development, but their contribution is detained by mistrust from politicians, the private sector and Academia. Young researchers often feel that opportunities for funding and societal interaction are not within their reach and that policies are not sufficiently evidence-based.

R&I in AWM is insufficiently developed. Part of the problem may be related to the exclusive attributions of the water agencies, in which Universities can only do R&I under their supervision. Coordination is needed since issues like digitalization, pollution control and policy writing would benefit from the contribution of early career researchers. In their view, irrigation in BiH is no longer supplementary: it is systematically needed in many agrosystems.

3.3.6. *De1, AWM policy makers*

At BiH level, Ministries coordinate and harmonize the different levels of government. Entity-level policymakers often use research outputs to produce strategic documents and laws. The water laws from the Entities show awareness about irrigation in their legal texts. Regulations for agricultural water abstractions are limited. The EU Nitrates Directive is considered for policy issues. A plan for vulnerable areas to nitrates has been defined, including monitoring. BiH institutions have developed some statistical data which are used by researchers.

At the Ministries, capacities for policy development are moderate. Policy makers appreciate researchers' capacities for analytic thinking and networking, for instance in rural development. Entities believe that water agencies are responsible for establishing links to researchers. Public capacities for planning water resources in agriculture do not seem to be mature in BiH. There are small teams in the Ministries, with limited control of key issues. Ministries seem to request from researchers more operational support than policy documents, and state that Universities lack these experimental capacities today.

Water Agencies need to play a role in AWM, but this role has not yet been firmly established. They intervene in hydrology, water abstraction and water quality, and they are increasing their digitalization. Water quality for irrigation has been measured since 2000. Agencies see that WUAs are key for water fee collection. There is an urgent need to create an inventory of irrigated areas, update water concessions and record water use, particularly in individual abstractions.

Policy makers would like to see more funds applied to problem-solving research. In their view, World Bank projects to rehabilitate irrigation systems are problem-solving research. The country is currently discussing a new project to develop small (up to 30 ha), new irrigated areas, strengthening the capacity of the institutions involved. The involvement of Faculties, Institutes and Advisory Services will be required. Considerable public investments are being made to upgrade

BiH irrigation systems. The creation of WUAs has had moderate, variable degrees of success. Public organisms continue to pay a variable share of WUA costs. Doubts exist as to how to implement irrigation management transfer. Decreasing rural population calls for action and at the same time makes projects more difficult to implement. In new projects, telemetry systems will be used to monitor irrigation activities. Some irrigation systems from the 20th century were never used, calling for rigorous analyses of the projects currently being conceived.

3.3.7. *De2, agencies advising farmers on water issues*

BiH advisory services have a small dimension, and cannot cover neither all areas nor all specializations. The coverage of AWM is poor in comparison with other topics, and shows relevant limitations. Despite these limitations, advisory services are in direct contact with farmers. Farm advisors are aware of the challenges related to agricultural water. Drought has been intense in the last years, and the yield of many key crops has been affected. Small farmers meet difficulties in using the right equipment and techniques and obtaining the data acquired at different administrative levels. The network of agrometeorological stations is poorly developed and the quality of data is questionable due to inadequate maintenance. Moreover, there is no obligation and willingness to share the data among interested stakeholders. The same is true also for the network of hydrological stations. Irrigation training programs are being promoted for field crops (using rain gun type sprinklers) and particularly for greenhouses (using drip irrigation). A comprehensive approach is required in BiH for advisory services, integrating all science and disciplines of science and technology supporting irrigated agriculture.

3.3.8. *De3, farmers, farming companies and farmers' organizations involved in AWM*

Irrigation farmers produce a wide variety of crops: field and greenhouse vegetables, berries, vineyards, orchards and field crops. Agriculture is fragmented, and holdings have a typical area of 0.2 to 0.5 ha. Larger farms are often devoted to field crops. Irrigation networks are also very important for water supply to animal farms. Many farmers use short commercial circuits to sell their products. Professional farmers are slowly emerging. They specialize in crops (i.e., berries, vineyards) and have developed commercialization skills. Farmers are increasingly dependent on irrigation water supply, but their capacities in irrigation are usually low.

