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Assessment of nature-based solutions for water resource management in agricultural environments: a stakeholders' perspective in Southern Italy

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This paper explores the potential implementation of Nature-Based Solutions (NBSs) in agriculture, specifically focusing on soil and water management in Southern Italy, particularly in the Apulia and Basilicata regions. Through a tailored questionnaire, it investigates farmers' perceptions of the utility of NBSs, addressing key issues in the region and evaluating their role in addressing soil and water management challenges. Findings reveal primary challenges such as drought, floods, and water pollution, with soil erosion being a major concern. Several NBSs, including wetlands and bioswales, demonstrate consistent utility and performance, while disparities exist for agroforestry and strip cropping. The study underscores a significant gap in the economic valuation of NBSs, emphasizing the need for comprehensive assessments that incorporate livability improvements, water quality enhancement, and socio-cultural benefits. Additionally, an analysis of NBS implementation across Italian agriculture reveals limited case studies, suggesting the need for strategic expansions to meet Sustainable Development Goals. This research offers critical insights into the effectiveness and challenges of NBSs in agricultural soil and water management, advocating for enhanced stakeholder engagement and the development of multidimensional evaluation frameworks to support sustainable practices.

Keywords Stakeholders' perspective, Nature-based solutions (NBSs), Soil and water management, Drought, Erosion

Hydro-meteorological risks, including floods, droughts, and landslides are exacerbated by climate change and urbanization worldwide[1]. Among the different policies and actions proposed at the international, European and national level, Nature-Based Solutions (NBSs) are currently addressed as suitable strategies for mitigating these hazards, as well as supporting the transition to sustainable and resilient development for cities and territories[1], addressing also many challenges in the agriculture sector.

Specifically related to the main impacts that hydro-meteorological phenomena have on agriculture, NBSs can be considered suitable strategies, especially for mitigating the soil erosion phenomenon and providing suitable water management, among other challenges[2–4]. It is because NBSs offer a sustainable approach to tackling climate-related issues, conserving nature, and fortifying ecosystems, strategically harnessing and managing nature to benefit biodiversity, climate resilience, and human communities[5].

Concerning agricultural lands, soil erosion can undermine soil fertility, leading to yield decline[6–8]. Thus, NBSs can be adopted as a mitigation measure because soil erosion prevention cannot be achieved solely through civil engineering actions, due to the costs and environmental impacts, which would be excessively high[9–11]. Moreover, Mediterranean experts in climate and environmental change recommend the implementation of NBSs and adaptive sustainable land management practices because climate change is expected to increase soil erosion in a complex and non-linear manner[12].

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On the other hand, sustainable water resources management is critical for addressing erosion challenges and controlling nutrient transport. In this context, NBSs play a pivotal role in optimizing the utilization of water resources, fostering soil quality preservation, and ensuring a reliable water supply for crops[13]. These innovative approaches not only tackle erosion and nutrient transport but also provide solutions for water conservation, which is essential for sustaining agricultural activities in such climates[14]. As well, NBSs play a fundamental role in supporting the implementation of directives like the Water Framework Directive (WFD) and other policies concerning water resources. NBSs could thus offer particularly cost-effective alternatives for addressing diffuse water pollution and the reuse of wastewater in agriculture[5,15–17]. Moreover, they yield numerous benefits, including climate mitigation and adaptation and enhancement of water management practices[18], bolstering coastal resilience, fostering urban biodiversity conservation, enhancing air quality, facilitating urban regeneration, promoting stakeholder engagement, fostering social cohesion, providing recreational opportunities[19], and improving public health and well-being through direct ecosystem restoration[20]. Furthermore, the application of NBSs has been proven to generate significant economic outcomes.

In recent years, there has been a growing recognition of the importance of stakeholder engagement for the successful implementation of environmental and agricultural interventions[2,18,21,22], which include NBSs. Stakeholder engagement refers to the involvement of individuals, groups, or organizations that may be affected by or have an interest in a particular project or decision. Engaging stakeholders is thus fundamental for engaging different perspectives, fostering collaboration, and enhancing the legitimacy and sustainability of the interventions[23–25]. Therefore, the engagement of stakeholder could help to fill the gap between scientific research and practical application by incorporating local knowledge and preferences into planning and implementation processes[26]. Moreover, many works in the social sciences have demonstrated that participatory approaches can lead to more effective and equitable outcomes in environmental management[27].

Stakeholder consultation and involvement are thus necessary also to support the decision-making concerning the development and implementation of NBSs in the agricultural sectors. Engaging farmers and local communities ensure that different perspectives are considered, fostering collaboration and enhancing the legitimacy of interventions, ensuring that NBSs interventions are tailored to meet the specific needs of the community.

In this context, this research addresses the adoption and application of NBSs in the agricultural sector of Southern Italy, focusing on the regions of Apulia and Basilicata. This choice has been made according to the fact that the perspective of implementing NBSs as a mitigation tool is increasingly recognised as crucial for mitigating soil erosion and water management within agricultural landscapes in semi-arid regions like Southern Italy[12].

This study aims to address some critical research questions concerning the environmental challenges faced by farmers, as well as their perceptions of NBSs utility, practical considerations for implementation, and how enhancing stakeholder engagement in the Apulia and Basilicata regions of Southern Italy.

In detail, this study addresses the less studied topics the literature, or rather the perceived utility and feasibility of implementing these NBSs among stakeholders. Therefore, this research is mainly based on the following research questions (I) 'What are the primary environmental challenges encountered by farmers in Southern Italy regarding soil and water management?', (II) 'How do farmers perceive the utility and benefits of various NBSs in addressing these challenges?', (III) 'What are the practical and feasibility considerations for implementing NBSs in this context?', and (IV) 'How can stakeholder engagement be enhanced to support the successful implementation of NBSs?'. To properly answer to the research questions, a tailored questionnaire was distributed – as a Google Form document – to local farmers through social media platforms such as LinkedIn, Facebook, and Instagram. The questionnaire covered 11 NBSs measures to gather insights into farmers' perceptions including the benefits, synergies, and trade-offs associated with the adoption and application of these measures. The active involvement of farmers through a questionnaire plays a fundamental role in collecting meaningful data, providing a comprehensive overview of the challenges faced and the most convenient solutions[28,29].

The main novelty of this research stands in addressing the main lacks the available studies, which have primarily examined the benefits of NBSs in urban areas and rarely in agriculture, typically at broader European and global scales, without involving local stakeholders. This research is driven by the urgent need to tackle soil erosion, water management, and other environmental challenges exacerbated by climate change, and to evaluate the potential of NBSs as sustainable remedies in the agricultural sector of Southern Italy, particularly Apulia and Basilicata. The primary goal is to assess the adoption and application of NBSs in the agricultural sector of Southern Italy.

The present study is aligned with ambitious goals to preserve natural capital and achieve climate neutrality by 2050. Specifically, it addresses Task 3.2.5 of the National Center for Technology in Agriculture (AGRITECH) project, which aims to achieve the tailored and integrated application of NBSs to enhance water availability and quality and to promote sustainable land use. These challenges are vital for sustaining agricultural activities and achieving long-term environmental and economic sustainability.

Furthermore, this study also investigates the integration of NBSs into agricultural systems to address both economic and environmental challenges, which is aligned with global and national policies, including the European Green Deal, the United Nations (UN) Sustainable Development Goals (SDGs), and the Italian Recovery and Resilience Plan (PNRR).

Nature-based solutions

In the existing literature, there is significant interchangeability of terms and concepts relating to NBSs. However, two main definitions are more widely recognized at international level, originating from the International Union for Conservation of Nature (IUCN) and the European Commission (EC). The EC characterizes NBSs as solutions designed to help societies address environmental, social, and economic challenges sustainably. These solutions leverage, enhance, or replicate nature-inspired actions, utilizing the features and processes of nature to achieve outcomes like reduced disaster risk and an environment conducive to human well-being and socially inclusive green growth[30]. The IUCN defines NBSs as actions that protect, sustainably manage and restore natural and modified ecosystems, effectively addressing societal challenges while simultaneously providing benefits to human well-being and biodiversity[31]. Both definitions consider nature as a valuable resource and encourage its synergic integration for development strategies. According to the abovementioned definitions, NBSs can be described as a holistic approach that aims to combine environmental protection with human well-being, promoting a sustainable and integrated vision. The concept of NBSs can be categorized across various sectors and thematic areas, including water management, forests and silviculture, agriculture, urban areas, and coastal regions[32]. The term NBSs is frequently employed as a comprehensive label encompassing various concepts such as Low-Impact Developments (LIDs), Best Management Practices (BMPs), Water Sensitive Urban Design (WSUD), Sustainable Urban Drainage Systems (SuDS), Green Infrastructure (GI), Blue-Green Infrastructure (BGI), Ecosystem-based Adaptation (EbA), and Ecosystem-based Disaster Risk Reduction (Eco-DRR)[33,34]. In the literature, references to NBSs are found primarily in discussions concerning urban landscapes[30] and the conservation and rehabilitation of water and forest ecosystems[2,35,36]. Particularly in the urban field, substantial progress has been achieved in the development of planning and impact evaluation frameworks for NBSs[37,38].

