Sustainable Land Productivity and Community Resilience: Micro and Meso-Scale Water Harvesting in Jordan's Rangelands and Rainfed Areas

Working Paper

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Executive Summary

This section should provide a snapshot of the entire document and highlight the most important findings. This working paper highlights the economic and environmental benefits of implementing micro and meso-scale water harvesting (RWH) technologies in Jordan's arid and semi-arid regions, emphasizing their potential for sustainable water and land management. Technologies analyzed include Vallerani RWH, Marab RWH, and olive farming techniques (soil and stone bunds) tailored to diverse topographical and ecological conditions.

Key findings demonstrate the cost-effectiveness and profitability of these systems. Olive soil bunds emerge as the most cost-efficient option, with a low investment of US$76 per hectare and an exceptional Benefit-Cost Ratio (BCR) of 23.36, reflecting significant economic returns. Marab RWH shows moderate capital expenditure (US$918/ha) but offers strong financial viability with a Net Present Value (NPV) of US$6,699 and a payback period of just three years. Vallerani RWH, while having a more extended payback period (6 years), provides extensive ecosystem restoration benefits alongside economic returns.

Beyond financial indicators, these technologies enhance ecosystem services by reducing runoff and soil erosion, improving soil fertility, and increasing water retention. They support agricultural productivity, stabilize degraded lands, and contribute to climate resilience. The integration of these systems into national water management strategies can address pressing challenges like water scarcity, desertification, and land degradation.

Policy recommendations emphasize scaling up these RWH systems across suitable regions, ensuring community engagement, and integrating them into broader watershed management frameworks. Strategic investment in these technologies will not only enhance agricultural sustainability but also strengthen Jordan's resilience to climate variability and resource scarcity.

Keywords

Rainwater harvesting technologies, climate resilience, cost-effectiveness, ecosystem, Jordan.

Highlights

- Technologies like olive soil bunds and Marab RWH offer high profitability, significant Benefit-Cost Ratios, and Short Payback Periods.
- RWH systems reduce runoff, improve soil fertility, and enhance water retention, contributing to ecosystem restoration and climate resilience.
- Scaling up these technologies and integrating them into national water management frameworks can address challenges related to water scarcity, desertification, and land degradation.

1. INTRODUCTION

Drylands, covering nearly half of the Earth's surface, span regions ranging from dry sub-humid to hyper-arid climates [1, 2]. These areas are predominantly rangelands, characterized by natural fodder growth but generally unsuitable for arable farming due to constraints such as low rainfall, poor soil fertility, and rough terrain [3, 4]). Rangelands play a crucial role in ecosystem services, comprising 91% of global grazing lands and supporting approximately half of the world's livestock population [5, 6]

Jordan exemplifies a dryland country and ranks among the world's most water-scarce nations, a challenge shared by nearly all its neighbours. Approximately 92.5% of Jordan’s annual rainfall evaporates, including transpiration in rainfed and rangeland areas (green water). Of the remainder, about 5% recharges groundwater, and only 2.5% contributes to surface runoff [7].

With 90% of its land classified as rangelands, locally known as the Badia, Jordan receives less than 200 mm of annual rainfall [8]. The Badia supports Bedouin communities whose livelihoods primarily depend on livestock [9]. Historically, the Badia exhibited a sustainable balance between environmental dynamics and resilience until the 1960s [10, 11]. However, government settlement programs initiated in the 1960s—focusing on irrigated agriculture and providing subsidies—disrupted this equilibrium [12-14]. Combined with low rainfall, frequent droughts, high population growth, and unsustainable land management practices, these changes have led to widespread land degradation. In response, farmers and herders increasingly cultivated barley for fodder, further depleting vegetation and exacerbating environmental challenges [15, 16]. This degradation has contributed to soil crusting, altered rainwater infiltration, and increased surface runoff, threatening pastoral systems and necessitating urgent restoration efforts [17-19]

Only 8% of Jordan’s land receives over 200 mm of annual rainfall, forming the rainfed agroecological zone (AEZ). This zone is concentrated in the highlands, where most precipitation occurs during winter. While 200 mm marks the lower threshold for this zone, some areas receive over 350 mm annually. The rainfed AEZ supports diverse agricultural systems, including tree crops like olives and stone fruits, field crops such as barley, wheat, and clover, and vegetables like tomatoes, potatoes, and watermelons. Olive production is particularly significant, with two-thirds of the national olive harvest originating from rainfed areas. However, the steep terrain and erratic precipitation patterns make the AEZ highly vulnerable to soil erosion during the rainy season. To mitigate land degradation, farmers, particularly olive growers, have adopted terracing techniques to conserve soil and water.

Efforts to rehabilitate Jordan’s degraded rangelands focus on implementing water harvesting (WH) measures combined with native shrub planting. WH structures concentrate surface runoff, enhance local water storage, and mitigate erosion, contributing to the restoration of rangeland ecosystems [17, 20].