Most farmers believe that the future will not bring major changes to local agriculture. However, they see that improvements are required in irrigation to ensure product quality and their quality of life. They are ready to invest in irrigation, but they count on public subsidies. When asked about R&I needs, farmers identify the use of irrigation systems in different agroclimatic areas and their financial viability as key issues, followed by R&I on water availability and infrastructure. Farmers believe that informal water abstractions have increased in the last years and that the official figure of 0.65% of the total arable land in BiH being irrigated is no longer real. They also believe that the WUA model does not work in their conditions, since collaborative efforts often last as long as the irrigation construction phase. Farmers are very inclined to see these responsibilities in the hands of government offices.

Irrigation problems are often related to structural issues: small plots requiring land tenure consolidation, or collective infrastructure in need of rehabilitation. In other cases, infrastructure is to be developed, but costs are very high. The quality of irrigation equipment is very variable: standardization and advice are needed to protect farmers' investments. Farmers in WUAs typically contribute to irrigation water costs with less than 50 Convertible Marks per hectare (25 €).

In farmers' perception, water pollution will continue to gain relevance. However, farmers see municipalities and industries as the key sources of water pollution. Water scarcity may become a relevant issue for BiH: natural water flows are decreasing, and the irrigation season has extended. Small farmers often resort to tap water for small-scale summer

irrigation. Farmers have a variable capacity to cope with AWM problems. Flooding and irrigation water quality are mostly out of their control. They can only invest in on-farm irrigation and drainage equipment.

Farmers obtain technical support from WUAs if they exist. WUAs are frequently managed by Municipalities. It is often difficult for farmers to make a difference between the WUA and the Municipality. In some cases, Municipalities provide water for irrigation from their urban water network. Farmers can also obtain support from advisory services (only partially available in BiH) or University Faculties, though this is infrequent. Finally, farming companies obtain information from Universities, public agencies and other companies. These companies think that advisory services should intensify their activities and that Universities should provide more practical information.

3.3.9. De4, Water users associations

When a WUA is in operation, farmers rarely resort to alternative water sources. WUAs often recover operational costs (not investment costs), maintain irrigation structures and foster farmers' participation in water management. WUAs believe that the relationship with Municipalities is much closer than the one with the Government. WUAs provide advice to farmers on irrigation, specializing in local crops. Two irrigated areas have been targeted in this research. Specific workshops were performed with WUA representatives and farmers.

3.3.9.1. Bratunac (WU-BR). In 2014 the Municipality of this sub-humid area proposed a drip irrigation project for berries (mostly raspberries), also irrigating vegetables, pastures and supplying animal farms. The irrigation system was built in 2018 through the World Bank IDP project, on an area of 440 ha, with about 600 users. A World Bank loan covered 85% of the investment, while the Municipality participated with 15%. The system is composed of 24 independent subsystems covering an area 60 km long on the left side of the Drina River. Pumping stations send water to elevated reservoirs, and water flows by gravity to farms. 250 shared hydrants serve about 2 ha each. A typical family berry farm has an area of less than 1 ha. Water application is low, about 300–500 m³/ha, but very important to sustain yield. Farmers are requested to pay for half of the system operation costs, while the other half is covered by the Municipality. Water meters are installed in some hydrants, and farmers pay either by volume or by the area. The system is currently expanding its users and irrigated area. Farmers are very satisfied with the irrigation system and with berry production. A section of Malina-Bratunac, a Municipality company for berry production, takes the roles of the WUA and Advisory Service. The workshop evidenced some open R&I questions: the relation between irrigation, fertilizers and yield, the optimization of irrigation scheduling and the differences in water requirements among berry species and cultivars. Apart from water, problem-solving research is needed in issues like post-harvest and commercialization. Berry plantations equipped with irrigation systems are providing local families with key income opportunities in the area.