Concerning our case study, the Apulia and Basilicata regions, NBSs offer promising pathways for sustainable agricultural practices in the Mediterranean region, which faces unique challenges due to its specific climate, soil conditions, and socio-economic context. Different NBSs are already practiced to counteract soil erosion and degradation, involving minimum tillage, cover cropping, and crop rotation[39–41]. In response to water scarcity, strategies such as rainwater harvesting, drought-resistant crop varieties, and the restoration of traditional water systems like canals and terracing are employed[42,43]. Agroforestry, which integrates trees and shrubs into agricultural landscapes, enhances biodiversity, provides shade, and improves microclimates[44,45].

Recent studies with some of them specific to the case study area have shown the benefits of traditional practices in improving ecosystem services and agricultural productivity. For instance, a study by Troccoli et al.[46] examined fifteen years of durum wheat monoculture in Apulia region of southern Italy, revealing significant seasonal variability in yields between no-tillage (NT) and conventional tillage (CT). Despite this, the overall grain yield of NT (2.61 t/ha) was only 1.5% lower than CT (2.65 t/ha), a difference that was not statistically significant. In specific years, 2007 and 2008, CT outperformed NT by 3.5% and 3.2%, respectively. However, over the 15-year period, NT had a positive average yield balance of about 5% and a cumulative net income advantage of 71 €/ha compared to CT. Similarly, Alhaj Ali et al.[47] reported that the terraced Agroforestry System (TAS) is significant in hilly and mountainous marginal areas in Apulia, integrating fruit trees with vegetables or cereals to conserve biodiversity and soil and water. Olveira et al.[48] found that rotating wheat with legumes like chickpeas under Mediterranean conditions of Apulia reduces environmental impacts, notably global warming (18%) and freshwater ecotoxicity (20%), and increases gross margin by 96%. Dal ferro and Borin[49] indicated that Italy is the second-largest EU country in organic agriculture area. Italy's organic farming occupies 781,489 hectares, representing 6.1% of its Utilized Agricultural Area (UAA). Calabria and Basilicata have the highest organic farming percentages (up to 18%). Paris et al.[50] indicated that agroforestry practices have enhanced biodiversity and provided additional income sources for farmers. Another study by Tarolli et al.[51] showed that terraces are prominent human-made features on landscapes worldwide, designed to retain water and soil, reduce erosion, and facilitate cultivation on steep slopes. They improve water infiltration, control overland flow, and support agricultural activities, particularly in Mediterranean basins, where they are crucial cultural heritage.

Based on this situation, the implementation of NBSs is crucial for achieving the intended benefits in agricultural systems, which include improving soil health, enhancing water management, increasing biodiversity, and providing economic benefits to farmers[11,52]. Effective NBSs must align with environmental goals[53], be economically viable[54], achieve social acceptance[26], and enhance resilience to climate change[2]. Meeting these criteria ensures NBSs effectively address environmental challenges and contribute to sustainable agricultural practices in the region. The successful implementation of NBSs also requires supportive policies and active engagement by stakeholders, including farmers, policymakers, and local communities[55]. Involving farmers, ranchers, and food producers is essential since their traditional knowledge, combined with modern training, makes them vital in developing sustainable agricultural practices and addressing global soil and water challenges. Economic and social benefits are significant, with practices such as conservation agriculture and agroforestry reducing input costs and improving crop yields, thereby providing financial incentives for farmers while enhancing food security and community resilience[56,57]. Collectively, these NBS measures could transform productive landscapes from environmental impact drivers to environmental solution providers, increasing agricultural production and resilience, mitigating soil and water issues, and enhancing biodiversity[58].

Materials and methods

This section illustrates the proposed methodological framework for collecting stakeholders' perspectives regarding the implementation of NBSs in the agricultural system, focusing on the case study area analyzed and the observed outcomes. As mentioned in Sect. 2.1, considering the obstacles and challenges hindering the agricultural sector and farmers in the study area, an exercise to select the relevant NBSs was carried out by the researchers, previous to the consultation phase and a total of eleven NBSs deemed useful in the agricultural context of the area studied were considered. Subsequently, a questionnaire was developed for farms, focusing on various business aspects and farmers' perceptions regarding the NBSs selected. Finally, a comparison was made between the average utility of the NBSs considered, as derived from the questionnaire responses, and their average performance in terms of the multidimensional impacts considered by the Natural Water Retention Measures (NWRM) platform. The NWRM is a European initiative focused on identifying, promoting, and implementing sustainable water management practices that use natural processes to enhance water retention in landscapes. These measures aim to manage water resources in a way that reduces flood risk, improves water quality, enhances biodiversity, and contributes to climate change adaptation and mitigation (http://nwrm.eu).

This platform proposes a list of 53 NBSs, which are classified under the following four sectors, namely (1) Agriculture, (2) Forest, (3) Hydro morphology, and (4) Urban. Moreover, this project focuses on implementing NBSs that are multifunctional strategies aimed at managing and retaining water within landscapes, protecting water resources and addressing water-related challenges by restoring or maintaining ecosystems and natural characteristics of water bodies.

Eventually, the authors hereby confirm that all methods were carried out in accordance with relevant guidelines and regulations. The authors confirm also that all experimental protocols were approved by a named institutional and/or licensing committee. Additionally, authors confirm that informed consent was obtained from all subjects and/or their legal guardian(s).

According to the decree of Academic Senate and the Board of Directors regarding the Regulations of the Research Ethics Committee in Bari university Art.2 Point 3, comma B, the Ethic Committee of the University of Bari is ought to express the approval to the carried out research just in the case of collected personal identification data that would be diffused or published. In our current research this is not the case, since we did not collect or publish any sensitive, identification or personal information regarding any of the stakeholders involved in the questionnaire process based on which the study is carried out.

Case study

The Apulia region (Fig. 1) is located in the South-Eastern part of Italy, extending over 19,350 km^2 with a perimeter of 1,260 km and an overall coastal development of 784 km. This region has mostly gentle terrain, with only 1.4% of its land being above 700 m in elevation (Fig. 1). The western part of the Apulia region is bordered by the Daunia Mountains and the Gargano promontory, with peaks including Mount Cornacchia. The central area features the Murge plateau, while the Salento peninsula has highlands of tectonic origin, called 'Serre', aligned from North-West to South-East. Despite its low relief, Apulia lacks significant rivers due to low rainfall and karstic terrain. The main river is the Ofanto, while other watercourses include the Candelaro and Sàlsola. Surface hydrography is minimal, with erosion features called 'lame' on limestone areas. Underground water circulation is vital, with groundwater levels varying across the region. In Salento, freshwater sits above saltwater, forming a distinctive lenticular aquifer shape.

Apulia has a Mediterranean climate, with mild, low-rainfall winters and hot, dry summers. Protected from western winds by the Apennines, it is exposed to atmospheric currents from the Adriatic and the south. This results in lower rainfall compared to regions on the Tyrrhenian side of Italy and also causes frequent abrupt changes in weather patterns. Summer is marked by drought due to tropical air masses. Winters and autumns experience frequent rainfall, brought by southerly winds, alternating with clear, cold periods from northerly winds. Rainy days are few, with snow limited to high elevations. Annually the region receives on average just over 600 mm of rainfall. The greatest rainfall is observed on the Gargano, which has a total of 1,100-1,200 mm per year, while the smallest rainfall is observed on the Tavoliere, with total annual values below 450 mm. Annual rainfall peaks in November or December. The summer season in the region is typically dry, with rainfall generally below 30 mm except in certain areas like Gargano and the Sub-Apennine zone, where it exceeds 50 mm. Some summers experience no rain at all. However, brief but intense summer showers occasionally occur, with rainfall reaching 30–50 mm within minutes. Temperature averages range from 15 °C to 17 °C annually, with January being the coldest month and July/August the hottest. Frost days are limited, and 'tropical' days are more common along the coastlines[59].

The region's terrain is predominantly flat with some hills, almost devoid of mountains, comprising 7.5% forest land and 83.2% agricultural land, which represents 10% of Italy's utilized agricultural area (UAA). The UAA includes 51% arable crops, 8% permanent grassland, and 41% permanent crops such as vines and olives (Fig. 1). The most important agricultural land for production of cereals and vegetables is situated in the central northern zone (Tavoliere della Puglia), while olive trees and vineyards dominate central and southern parts of the region. Apulia has a large number of family-run farms, 94% of which are specialized, primarily in olive production (54%), with other significant sectors being vines, fruit, and vegetable farming. The average farm size is 4.7 hectares, and land fragmentation and generational renewal pose major challenges. Enhancing agricultural competitiveness through increased farm efficiency, either by enlarging farm sizes or through aggregation, is critical. Environmental issues in Apulia include drought, biodiversity loss, soil erosion, excessive agricultural water use, and a significant reduction in local species (EU Factsheet on the 2014–2022 Rural Development Programme for Puglia).

The Basilicata region (Fig. 1a) covers approximately 8,830 km^2 and features a diverse landscape characterized by the Lucanian Apennine mountain range and a vast hydrographic network encompassing rivers such as the Bradano, Sinni, Noce, Basento, Cavone, and Agri, which ultimately flow into the Ionian and Tyrrhenian Seas. This region is part of the Southern Apennine Arc, and it exhibits various tectonic units reflecting its geological history, contributing to abundant water resources crucial for agricultural, industrial, and domestic purposes[60].