1.1.Overview

This working paper synthesizes key insights from research conducted by the International Center for Agricultural Research in the Dry Areas (ICARDA), the National Agricultural Research Center (NARC), and the Ministry of Agriculture (MoA) in Jordan. The focus is on adapting water harvesting techniques across a diverse range of land uses in Jordan, particularly within areas receiving annual rainfall between 50 mm and 350 mm. These land uses include fruit tree orchards, forest plantations, field crop cultivation, and rangeland rehabilitation. The working paper is grounded in comprehensive biophysical and economic analyses that evaluate the suitability of various water harvesting technologies. These evaluations consider critical factors such as land use type, topographical features, soil characteristics, and rainfall distribution. By aligning technology applications with these parameters, the paper provides actionable recommendations for optimizing water resource utilization and supporting sustainable agricultural and ecological practices in Jordan's arid and semi-arid regions.

1.2.Research Objectives

This working paper is designed to provide policymakers at both national and local levels with valuable insights and actionable recommendations for effective policy formulation. It emphasizes the core principles required to adapt and implement coping strategies essential for restoring the productive capacity of Jordanian ecosystems. The research specifically addresses the challenges posed by prolonged periods of inappropriate land management and declining rainfall, which have significantly degraded ecosystem functions across the country.

Water harvesting techniques play a pivotal role in this restoration process. By enhancing land productivity, these techniques mitigate the adverse effects of soil erosion and reduce net runoff, thereby supporting sustainable agricultural practices and promoting ecosystem resilience. The recommendations aim to guide strategic interventions that align with Jordan’s broader environmental and economic goals, ensuring long-term sustainability and resilience in the face of climate change.

1.3.Ecosystem Services Improvement

Jordan, characterized by its arid and semi-arid climate, faces critical challenges in managing its limited water resources. With less than 200 mm of annual rainfall in most regions, water scarcity significantly impacts agriculture, livelihoods, and the overall economy. In this context, water harvesting technologies have emerged as vital tools for ensuring water security, enhancing agricultural productivity, and promoting sustainable development.

Water harvesting captures and utilizes rainwater, which would otherwise be lost through surface runoff and evaporation. This approach plays a crucial role in mitigating the adverse effects of drought, reducing soil erosion, and replenishing groundwater reserves. In Jordan, traditional and modern water harvesting systems are integrated into agricultural and rangeland management, offering practical solutions to water shortages. These systems include techniques like Vallerani contour ridges, Marab structures, olive soil bunds, and olive stone bunds, each tailored to the country's diverse topography and ecological conditions.

The adoption of water harvesting technologies contributes to the resilience of rural communities by stabilizing agricultural outputs and supporting the rehabilitation of degraded lands. By improving soil moisture and reducing dependence on overexploited groundwater, these technologies not only ensure sustainable agricultural practices but also align with national initiatives like the "Jordan Green" campaign. Furthermore, water harvesting serves as a strategic tool to address climate change impacts, fostering adaptive capacities in water management.

As Jordan seeks to balance its growing population's water demands with limited natural resources, water harvesting technologies stand out as an essential component of its national water conservation strategy. These technologies are key to achieving long-term food security, environmental sustainability, and economic stability in one of the world's most water-scarce nations.

Jordan, with its minimal natural resources and dramatic water scarcity, is seriously affected by desertification, urbanization, and a rapidly growing population. About 80% of the country’s territory can be defined as rangeland, whose economic and ecological value is still mostly neglected. Apparent effects of climate change, like erosion and land degradation, as well as unsustainable practices like overgrazing, illegal logging, and environmental pollution, cause dramatic pressures on the highly vulnerable ecosystems and threaten the numerous services provided to the people.

Ecosystem services are still rarely evaluated and considered in the political decisions of the Jordanian government, nor does the Jordanian society recognize them. The number of available and published case studies for the assessment and valuation of ecosystem services is still minimal for Jordan. The Jordanian Ministry of Environment (existing since 2003) is currently developing its national biodiversity policy with guidelines for the assessment and valuation of ecosystem services as a mandatory policy strategy. The establishment of a national information system about ecosystem services, based on their professional assessment and valuation and related aspects of biodiversity conservation, is another main objective of the Ministry.

Jordan is among the most water-scarce countries globally, with its limited natural resources exacerbated by desertification, urbanization, and a rapidly growing population. Approximately 80% of Jordan’s territory consists of rangelands, which hold significant economic and ecological value. However, these rangelands remain undervalued and are under persistent threats from climate change, overgrazing, illegal logging, environmental pollution, and land degradation. Sustainable water harvesting (WH) technologies are critical in addressing these challenges by rehabilitating degraded ecosystems and ensuring their services for livelihoods and biodiversity conservation. The following sections describe key water harvesting techniques used for various land uses and environmental conditions in Jordan.