3.3.9.2. Trebinje (WU-TR). This Mediterranean city has a rich irrigation tradition based on wooden wheels for water extraction from the Trebišnjica River and ditches for water distribution to the riparian areas. Summer droughts and winter floods have characterized the hydrology of this area devoted to the vineyards and the production of stone fruits. Early in the 21st century, big gun irrigation systems were introduced, but plant protection problems arose, and drip irrigation was identified as the key irrigation technology. The World Bank IDP project in the Trebinje Municipality covered about 800 ha. Funds were applied to infrastructure, participatory irrigation management and advisory services. Water is pumped from an existing pipeline crossing the valley and from the river bed. A complex system of remotely controlled pumping stations directly delivers water to hydrants. The Trebinje Municipality is in charge of infrastructure operation, delivering water to farmers in an

effective way. From the organizational perspective, the system is composed of 37 WUAs, mostly deriving from the local irrigation history. This complex governance is the source of many organizational problems, with large differences in performance and participation among irrigated areas. Attempts have been made to set the Trebinje project under the authority of Vode Srpska, but the Municipality continues to be in control through its Agrarian Fund. Electricity is a key operational cost, which is subsidized by the Municipality. Farmers are requested to cover operational costs by the area. Local farmers often have jobs in the services sector, and devote part of their time to agriculture. R&I questions in Trebinje are associated with the agronomy of the local crops and the relation between irrigation, fruit production and quality and vegetative development.

3.3.10. De5, agricultural companies (inputs, commercialization, transformation) related to AWM

A few of these companies provide expertise in irrigation systems, and can prepare water management plans for farmers and public institutions, controlling water risks in the agricultural sector. Companies perceive that traditional farmers need to improve their water management skills through the adoption of the latest technological achievements, education and awareness. Climate change requires new capacities and structures, which are not being developed at sufficient speed. Customers in specific areas contemporarily use irrigation and drainage systems to improve agricultural production. While irrigation can often be solved individually, drainage requires collective and/or public action. Companies obtain advice from manufacturers of imported irrigation equipment. Companies do not have specialists in irrigation or R&I departments. They do not contract R&I services and do not hire external technical consultants. When advice is required, companies resort to colleagues, universities or other companies.

3.3.11. De6, non-governmental organizations involved in water issues

Some NGOs are devoted to nature preservation, while others are concerned with increasing the income of agricultural communities. NGOs have been actively opposing projects threatening water resources. In parallel, they are active in water management by traditional farmers, co-financing on-farm irrigation systems and providing training programs on eco-efficient water use. In their views, farmers have little awareness of water quantity issues, and almost no awareness about water quality issues. NGOs believe that public institutions should cooperate in this effort to make farmers aware of the economic importance of water in their activities. They see the relationship between agriculture and water quantity/quality as an important topic for future activities. In their opinion, R&I activities would be an important starting point.

3.4. SWOT analysis

3.4.1. Strengths

- S1. A sharp vision of science in BiH, as expressed in the strategy documents. Relevant policy documents adopted in RS and under development in FBiH. The BiH research strategy claims for efforts to support rural development.
- S2. Steps are taken towards the creation of relevant, competitive R&I funding systems.
- S3. The relevant amount of funding obtained from the EU FP is comparable to national funding. Active participation in other European R&I initiatives.
- S4. Adoption of the key elements of EU water policy: river basin management plans, water agencies or similar entities, focus on water quality assessment.
- S5. The interest of the World Bank on irrigation investments in the country since the beginning of the 21st century.

3.4.2. Weaknesses

- W1. Very low public and private investments in R&I; very low number of researchers, particularly for AWM; complex, decentralized, often siloed responsibilities in R&I policy and funding, as well as in AWM.
- W2. The vision in the BiH R&I strategy document remains largely unimplemented.
- W3. Agricultural advisory services are largely disconnected from scientific research, and focus on implementing the distribution of subsidies.
- W4. R&I agendas in BiH are essentially “bottom-up”: no specific priorities have been set for AWM. Lack of a strategy for R&I specialization on AWM.
- W5. Poor return to society of the knowledge produced by the scientific system.
- W6. Relevant uncertainties about the effect of droughts on food security caused by the local climate, climate change and structural reasons. The possibilities to adapt in most crops through agronomy and/or irrigation remain largely unexplored.
- W7. Incipient development of a national system for data gathering and statistics on R&I, hydrology and agrometeorology.
- W8. Limited financial instruments for water resources management, including the development, operation and management of infrastructure such as drainage, flood control and irrigation.