Climatically, Basilicata experiences significant variations due to its complex and varied topography, influenced by both temperate-cold and Mediterranean climates. The Apennine Mountain range acts as a barrier to Atlantic disturbances, affecting precipitation patterns, with rainfall concentrated in the southwest and snowfall prevalent in the northeast (Fig. 1). Rainfall follows Mediterranean patterns, with distinct seasonal variations and averages ranging from 529 mm in Recoleta to approximately 2,000 mm in Lagonegro annually. Temperature fluctuations are considerable, with cold winters and hot summers typical of the Mediterranean climate. For instance, January, the coldest month, records average temperatures ranging from 2.0 °C in Pescopagano to 9.3 °C in Nova Siri Scalo, while July, the hottest month, sees temperatures reaching 27.0 °C in Recoleta and 19.0 °C in Pescopagano[61].

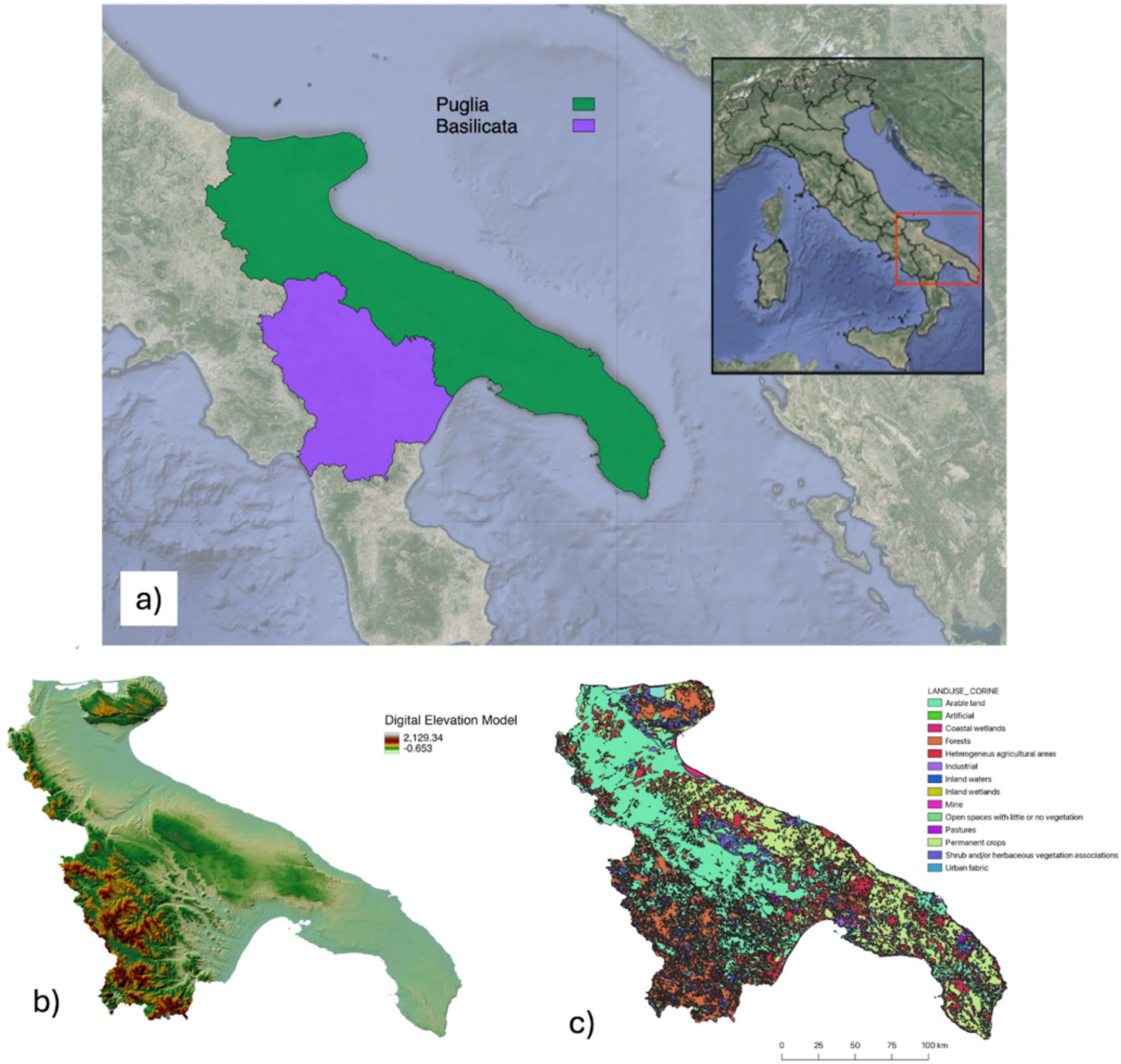


Fig. 1. (**a**) Territorial framework of the study areas; (**b**) Elevation map of the study area; (**c**) Corine Land Use Cover map 2018 (QGIS version 3.22.9 https://www.qgis.org/it/site/).

Basilicata is entirely rural, with a population of 576,194 and a density of 54.7 inhabitants per km². Half of its land is agricultural, and 35% is forested, with a utilized agricultural area (UAA) of approximately 519,000 hectares, 60% of which is arable land (Fig. 1c). The region's farms mainly produce cereals (35%), fruits, vegetables, olive oil, and wine. Organic farming is limited, covering only 44,390 hectares (2.3% of farms). Extensive animal husbandry (particularly dairy cattle, sheep, and goats) is prevalent in mountainous areas. Environmental concerns include soil erosion, water quality, and biodiversity protection. Natura 2000 (the main instrument of the EU policy for the conservation of biodiversity) sites cover 23.7% of the region (EU Factsheet on the 2014–2022 Rural Development Programme for Basilicata). From a hydro-geological perspective, differences in permeability among geological formations influence groundwater circulation, with carbonate rocks serving as vital aquifers. However, recent trends indicate a decrease in spring flow rates, possibly due to climate change, raising concerns about water availability and resource management[60].

NBS selection

During the NBS selection phase, a range of studies[1,11,37,54,62–64] were reviewed and integrated. It is important to highlight the fact that despite the growing interest, the use of NBSs in agricultural landscapes to address issues stemming from environmental degradation, disasters, and climate vulnerability is still only supported by limited evidence. For instance, Cohen-Shacham[26] noted that only a small number of NBS initiatives specifically focus on agriculture, as defined by the International Union for Conservation of Nature (IUCN).

The studies by Eggermont[65], Simelton[11], and Ruangpan[1] were considered as references for this phase. In particular, the work of Eggermont and colleagues[65] outlined three levels of NBS implementation, namely (I) ecosystem restoration, (II) sustainable management of existing ecosystems, and (III) the creation of new engineered ecosystems.

Building upon this approach, Simelton et al.[11] developed a technical framework to characterize NBSs in agricultural systems, considering sustainability also at production level. The framework identifies four key functions: (I) sustainable practices, (II) green infrastructure, (III) enhancement, and (IV) conservation.

The study conducted by Simelton[11] served as a basis for the analysis of NBSs and related indicators. In line with the guidelines outlined in the European Commission Report[30] and in a manner consistent with the studies mentioned earlier[37,54], the research methodology employed involves the use of effectiveness indicators covering both qualitative (expressed through descriptive criteria) and quantitative (measured through objective metrics like numbers) factors, derived from various previous EU projects and platforms [(I) World Bank Catalog of NBSs[66], (II) ThinkNature Catalog[67], (III) UNALAB NBSs Technical Handbook Factsheets[68], (IV) Green Infrastructure[69], (V) Guide for Water Resource Management[70], (VI) Guide of United Nations Office for Disaster Risk Reduction[71], (VII) BMP Pollution Reduction Guidance Document[72]), with particular attention being paid to the NWRM platform[70] (please see Supplementary Section B).

Subsequently, applying Ruangpan's methodology[1], some filters were set to select NBSs that best fit the conditions of the study area. These filters include a risk-focused perspective, distinction between new interventions and improvements to existing ones, and analysis of prevalent land surface types in the area.

This multidimensional approach made it possible to identify eleven NBSs to be included in the questionnaire: (I) agroforestry, (II) wetlands, (III) bioswales, (IV) strip cropping, (V) terraces, (VI) biobeds, (VII) vegetated buffer strips, (VIII) crop residue management, (IX) cover crops, (X) biological agriculture, and (XI) retention ponds.

The involvement of stakeholders in data collection through the questionnaire ensures a comprehensive understanding of the landscape and facilitates the implementation of effective risk reduction measures.

Questionnaire

The questionnaire submitted represents the first attempt to collect and analyze farmers' perceptions of the utility of NBSs in the agricultural system[73]. The research was conducted through a multidisciplinary collaboration encompassing several key partnerships. Milan Polytechnic University and University of Bari contributed through academic expertise and research support, while the Apulia Region and ISTAT supplied essential data and resources. Additionally, authorized farmers' assistance centers [Centri di Assistenza Agricola (CAA)], including organizations such as Coldiretti and Confagricoltura, facilitated community engagement and outreach efforts. This collaborative effort was characterized by online meetings, data sharing, and joint writing initiatives. The questionnaire was designed through this multidisciplinary group of researchers to ensure it was properly aligned with the aim of the research. For this purpose, several studies[1,74,75] proposing questionnaires to address stakeholders' perceptions of NBSs or green capital were analyzed to identify commonalities in questionnaire structures and question types. Therefore, because this research focuses on farmers' attitudes towards the adoption of NBSs within the context of farming and on various facets such as agricultural practices, soil management, water management, the use of pesticide products, and the potential adoption of organic farming practices, the questionnaire includes both closed-ended questions with multiple-choice options and open-ended questions to gather detailed responses, with a total of 71 questions.

The first section of the questionnaire introduces the AGRITECH project so as to provide participants with information about the general framework of this research and clarify the goal of the proposed questionnaire. The second section is dedicated to the collection of general information about the farm, based on its location (municipality) and total area. Section two also collects information about crops and their rotation, considering land use for crops based on the area, cultivated crops, crop rotation, the presence of cover crops, and any perceived benefits of crop rotation. The third section addresses soil management issues recognized in the geographical context of the farm, with a specific focus on floods, droughts, landslides, and water pollution in the area. It examines soil management problems such as erosion, landslides, pollution, interventions implemented for soil improvement, and soil quality monitoring. The fourth section examines issues related to water resources recognized in the geographical context of the farm, including water pollution or the presence of floods. It also explores interventions for water resource management and the monitoring and evaluation of water quality. The fifth section looks at the implementation of organic farming practices, considering the presence of organic certification and discussing the benefits and challenges of organic management. In the sixth section, the focus shifts to the use of pesticide products, covering the monitoring and management of pests and diseases, as well as the types of plant protection products used. The seventh section introduces the concept of NBSs and asks participants to evaluate different solutions according to their perceived utility, with a qualitative evaluation performed using a 5-point scale.

In the eighth section, participants are asked to evaluate the importance of various objectives for the improvement of the local area, using a 5-point scale. In the ninth section, stakeholders are asked to assess how NBSs influence water quality, the environment, livability, the economy, and society.

The survey was conducted using an electronic-based questionnaire (Google Form document) and it was distributed from October 2023 to February 2024 (please see Supplementary Section A for the complete questionnaire), after it was tested on several farmers through face-to-face interviews to determine the clarity of the proposed questionnaire, and to obtain their suggestions for further information, clarifications, and questions. This testing was useful in providing feedback and improving the clarity of some sections and questions before the final release of the questionnaire. The questionnaire for the survey was then published on several social media, such as LinkedIn, Facebook and Instagram. Furthermore, the questionnaire announcement specified that it was a survey intended for farmers who might be interested in implementing NBSs in the agricultural sector of Southern Italy, in order to clarify the final target and obtain consistent responses. The engaged stakeholders were selected based on their involvement in or influence over agricultural practices, environmental management, and policymaking.

Results

After a review of the current situation in relation to the main challenges in the study areas, eleven NBSs were identified as described in Sect. 3.2 by the researchers, namely (I) agroforestry, (II) wetlands, (III) bioswales, (IV) strip cropping, (V) terraces, (VI) biobeds, (VII) vegetated buffer strips, (VIII) crop residue management, (IX) cover crops, (X) biological agriculture, and (XI) retention ponds.

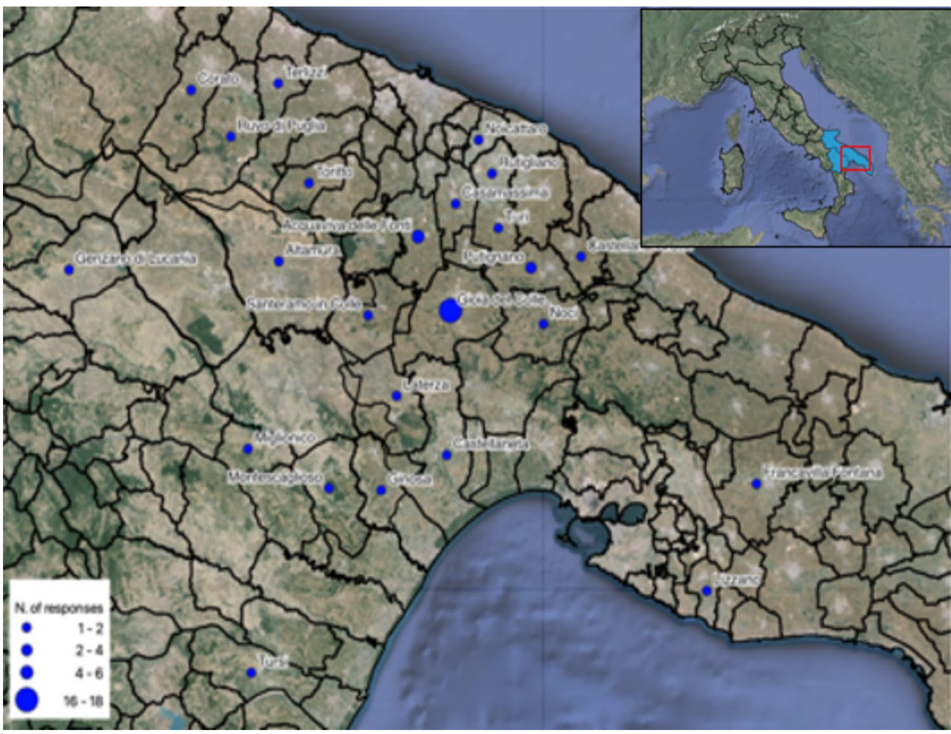
As introduced previously, this research proposes a questionnaire to collect information about farmers' awareness and the level of utility they perceive regarding the implementation of NBSs in the agricultural sector. In this section, the main results collected are illustrated and described. The results obtained are discussed according to the order of the questionnaire sections so as to be consistent with the structure of the analysis.

Figure 2 comprehensively illustrates the list of municipalities where the questionnaire has been submitted and the number of responses collected from each (please refer to Sect. 1, Question 2 of the questionnaire, provided in Supplementary Section A). A total of 52 valid questionnaire responses have been collected for the study. This number makes it possible to describe the sample of the population under examination (namely the farms present in the Basilicata and Apulia regions). Considering the size of the population (N) of farms in the survey areas, which stands at 48.833 (ISTAT, 2010 http://dati-censimentoagricoltura.istat.it/Index.aspx?DataSetCode=DICA_UTILTERRUBI), the margin of error of 10% and a confidence level of 85%, the size of the sample (s) of 52 responses can be considered representative despite the size of the study areas[76–79].

Therefore, by clarifying N and s, it is possible to illustrate the results obtained by the questionnaire in its different sections. This section illustrates the primary relevant results of the questionnaire, according to its structure. It is important to note that not all questions are analyzed and discussed here (please see Supplementary Section A for the complete questionnaire).

With regard to the relevant data collected through the first section of the questionnaire, the information related to the types of crops cultivated and the challenges addressed in the area is illustrated here to provide a general overview of the existing situation in the territories analyzed.

It is very important to provide a general description of the status of agricultural production in the territory analyzed. Figure 3 illustrates the results obtained for Question 5, '*What crops are grown on the farm?*', providing information about the various types of crops with the respective percentages. Results show that the main crops are cereals and legumes (25%), followed by legumes (17%), vineyards (11%), fruit (9%), horticultural crops (7%), and others (6%) (total number of answers: 52).



Province - Region	Municipality	Number of responses
Bari - Puglia	Acquaviva delle Fonti	6
	Altamura	1
	Casamassima	2
	Castellana Grotte	1
	Corato	1
	Gioia del Colle	17
	Noci	1
	Noicattaro	1
	Putignano	3
	Rutigliano	1
	Ruvo di Puglia	1
	Santeramo in Colle	2
	Toritto	1
	Turi	2
Taranto - Puglia	Castellaneta	2
	Ginosa	1
	Laterza	2
	Lizzano	2
Brindisi - Puglia	Francavilla Fontana	1
Matera - Basilicata	Miglionico	1
	Montescaglioso	1
	Tursi	1
Potenza - Puglia	Genzano di Lucania	1
Total		52

Fig. 2. Municipalities considered in the survey and the number of responses for each municipality (QGIS version 3.22.9 https://www.qgis.org/it/site/).

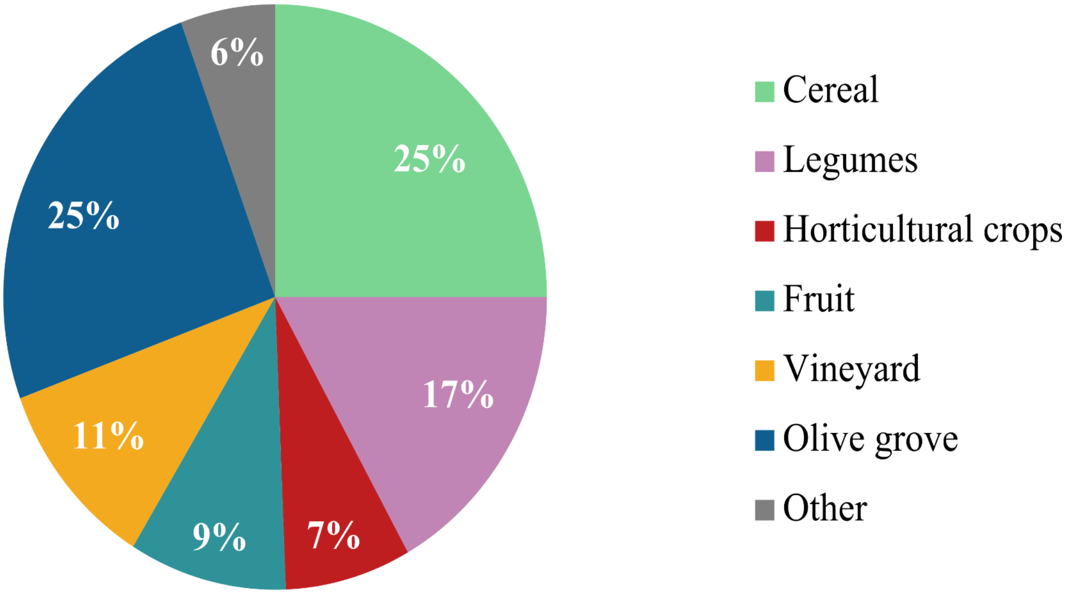


Fig. 3. Percentage of crop types with reference to the sample of companies participating in the survey.