3.4.3. Opportunities

- O1. The Green Agenda for the Western Balkans and the Smart Specialization Strategy, two processes for policy development and prioritization with associated funding for specific topics, including R&I for AWM.
- O2. Increased participation in the EU FP, spreading within BiH the experiences of successful groups.
- O3. International donors can improve water management institutions, rehabilitate and develop AWM infrastructure: irrigation, drainage and flood protection.
- O4. Regional partnerships can lead to communities of practice in finding solutions to shared problems, as is currently being done in international river basins.

3.4.4. Threats

- T1. Lack of convergence in R&I investments with neighboring countries and/or with the rest of European countries and the European Union.
- T2. Lack of convergence in AWM policy, the crafting of water institutions and infrastructure, widening the gap with the European Union.
- T3. Climate change reaching serious damaging effects in AWM without effective adaptation measures in place through R&I.
- T4. Degradation of BiH fertile soils and abundant water resources and/or control by multinational companies. Loss of food security.

3.5. TOWS analysis

The TOWS matrix produced four strategies leading to a policy roadmap (Table 4). We assessed each strategy in the light of the relative importance of strengths vs. weaknesses and opportunities vs. threats. The prevalence of weaknesses and opportunities led to the identification of the conservative or mini-max strategy as the optimum local strategy. This strategy requires recognizing and overcoming the weaknesses and removing barriers to reach the opportunities.

Table 4

TOWS matrix indicating four possible strategic directions for the policy roadmap.

Internal	Strengths	Weaknesses
External	S1. Sharp vision of R&I S2. Steps towards R&I competitiveness S3. Increasing EU FP funds S4. EU water policy being adopted S5. World Bank involved	W1. Low R&I investments W2. R&I vision not implemented W3. Very limited advisory services W4. Bottom-up R&I agendas W5. Poor R&I return to society W6. Low R&I for AWM adaptation W7. Poor data/statistics W8. Limited financing for water
Opportunities	SO, offensive or maxi-maxi	WO, conservative or mini-maxi
O1. Green Agenda / Smart Spec. O2. EU FP for R&I O3. International donors O4. Regional partnerships	1. Ambitious, top-down R&I Plan; coordination in BiH, the region and Europe (O2, O1, O4, S1-S3) 2. Ambitious AWM Plan; coordination in BiH, the region and Europe (O1, O3, O4, S4, S5)	1. Strengthen R&I efforts (O2, O1, O4, W1-W7) 2. Strengthen AWM efforts (O1, O3, O4, W4-W8) 3. Declare priorities for R&I on AWM (O1, O4, W4)
Threats	ST competitive or maxi-mini	WT, defensive or mini-mini
T1. No convergence in investments T2. No convergence in policies T3. Climate change T4. Natural resources degradation	1. Prioritize existing capacities to overcome threats (S3, S4, S5, T1-T4) 2. Prioritize investments and policy development (T1, T2)	1. Overcome critical weaknesses in a decade-long effort (W1, W4, W6, W7, W8) 2. Focus on opportunities to seize funds and establish alliances

3.6. Formulation of a policy roadmap

The proposed policy roadmap implements a conservative or mini-max strategy. The roadmap rests on the three policy goals resulting from the TOWS analysis (Table 4). Each of them is implemented through policy instruments. The roadmap derives from the SWOT and the perceptions of stakeholders' groups. Connections have been signaled in the paragraphs below using the acronyms presented in Tables 1 and 4.

3.6.1. Strengthen R&I

BiH University Faculties (agriculture, civil engineering, economy, political science...), Institutes and Extension services are called to stimulate the dynamism of local agriculture in days of relevant challenges (W5, Su4). Academic careers should be structured around the three classic university missions (lecturing, research and outreach), with explicit, nation-wide recognition of each mission in salaries and promotions (Su4, Su5). Extension services need to develop specific careers, recognizing efforts in problem-solving research (W3, De2, De3). Early career researchers also need to get recognition for research, and an effort should be made to improve their integration in all aspects of academic life (Su4, Su5). Universities need to adjust the duration of doctoral training to the academic standards (Su5). Efforts toward the internationalization of doctoral students should be intensified (Su2). For instance, doctoral scholarships in BiH could include mandatory stays in other countries (about six months) to gain experience in different R&I models without losing connection to local institutions and societal problems. Industrial doctorates (performed in the private and public sectors) would facilitate University outreach and intensify dialogue between Academia and society (Su2, Su4). Strong R&I evaluation procedures are particularly needed to identify and promote talent in early

career researchers (Su5). Gender neutrality should be assessed in all instances of scientific evaluation (Su2).