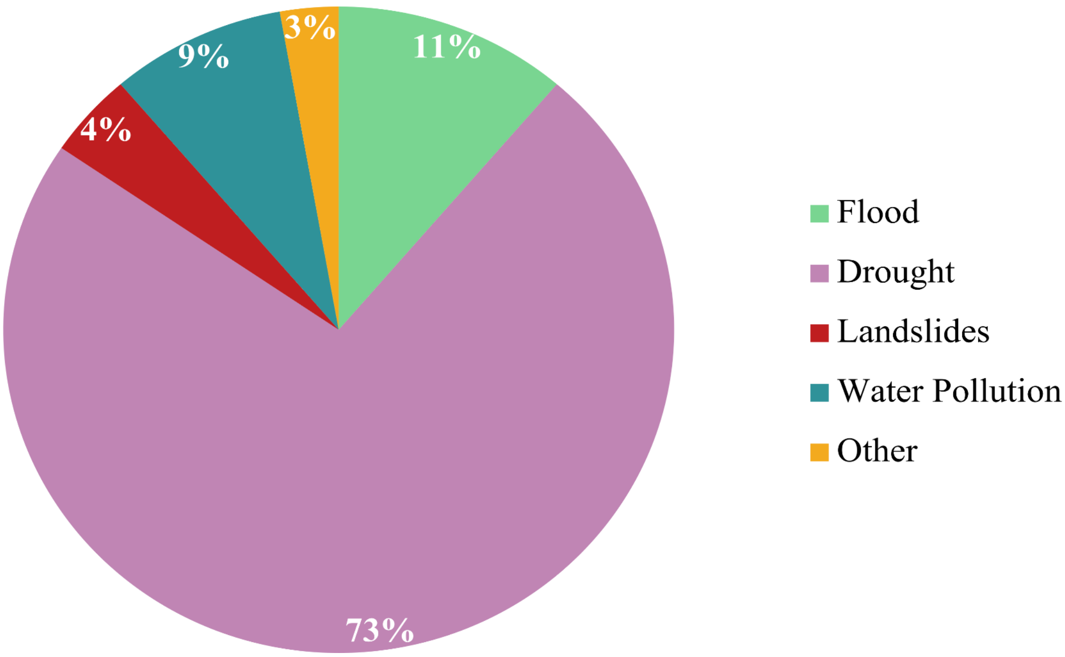


Fig. 4. Percentage of different issues recognized in the area.

Figure 4 represents the results obtained for Question 8, '*What are the most commonly encountered obstacles in the area*?', describing the existing situation related to soil issues recognized in the survey areas. As illustrated, the main challenges characterizing the areas surveyed are represented by drought (73%), followed by flood (11%), water pollution (9%), landslides (4%), and others (3%) (total number of answers: 52). Additionally, participants who declared 'other obstacles' had the possibility to specify which obstacles they were referring to where these were not included in the list of options.

As described above, the third section relates mainly to soil management issues. Figure 5 represents the results for Question 9, '*Does your farm have any issues with soil management? If so, what are they*?'.

Figure 5 provides an overview of the soil-related challenges identified within the farms investigated. While many survey participants indicate a lack of significant soil management problems, the primary challenge in this regard is identified as soil erosion induced by water (17%), followed by soil erosion induced by wind (7%), and soil pollution from pesticides (2%) (total number of answers: 52). These findings may be attributed to the

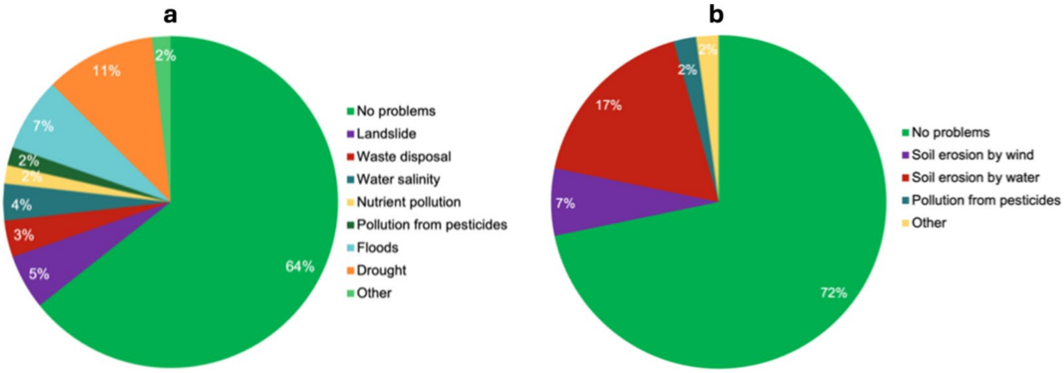


Fig. 5. Percentage of different soil (**a**) and water (**b**) issues recognized in the investigated farms.

concentration of farms in flood-prone areas. The hydrogeological structure plan and water hazard map of the areas studied are provided in the supplementary material (see Supplementary Section C, Figure S1), to provide insights in addressing these concerns. Moreover, these results can be discussed in relation to the fact that many farms have implemented different strategies to mitigate soil erosion problems induced either by water or by wind, described through Question 11. Some have focused their efforts on water management, constructing or restoring channels. Others have opted for agricultural practices such as no-till farming or minimum tillage to reduce soil exposure to erosive forces. Similarly, some farms have built dry stone walls to delineate property boundaries, thereby helping prevent soil displacement and erosion into surrounding properties.

On the other hand, section four of the questionnaire discusses the water management challenges encountered by farmers on their own farms. Figure 5 illustrates the results for Question 14, '*Does your farm have any water management challenges? If so, what are they?*'.

As can be seen from the responses, the majority of participants demonstrated that they do not encounter many water management challenges. Among the challenges reported, drought stands out as the most prevalent (11%), followed by landslide (5%), waste disposal (4%), floods (4%), water salinity (4%), pesticide pollution (2%), and nutrient pollution (2%) (total number of answers: 52). In this case also, the results obtained can be discussed in the context of mitigation measures already adopted by farmers analyzed in Question 16. First, many farmers affected by drought have adopted different water management measures, including reduction of irrigation volumes and implementation of systems for rainwater harvesting such as cisterns or wells, to ensure greater availability of water resources during drought periods. On the other hand, farms that have to deal with flood-related hazards mainly pursue alternative strategies to avoid obstructing natural water flow paths. Conveying and land leveling have only been implemented in one case.

The primary focus of the proposed questionnaire is in section seven, which analyzes the assessment of stakeholders' perceptions regarding the utility of NBSs, as outlined in the preceding section (Sect. 3.3). Questions 24 to 56 assess the participants' perceptions about the utility[80] of each NBS measure analyzed in relation to its main objective (please refer to Supplementary Section A for descriptions of the NBSs and corresponding objectives, with ratings expressed using a 5-point scale, from (1) representing 'not useful' to (5) representing 'extremely useful'[81–83].

Figure 6 illustrates the results obtained when the participants were asked to express their perceptions of the utility of NBS implementation in the agriculture context. Overall, the percentage distribution of responses indicates that the majority of stakeholders believe the 11 NBSs selected to be extremely useful in achieving the objective considered. Upon careful examination of the results, it is evident that retention ponds show the highest percentage (65%) of 'extremely useful' ratings (total number of answers: 52).

Moreover, the analysis highlights the fact that three other NBSs achieved significant consensus, with 60% of participants considering them extremely useful. These NBSs are crop residue management, cover crops, and biological agriculture. Conversely, the strip cropping measure received the lowest score in terms of extreme utility (27%) and 15% of participants rated this solution as not at all useful. However, the evaluation obtained for the utility of strip cropping is in line with the current situation regarding soil management issues. Specifically, soil erosion in the areas studied predominantly stems from fluvial floods rather than pluvial ones, as these regions also experience significant drought conditions.

Despite the fact that the level of utility of the different NBSs perceived by farmers is considerable, as shown in Fig. 6, their attitude regarding the possibility of applying these measures on their own farms is quite different. This can be seen from an examination of the responses to the questions 'Would you implement this measure on your farm?' and '*Provide an explanation for your choice*'. In fact, considering the four NBSs deemed most useful (retention ponds, biological agriculture, cover crops and crop residue management), only 67% of all participants would apply retention ponds, compared to biological agriculture (86%, of which 71% already implement this practice), cover crops (73%, of which 26% already implement this practice), and crop residue management (71%, of which 38% already implement this practice) (total number of answers: 52).

Section 8 addresses the effect of NBSs in achieving various multidimensional objectives that have been selected from the study proposed by Ruangpan[1] according to their relevance within the specific NBS measures analyzed (please see Supplementary Section A). Specifically, the objectives considered are the following: (I)

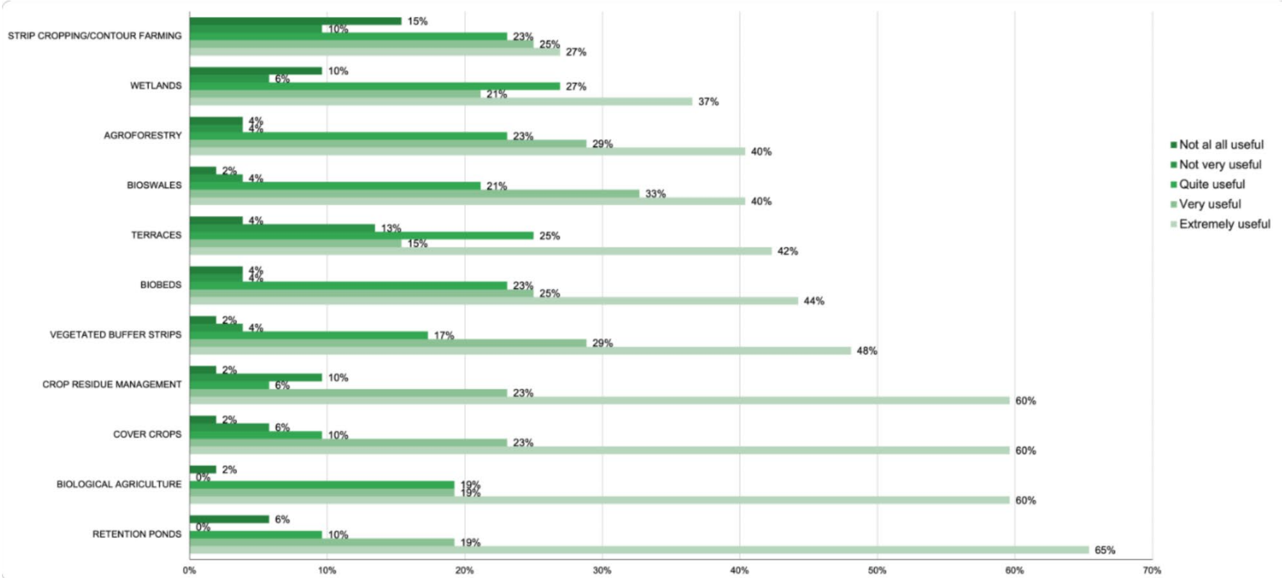


Fig. 6. Participants' assessment of NBS utility to achieve the related objective.

improvement of water quality, which refers to the overall capacity of NBS measures to remove pollutants within the water system; (II) environmental benefits, which encompass the ability of NBSs to contribute to ecological diversity, habitat creation for species, groundwater recharge, water reuse, and air quality; (III) enhancement of livability, which refers to the capacity of NBSs to enhance local aesthetics, pleasantness, with community acceptability, and low risk to public safety; (IV) economic advantages, which are related to the ability of NBSs to enable food or material production and the potential to generate energy savings; and (V) socio-cultural benefits, which include the capacity of NBSs to create educational spaces, foster community engagement, and provide recreational areas.

In this context, it is fundamental to underline the fact that the objective concerning the improvement of water quality has been addressed separately, in line with the focus of this study. The assessment of the relative importance of various NBSs in achieving the specified objective has been carried out through a quantitative approach, using a rating expressed on a 5-point scale, from not important at all (1) to extremely important (5).

Figure 7 represents the results for this section. As shown in the figure, the NBSs selected are recognized by the participants as extremely important in achieving the environmental benefits.

On the other hand, with regard to economic benefits, the percentage of participants who rated this objective as 'extremely important' is the lowest among the options, at 46%. This is followed by a significant proportion who rated them as 'very important' (25%) and 'quite important' (21%) (total number of answers: 52).

Discussion

On a regional scale, the results obtained showed that drought is the main issue encountered, based on the participants' responses to Question 8, which discusses the main challenges in the area analyzed. This outcome is in line with the current situation in respect of the issue of drought in Southern Italy, as documented by Bollettino Italia (2023–2024). That report emphasizes the finding that the Standardized Precipitation Index (SPI) for the period from July 2023 to December 2023 reached its peak value, indicating an extreme drought situation (https://droughtcentral.it/bollettino-italia/bollettino-dicembre-2023/)[84,85]

On the other hand, the responses provided by the farmers showed a lower impact of water and soil problems on individual farms, as shown in Fig. 5, which indicates that 64% and 72% of the participants did not experience water or soil problems, respectively. These findings reflect the specific challenges and priorities within the agricultural sector in the study area. The lower impact of soil management issues could be due to the widespread adoption of traditional practices, such as terracing and crop rotation, which have historically mitigated soil erosion[86–88]. On the contrary, water management remains a critical concern due to the regions' vulnerability to drought and increasing water scarcity exacerbated by climate change[89]. This discrepancy highlights the need for targeted NBS interventions that address the most pressing issues, such as enhancing water use efficiency and developing drought-resistant crop varieties.

The analysis of the results revealed that retention ponds were attributed the highest percentage (65%) by survey participants (Fig. 6) who deemed them extremely useful. This can be justified by the fact that retention ponds play a crucial role in collecting water for future use by acting as reservoirs that capture and store rainwater or runoff. These ponds are strategically designed to retain stormwater, preventing it from immediately flowing off-site. Instead, the water collected is held within the pond, allowing it to slowly seep into the ground or be used for various purposes such as irrigation, replenishing groundwater, or other agricultural and industrial needs. By retaining water on-site, retention ponds help mitigate flooding, reduce erosion, and ensure a sustainable water supply, especially in areas with limited water resources or those prone to drought. The analysis also demonstrated

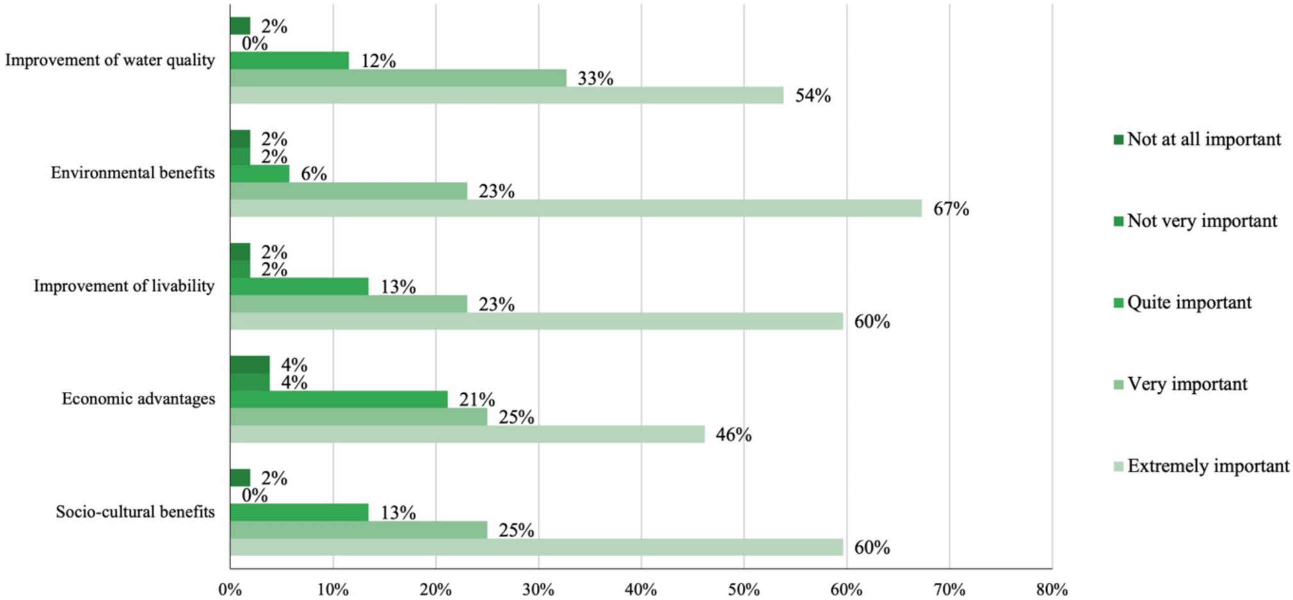


Fig. 7. Participants' assessment regarding the importance level of the selected NBSs in achieving several objectives.