The increase in public research R&I funding should be a reality after two decades of GDP growth (W1, Su4, Su5). In parallel, three cost-effective actions seem critical in the short term. The first one is to increase efforts to attract international funding (i.e., the EU FP) (O1, O2, Su3, Su4). Young doctors could specialize in this task, deploying their activities in the Faculties. The EU FP has identified this opportunity and is explicitly funding the reinforcement of Project Offices in its Horizon Europe Widening Calls. The second one is to break the funding silos of the Country, Entities and Cantons (O4, Su2) by using soft cooperative funding models like the Virtual Common Pot (Hünermunda, Czarnitzki, 2019). In this model, every member of a consortium has its part of the proposal funded by the local funding agency, following a unified evaluation. Small R&I communities, like that of BiH AWM, may lack the critical mass to formulate a proposal by themselves, but can get funded and boost their capacities through consortia. Finally, BiH urgently needs to develop a comprehensive, open statistics system on R&I (W7). These measures will accelerate the reorientation of the R&I system, increasing trust by stakeholders.

3.6.2. Strengthen AWM

BiH needs to systematize the generation, curation and publication of hydrology and agronomy data (W7, Su4, De1, De2). This database will feed policy development, environmental sustainability and entrepreneurship. Records are particularly required on water and soil science, meteorology, agricultural profitability, structures, agricultural water use (collectively and individually) and the nitrate levels of return flows from agricultural areas. The database could promote and document the sustainability of local agricultural production. Progress in the consolidation of WUAs should also be assessed with a research perspective to stimulate international donors (W8, O3).

There is an urgent need to consolidate and digitalize AWM in BiH (Su4). Governments need to exploit data and disseminate tools. The introduction of business intelligence practices and information technologies will support the development of sustainable, intelligent and site-specific AWM. In turn, this will attract young, capable professionals to the rural environment. AWM needs to be integrated into a sustainable, technology-rich, dynamic, gender-equal rural life (De1), creating synergies with other pillars of societal development such as innovation, nature-based solutions, organic farming, landscape valorization or tourism. These actions are very much in line with the Green Agenda for the Western Balkans and Smart Specialization. Both processes represent critically important funding opportunities for BiH AWM (O1, O3).

Finally, the interaction between the R&I community, policy makers, governmental institutions and international donors will accelerate developments in AWM structures adapted to the local conditions of BiH farmers (W8, De1, De3). Research results will be needed to facilitate the adoption of technology for climate change adaptation, irrigation, drainage and flood control (W4, W5, W6, Su4). Particular attention should be given to smallholders to overcome their difficulties in access to technology and to develop specific business models adapted to their needs (De2, De3, De6).

3.6.3. Identify and fund local priorities for R&I in AWM

The R&I funding system needs to develop capacities to support problem-solving, site-specific research on specific aspects of AWM (W4, Su1, Su2, Su4, Su5, De1, De3, De5). Among them, adapting to extreme climate events (droughts, heat stress and floods) (Su4, Su5, De3, De5, De6), controlling nitrates pollution (in non-irrigated and irrigated areas) (Su5, De1, De3), generating added value in irrigated areas through specific crops and agronomic recipes, or regulating groundwater tables (Su5, De3, De4, De5, De6). Research objectives should focus on the adoption technological, management and social innovation solutions based on the eco-efficiency concept (De6), i.e., increasing the economic benefits of agricultural production while reducing negative

environmental impacts (Keating et al., 2010). Pilot projects in cooperation with the private sector should be set up to demonstrate viability and facilitate technology adoption (Su1). These priorities will have an impact on food security (balancing imports and exports) and contribute to cleaner environment, sustainable development and resilient socio-economic growth of rural areas. Priorities could be established at the regional scale, so that funding could be seized from international R&I programmes (O1, O4).