that three other NBSs were also rated as extremely useful by a substantial percentage (60%) of stakeholders. The first of these was cover crops, which are aimed at cultivating protective plant cover between main crop cycles to shield the soil, enhance its structure, and encourage biodiversity, and were recognized very positively. In the transition from one crop to another, especially in the summer months where flash floods are an evident characteristic of Mediterranean areas, the soil is more subject to erosion by flash flood events if left uncovered. The study area is also mostly cultivated with wheat, which is harvested at the end of June/beginning of July, ensuring that the soil remains bare during the months most subject to these atmospheric events[90]. Cover crops in the Mediterranean region offer significant benefits. They control erosion and enhance soil fertility[91,92], improve soil moisture retention[93], reduce herbicide use through weed suppression[94], and may enhance the soil microbial community by increasing mycorrhizal abundance, microbial biomass phosphorus, and phosphatase activity[95]. However, in dry agro-ecosystems, cover crops can lead to soil water content inconsistencies and potential yield reductions due to water depletion. Adaptation strategies include selecting appropriate cover crops, optimizing management practices, and integrating cover crops into cropping systems to maximize benefits and minimize trade-offs[96]. Another constraint of cover crops is the initial costs and management challenges[97], and the need for technical knowledge[98]. Tradeoffs involve balancing short-term costs with long-term soil health benefits and managing water use efficiency and biodiversity with pest risks[99]. Economic incentives and policies can support adoption of these crops by mitigating financial constraints[98]. The second measure that was considered significant by participants is crop residue management, which targets the efficient and sustainable management of plant residues through minimum tillage or no-tillage practices to enhance soil fertility, diminish erosion, and foster soil health. Lastly, biological agriculture, emphasizing sustainable farming practices without the use of pesticides and synthetic chemical fertilizers while prioritizing biodiversity and soil health, also earned significant recognition. It is therefore clear that farmers showed an interest in those NBS measures that prioritize safeguarding and enhance biodiversity and soil health.

In the Mediterranean region, biological agriculture and no-tillage practices offer distinct approaches to sustainable agriculture, each with unique advantages and tradeoffs, particularly regarding chemical usage and pest management. Biological agriculture minimizes the use of synthetic chemicals and pesticides, relying on natural alternatives like compost and biological pest control, which enhances soil health and biodiversity but often results in lower yields and higher labor costs[100–102]. In contrast, no-tillage practices improve soil structure, reduce erosion, and enhance carbon sequestration, but typically depend on herbicides for weed control, potentially increasing chemical usage and posing long-term environmental risks[103–105]. The tradeoff between these methods involves balancing the reduced chemical usage and enhanced biodiversity of biological agriculture against the labor savings and immediate soil conservation benefits of no-tillage, despite its reliance on chemicals[106]. Therefore, while biological agriculture offers significant environmental benefits, no-tillage approaches provide economic advantages in the short term, with potential long-term soil health challenges due to chemical dependency. The different utility scores attributed by farmers for crop residue management (no/minimum tillage) and biological agriculture practices can be attributed to the fact that they all face different challenges on their own farms. Crop residue management, particularly no-tillage, is highly effective against soil erosion, making it essential for farms dealing with this issue to prevent soil loss. Conversely, farms with limited soil erosion problems often prefer biological agriculture. According to the questionnaire, most farms do not experience soil erosion (72%), so 86% of the farms analyzed would adopt biological agriculture (71% already practice it).

On the other hand, strip cropping practices achieved the lowest score in terms of extreme utility, with only 27% of participants rating this option as extremely useful, and 15% finding it not useful at all. Strip cropping has the objective of preventing soil erosion in hilly or sloping terrain using horizontal contour lines to slow rainwater runoff and allow it to infiltrate the soil. The evaluation of the value of strip cropping achieved in the questionnaire is in line with the current soil management challenges in this area, which shows more interest in problems associated with high drought levels. In fact, soil erosion in the areas analyzed is mainly due to the occurrence of fluvial flooding and not pluvial floods, based on the fact that these areas experience high drought levels. Those results are in line with the Common Agricultural Policy (CAP) 2023–2027, in which these NBSs are indicated as useful practices in accomplishing specific objectives in the Regional Complement for Rural Development (CRD) 2023–2027.

Table 1 illustrates the comparison of the average utility of the NBSs considered based on the stakeholders' perspectives recognized through the questionnaire, with their average performance concerning the multidimensional impacts addressed by the NWRM platform (http://nwrm.eu/catalogue-nwrm/benefit-tables). In detail, the utility perceived by stakeholders was assessed according to a 5-point scale as illustrated previously (Sect. 3.3), and the average utility represents the average value obtained from the stakeholders' answers. On the other hand, the NWRM platform also uses a 5-point scale, from (1) negative to (5) high (positive), to assess the performance of different NBSs concerning different impacts. Therefore, as both scales are 5-point scales, the different scores can be comparatively discussed.

The comparison between the results obtained by this survey and the NWRM platform findings is crucial in viewing these results in the context of the general theme of NBSs adoption and implementation in the agricultural sector. By benchmarking the proposed survey against the NWRM platform outcomes, it is possible to address whether the public perception of NBS measures is aligned with the practical evidence of their effectiveness and challenges obtained by the NWRM platform. This comparison is significant and useful, as it makes it possible to identify potential discrepancies between perceived and actual effectiveness, thus providing valuable insights for refining communication strategies and informing policy adjustments.

Before going through the discussion and comparison of the obtained results, it is of importance to clarify that (I) biobeds and (II) biological agriculture measures have not been considered in this analysis, as they are not considered in the NWRM list of measures. However, both have been included in the questionnaire submitted to farmers, since both are considered of major importance as NBS measures in mitigating soil and water pollution resulting from chemicals and the adoption of sustainable farming practices free from pesticides and synthetic chemical fertilizers while prioritizing biodiversity and soil health.

If we examine Table 1, we can see clearly that most of the NBSs considered show the same score for average utility and NWRM average performance. These NBSs are wetlands, bioswales, terraces, vegetated buffer strips, crop residue management, and cover crops. These NBSs achieved a score of 4 (very useful) for their average utility, reflecting their high value from the farmers' perspective. Meanwhile, their overall performance has been rated as medium on the NWRM evaluation scale. This demonstrates that farmers' perceptions of NBSs impacts are consistent with the recognized and evaluated benefits.

On the other hand, there some results show notable differences. Strip cropping and agroforestry exhibit lower average utility compared to their assessed performance, whereas retention ponds display higher average utility than their evaluated performance on the NWRM platform scale. These results can be attributed to various factors uncovered through open-ended questions.

Regarding the agroforestry measure, it has become evident that farmers are unlikely to adopt this option easily. This reluctance may stem from the fact that agroforestry is subject to several constraints and requires careful tradeoff analysis, particularly concerning socio-economic, ecological, and technical factors. Socio-economic challenges include insecure land tenure, limited market access, and high initial costs[107–109]. Ecologically, site-specific conditions and biodiversity concerns require meticulous management[110,111]. On the technical side, farmers often lack the necessary knowledge and support services[112,113]. Economically, while agroforestry offers long-term benefits, short-term financial returns can be limited, necessitating a balance between immediate income needs and sustainability[114,115]. Investment in ecosystem services and robust value chains, along with economic incentives like subsidies and Payments for Ecosystem Services (PES), are crucial for adoption of measures of this kind[116–119]. The absence of economic compensation for community benefits

	Average utility	**NWRM average performance**	**Legend**			
Strip cropping	3	4	**Utility scale of evaluation**		**NWRM scale of evaluation**	
Wetland	4	4	Not at all useful	1	Negative	1
Agroforestry	4	5	Not very useful	2	None	2
Bioswales	4	4	Quite useful	3	Low	3
Terraces	4	4	Very useful	4	Medium	4
Vegetated buffer strips	4	4	Extremely useful	5	High	5
Crop residue management	4	4				
Cover crops	4	4				
Retention ponds	4	3				

Table 1. Comparison among NBSs average utility obtained by stakeholders and NBSs performance metrics by NWRM.

derived from agroforestry further reduces its perceived utility among farmers. The available economic tools, such as the Regional Rural Development Programme (PSR) at regional level and the PES at national level, could play a fundamental role in providing adequate financial support and facilitate the adoption and implementation of this practice[90,120]. Addressing these constraints and leveraging tradeoffs can optimize agroforestry's potential as a sustainable agricultural practice.

The strip cropping measure also was not rated as highly useful by participants. This result could be due to the fact that the area analyzed is characterized by flat terrain that diminishes the effectiveness of this measure. On the other hand, the average utility rating for retention ponds was higher than their evaluated performance by the NWRM. This divergence can be explained by farmers' proactive measures to address water scarcity issues. Many participants have implemented rainwater harvesting interventions like cisterns or wells to bolster water resource availability during drought periods. Consequently, retention ponds are perceived as highly valuable NBSs for mitigating water-related challenges, surpassing the assessed NWRM performance metrics.

In conclusion, while some NBSs show alignment between perceived utility and NWRM assessed performance, disparities exist, driven by factors such as topography and economic considerations. Understanding these nuances is crucial for optimizing NBS implementation strategies and fostering sustainable agricultural practices.