3.7. Implementation of the policy roadmap

Implementing the policy map requires successful interaction with a number of additional concurrent policies and processes:

- Higher Education. Efforts to reform higher education and extend the role of local Universities to intensify research and outreach activities need to be in line with the proposed roadmap.
- Agricultural knowledge and innovation systems (AKIS). The proposed roadmap needs to be coordinated with the AKIS action plans produced for FBIH (Bajramović, 2022) and RS (Vaško, 2022). AKIS maps locate farmers in the center, surrounded by knowledge supply and the rest of knowledge demand actors.
- Social innovation. New solutions are required to the sustainability problems of BiH agricultural water management, which may come from business, academia, civil society and governments.
- Digital transition. The need for open-data repositories of R&I and AWM information is in line with the current drive for digitalization and the priorities identified by international funding organizations.
- Green transition. Innovative actions in clean technologies, ecosystem services, carbon-neutrality and renewable energy are required in BiH alongside with more conventional AWM R&I lines.

Interaction with these policies and processes needs to be considered when designing the action plans and their milestones, deliverables, resources and time lines.

4. Discussion

Stakeholder consultations were a critical source of information to develop a policy roadmap to consolidate R&I in AWM in BiH. Similar participatory stakeholder engagement methodologies have been used in the literature to address the strong relations between water and research policies in agricultural environments. Recently, D'Agostino et al. (2020) analyzed AWM policy and practice in Malta, and found relevant links to R&I policies, such as the need for applied research, the development of local priorities and the empowerment of advisory services.

In the case of BiH, an effort has been made to improve the situation of R&I, intensifying participation in EU programmes and obtaining a relevant volume of international competitive funds. Efforts are also being performed in the Entities to establish R&I programmes, though the investment level remains fairly low. BiH Universities have a relevant potential to contribute to improve AWM. Despite the large number of academic institutions, their cooperation and outreach capacities are frequently low, concentrating on teaching. The focus of agricultural advisory services on AWM is weak; Rokvić and Vaško (2016) reported that local advisory services give more priority to the implementation of governmental support measures than to technology development.

Increasing the number of BiH AWM researchers, their international connections and funding seems urgent to produce the knowledge required to contribute to farmers (particularly smallholders), agricultural production, water management and the related policies. This will result in a growing number of AWM R&I proposals submitted to BiH funding entities, which should be integrated in the local policies. It is recognized that science has become more predominant in public debates and that governments are increasingly willing to include scientific knowledge in policy discussion, even recurring to the co-creation of

research output (European Commission, 2023). An integrated approach to water management is nowadays pursued worldwide (Fritsch and Benson, 2020). BiH is not an exception to this rule, although this integrated approach is observed at uneven levels across the country: either strategic, legal or implementative.

Connecting universities to the solution of AWM problems requires R&I career evaluation procedures based on quality and impact, more than on bibliometric analyses. For example, Weissshuhn et al. (2018) reviewed impact assessment procedures in agricultural research, reporting that economic and societal impacts were often considered, but environmental impact was rarely assessed. The San Francisco Declaration on Research Assessment (DORA, 2013) or similar declarations claiming for expert assessment of the quality of individual research products (instead of using surrogates such as journal-based metrics) will be useful to assess individual scientist's contributions in hiring, promotion, or funding decisions.

The identification and funding of R&I priorities will accelerate adaptation to climate change, transform water use in agriculture, promote the eco-efficient use of resources and facilitate sustainable development in rural areas. Agronomy tools, such as the modification of sowing dates, the choice of cultivars, the introduction of more adapted crops, the deployment of conservation/organic agriculture or the wise use of water and fertilizers, can promote water conservation and water quality in the local agroecosystems (Stricevic et al., 2018). Recently, Mitrović et al. (2023) emphasized the importance of optimized application of resources (water, fertilizers, and energy) to reduce the environmental impact of rainfed and irrigated maize and to promote sustainable management practices. The irrigation sector in BiH requires an assessment of its current extension, performance and impact, as well as plans for future developments. Recent interventions by the World Bank have a number of positive traits, but a comprehensive sustainability analysis is required to steer future developments. Within a general context of success in irrigation practice, governance, water abstraction, water pollution and cost recovery need R&I attention.

Many of these R&I priorities have a regional character, and will benefit from cooperation at national and international level. In fact, international cooperation is a critical source of funding for BiH researchers. Cooperation with non-academic partners – such as the Water Agencies and companies – seems critical to address these priorities with a problem-solving methodology.

The policy goals proposed for BiH establish guidelines for a reorientation of local R&I in AWM in agreement with stakeholders' perceptions and in consideration of the policy environment (Iglesias and Garrote, 2015). The implementation of the policy roadmap requires coherence with the reform of higher education, the AKIS process, social innovation and the green and digital transitions. Consideration of these interactions seems critical to facilitate the adoption of the roadmap in future BiH strategic documents for R&I and for AWM.

5. Conclusions

More priority is currently given in BiH to the implementation of governmental measures than to R&I development, being R&I not a direct responsibility of the government at the national level. Thus, there is an increased difficulty to create a concerted countrywide strategy. Even so, the situation of science is improving and it is expected that positive results will intensify in the near future.

AWM is rarely addressed by BiH R&I funding entities. However, climate change should soon alter this situation, since irrigation is a tool to overcome an increasingly risky situation for farmers recurring only to rainfed production. Severe droughts in recent years have highlighted the need to rethink agriculture and AWM in BiH. Increasing irrigation in BiH is technically possible, though sustainability needs to be safeguarded.

BiH has entailed an effort to improve R&I through international competitive funds. Still, the internal investment level in R&I programs is low. Academic institutions are more focused in teaching than in

research. Reversing this situation will increase the capacity to seize international R&I funds.

For the development of a policy roadmap, major strengths were identified in the R&I vision, the funds obtained from the EU FP and the steps taken to increase the competitiveness of R&I and to adopt EU water policies. Very relevant weaknesses were found: low investments in R&I and AWM, slow implementation of the R&I vision, poor curation of R&I and AWM statistical data and low thematic R&I on AWM adaptation to current challenges. Opportunities were very important: the Green Agenda for the Western Balkans, the Smart Specialization Strategy, the cooperation with international donors and the prospects for regional partnerships. Threats focused on the lack of regional convergence in investments and policies, climate change and the degradation of natural resources. The TOWS matrix led to the selection of a conservative strategy based on weaknesses and opportunities. A policy roadmap was proposed to consolidate R&I in AWM in BiH around three policy goals: strengthen R&I, strengthen AWM and identify/fund local priorities for R&I in AWM.

CRedit authorship contribution statement

Vaško Željko: Writing – review & editing, Investigation, Formal analysis. **Marković Mihajlo:** Writing – review & editing, Resources, Project administration, Investigation, Funding acquisition, Conceptualization. **Mujčinović Alen:** Writing – review & editing, Formal analysis, Conceptualization. **Vekić Marinko:** Writing – review & editing, Investigation. **Paço Teresa A.:** Writing – review & editing, Project administration, Investigation. **Almeida Wilk S:** Writing – review & editing, Investigation. **Paniagua Piluca:** Writing – review & editing, Investigation. **Dechmi Farida:** Writing – review & editing, Investigation. **Zapata Nery:** Writing – review & editing, Writing – original draft, Project administration, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Hajder Đurađ:** Writing – review & editing, Resources, Project administration. **Čadro Sabrija:** Writing – review & editing, Project administration, Investigation. **Bećirović Emir:** Writing – review & editing, Investigation. **Šipka Milan:** Writing – review & editing, Investigation. **Grahić Jasmin:** Writing – review & editing, Investigation. **Playán Enrique:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Musić Osman:** Writing – review & editing, Investigation. **Stojaković Nevena:** Writing – review & editing, Investigation. **Todorović Mladen:** Writing – review & editing, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **Čerkević Nataša:** Writing – review & editing, Writing – original draft, Project administration, Formal analysis, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Appendix A. Supporting information

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