Following on from the discussion of the results obtained from stakeholders' evaluations of the effectiveness of individual NBSs, it is essential to analyze their perspective regarding the role of NBSs in achieving various objectives. As shown in Fig. 7, the findings show that the NBSs selected are perceived by participants as crucial for attaining environmental benefits. This response may be attributed to the ongoing discussions and evaluations of NBSs in both academic and policy spheres, particularly regarding their environmental advantages, which have fostered a shared understanding of this topic. However, concerning economic benefits, the viewpoint of the farmers underscores the inadequate level of evaluation and communication in terms of the economic advantages of implementing NBSs. This observation is consistent with discussions found in the literature[28,29]. This lack of economic evaluation of benefits implies a gap in common knowledge and consciousness of the potential for achieving economic benefits through NBS implementation. Moving on to another objective, which emphasizes the importance of livability enhancement metrics, it is noteworthy that this aspect received considerable attention from participants during the evaluation process. Constituting 60% of their overall scores, it emerged as a pivotal indicator of the objectives of NBS application. It is likely that this heightened interest arises from the significant positive impacts that certain NBSs, such as wetlands and retention ponds, could have on human well-being. These green areas not only promote improved mental well-being and reduced chronic stress but also play a crucial role in combating the heat island effect and enhancing air quality[37,121].

The improvement of the water quality indicator garnered slightly more than half (54%) of the participants' scores as one of the significantly important primary objectives in NBS application. Many proposed NBS measures (such as retention ponds, vegetated buffer strips, and cover crops) demonstrate promising potential in enhancing water quality by acting as sediment and chemical traps, thereby preventing the transport of these substances from agricultural landscapes and subsequent pollution of watercourses. This finding aligns with a similar study by Alves[122], where water quality improvement was ranked as the second most important benefit when participants were asked to compare a range of environmental benefits. Socio-cultural benefits also received substantial weighting (60%) from stakeholders due to their role in establishing educational spaces and providing recreational areas conducive to moments of leisure and community gathering.

Based on the results obtained, efforts are being made to find confirmation in national-level applications. One example is the case of the Lamone River basin in the Emilia-Romagna region (Italy), known for its significant seasonal variability in flow and water availability, which is particularly relevant in the agricultural context. In this area, characterized by considerable reliance on irrigation for agricultural production, water retention ponds are systematically applied. These ponds serve the purpose of storing water during winter periods, thereby ensuring its availability during dry seasons. The presence of such structures plays a strategic role in preserving water availability for irrigation while also contributing to maintaining a minimum flow in the surrounding river environment[123]. Within the scope of agricultural practices aimed at managing soil erosion and improving land microtopography, cover crops have been introduced as a promising solution. In a case study conducted in vineyards located in the northwestern regions of Italy, the effectiveness of cover crops in improving soil surface roughness (SSR) and reducing erosion was examined. The results demonstrated that the use of cover crops significantly improved soil surface roughness and reduced soil erosion in the vineyards. Specifically, the model's performance in predicting soil losses improved using spatialized soil roughness input data compared to a uniform applied value[124].

With regard to crop residue management, the introduction of zero-tillage practices with residue retention in field crops represents an important alternative technique to counteract resource degradation and reduce production costs in intensive agriculture[90,125]. In a study conducted in the Campania region in Southern Italy, a methodology based on the ARMOSA crop model was used to evaluate the effectiveness of tillage and no-tillage practices in durum wheat cultivation systems. The study supports the potential of the ARMOSA model in assessing and designing soil management practices suitable for current and future climatic conditions within the context of Italian agriculture[126]. In terms of agricultural NBSs in Italy, the distribution of case studies on nature-based water resources management within the NWRM platform is diverse and covers various sectors such as hydro-morphological, forestry, urban, and agricultural. However, there is a limited number of applications in agricultural environments, as highlighted by the scarcity of case studies in this category[11].

Analysis of NWRM case studies (https://lc.cx/S6KvCs) in agriculture in Italy reveals only four case studies: (I) Traditional terracing in Veneto: aimed at the recovery and maintenance of cultural and historical terraces by promoting new agricultural activities, such as the creation of vegetable gardens. This initiative aims to combine social and economic objectives with the preservation of infrastructure to prevent hydrogeological disasters; (II) Reforestation in Veneto: this study responds to the need for increased groundwater recharge and water purification in areas previously used for intensive agriculture. Payment for ecosystem services (PES) systems play a crucial role in incentivizing landowners to participate in reforestation efforts. (III) River restoration of the Lower Aurino: this project implements river restoration interventions to enhance flood protection and improve the natural environment. Community engagement and stakeholder involvement are crucial for successful implementation; (IV) Effluent network restructuring: this study aims to reduce nutrient pollution reaching the Venice Lagoon through phytoremediation and to mitigate flooding problems caused by urban development. Measures include riparian buffer zones, wetland creation, and canal naturalization.

With regard to the dissemination of NBSs related to drought and soil erosion risks, the GeoIKP operandum project (https://geoikp.operandum-project.eu) has been considered. The primary objective of this project was to demonstrate and adopt NBSs to mitigate hydro-meteorological risks. However, a review of the case studies present in the project highlights a considerable disparity in results observed when different search filters are applied. Specifically, the use of the 'agricultural drought' filter generates only eight results worldwide, while applying the 'soil erosion' and 'soil management and soil quality' filters yields a total of 51 results on a global scale, out of a total of 677 cases examined by the project. GeoIKP Operandum project categorizes NBSs under five main risk categories: (I) fire hazard (II) meteorological/climatological hazards; (III) geological/hydrological hazards; (IV) environmental hazards; and (V) other hazard categories. In Italy, there are 26 NBSs, with three located in Apulia: (I) coastal lagoon and dune restoration in the Sipontine wetlands in Manfredonia; (II) restoration of intermittent rivers for flooding management in Bari; and (III) greening of the city to reduce flood and heat wave risk in Bari.

Additionally, GeoIKP considers the evaluation of the score for UN Sustainable Development Goals (SDG), which serves as an indicator of the results achieved by each country in relation to the SDGs. This measurement reflects a synthesis of global results reported by each nation by the end of 2020, encompassing all outlined objectives. In particular, Italy falls within a score range of 70 to 80, compared to the maximum score of > 80, indicating satisfactory but not excellent performance in achieving sustainable development goals.

The current study highlights stakeholders' perceptions regarding the importance of different objectives associated with NBS implementation, aligning with SDGs. Environmental benefits were considered highly important, emphasizing the role of NBSs in achieving Goal 13: Climate action through the implementation of a wetlands and agroforestry system that could enhance ecological restoration and recovery of ecosystem services. Additionally, NBSs contribute to Goal 2: Zero hunger by mitigating drought and hydrogeological instability, favoring agricultural production and thereby reducing hunger and ensuring food security. They also support Goal 6: Clean water and sanitation, by promoting the sustainable management of water resources through prevention NBS measures that consider biological agriculture, emphasizing sustainable farming practices free from pesticides and synthetic chemical fertilizers, and then curative measures by adopting NBSs (bio-beds, retention ponds vegetated buffer strips) that contribute effectively as sediment and chemicals traps to prevent the transport of these substances into water courses, improving water quality, and preserving water ecosystems. Ultimately, NBSs are directly linked to Goal 15: Life on earth, as they contribute to the conservation and sustainable management of terrestrial ecosystems through practices such as agroforestry and sustainable forest management.

Overall, our research contributes to the growing body of literature on NBS implementation in agriculture, providing valuable insights for policymakers, practitioners, and researchers. By aligning stakeholders' perceptions with evaluated benefits, our study offers practical implications for optimizing NBS interventions and fostering resilience in agricultural systems.

Conclusion

This study is a pioneering effort to assess farmers' perceptions of NBSs in agriculture, focusing on the regions of Basilicata and Apulia in Southern Italy. Through a detailed questionnaire-based approach, 52 valid responses were gathered, offering a representative sample. The findings highlight the primary challenges faced by farmers, with drought being the most significant, followed by floods, water pollution, landslides, and soil erosion due to water. Retention ponds were deemed highly useful, followed by crop residue management, cover crops, and biological agriculture. Conversely, strip cropping received lower utility ratings, reflecting its limited applicability in certain terrains. The study underscores the necessity of stakeholder collaboration, innovative funding mechanisms, and community engagement for successful NBSs implementation. Stakeholders perceived the environmental benefits of NBSs as highly important, while economic benefits were rated lower, suggesting a need for better economic evaluation and communication. The significant knowledge gap among farmers that emerged from the results calls for increased workshops, field events, and testimonial events to enhance understanding of NBSs' benefits and tradeoffs. Unlike previous theoretical studies reported in the literature, this research engages local stakeholders, assessing their perceptions and willingness to implement NBSs, thus addressing practical constraints and economic considerations at local level in a manner consistent with other studies that emphasize the importance of stakeholder engagement and local adaptation for the successful implementation of NBSs.

However, it is important to acknowledge some limitations of the proposed study, such as the relatively small sample size of stakeholders involved, which may limit the upscaling of the findings. Additionally, the reliance on stakeholders' perceptions alone may introduce bias and subjective interpretations. Future improvements could include comprehensive economic analyses and comparative studies across different regions to assess NBS transferability and scalability. Lastly, the study recommends that policymakers promote awareness and education through public campaigns and training programs, introduce financial incentives such as subsidies and tax breaks, and facilitate collaboration through stakeholder networks and public-private partnerships. Continuous research and monitoring should be supported to evaluate NBS effectiveness, and integrating NBSs into existing policies with local adaptation plans will help prioritize these solutions. Addressing barriers through technical assistance and infrastructure support will further aid in the implementation of sustainable and resilient agricultural practices.

Data availability
All data generated or analyzed in the current study are available from the corresponding author on reasonable request.

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Author contributions

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Declarations

Competing interests

The authors declare no competing interests.

Additional information

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