2. WATER HARVESTING TECHNIQUES

2.1.Vallerani System (Shrub Rehabilitation)

The Vallerani system employs mechanized contour ridges to capture rainwater efficiently, supporting the rehabilitation of degraded rangelands. This technique is particularly effective in areas with sparse vegetation, as it aids in re-establishing drought-tolerant shrubs like *Atriplex halimus* and *Salsola vermiculata*. These shrubs improve soil stability, reduce erosion, and serve as vital forage for livestock, ensuring both ecological and economic benefits [21-24].

2.2.Marab Structures (Barley and Vetch Cultivation)

Marab structures are traditional water harvesting systems that channel and store rainwater to support cereal and legume cultivation, such as barley and vetch. These systems are particularly suited for lowland areas with clay-rich soils, where they improve water availability and enhance agricultural productivity. Marab systems have been instrumental in mitigating the impacts of drought and sustaining rural livelihoods [21, 23-25].

2.3.Contour Earth Banks (Field Crops)

Contour earth banks are designed to reduce surface runoff and increase soil moisture for field crops. By creating barriers along contour lines, this technique slows down water movement, allowing for more significant infiltration and reduced soil erosion. Contour earth banks are especially beneficial in arid zones with moderate slopes and low annual rainfall [23, 24, 26-28].

2.4.Contour Trenches and Gradoni Terraces (Forest Trees)

Contour trenches and gradoni terraces are used to establish forest trees on degraded hill slopes. These structures collect and retain rainwater, preventing runoff and promoting tree growth. They are particularly effective in stabilizing slopes, reducing erosion, and restoring vegetation cover in areas prone to desertification [23, 24, 29, 30].

2.5.Semi Circulare Basin Rainwater Harvesting for Fruit and Forest Trees

Semi-circular and eyebrow systems include techniques like earth tree basins, stone tree basins, contour earth walls (Tabia), and contour stone walls. These systems are tailored for olive trees, orchards, and forest plantations. By capturing and storing water directly around tree roots, the water harvesting system enhances water availability and supports sustainable tree growth in areas with limited rainfall [23, 24].

2.6.Land Use and Environmental Suitability

Each water harvesting technique is applied based on specific land use, topography, soil type, and rainfall conditions:

- Vallerani system: Ideal for rangelands with gentle slopes and degraded vegetation.
- Marab structures: Best suited for lowland areas with clay soils and cereal-legume cropping systems.
- Soil or Stone Bunds RWH techniques: Effective in orchards and forest plantations in semi-arid regions.

2.7.Ecosystem Services and Policy Integration

Despite the critical role of rangelands in providing ecosystem services such as erosion control, water regulation, and biodiversity conservation, these benefits are rarely quantified or integrated into policy decisions in Jordan. The Ministry of Environment, established in 2003, is working on a national biodiversity policy to address this gap. Key objectives include the assessment and valuation of ecosystem services and the establishment of a national information system to guide sustainable land and water management [10, 29].

Water harvesting technologies represent a vital strategy for rehabilitating degraded rangelands, ensuring sustainable livelihoods, and addressing the multifaceted challenges of climate change and resource scarcity in Jordan. Their adoption and integration into national policies are essential for preserving Jordan's fragile ecosystems and promoting resilience among its communities.

3. TECHNOLOGY DESCRIPTION

3.1.Vallerani Mechanized Micro-Catchment Water Harvesting Technology

The Vallerani mechanized micro-water harvesting system is an innovative solution designed to address land degradation and water scarcity in arid and semi-arid regions. This technology breaks up crusted and compacted soils, enhancing the capture, retention, and deep infiltration of surface runoff during heavy rainfall events. The water-harvesting pits store rainwater, providing critical soil moisture to out-planted shrub seedlings and encouraging the germination of local seeds. These processes foster the development of resilient vegetation patches, ultimately contributing to the rehabilitation of degraded rangelands.

This system is particularly suitable for areas with annual rainfall between 70 and 150 mm. It is effective on land slopes ranging from 2% to 7%, provided that the soil depth is no less than 60 cm and comprises textures such as loam, silty loam, silty clay loam, or clay loam. On gentler slopes, between 0.5% and 2%, smaller pits are more appropriate to optimize water retention and seedling establishment[31].

3.1.1. Integration in Watershed Rehabilitation

The micro-water harvesting technology is a vital component of an integrated watershed rehabilitation framework. It functions as the most upstream intervention in a coordinated approach that includes:

- **Upland Rehabilitation**: Utilizing Vallerani contour plowing for degraded hill slopes.
- **Gully Erosion Control**: Employing gully plugs to stabilize soils and reduce sediment transport.
- **Revegetation**: Supporting the growth of native shrubs and trees.
- **Downstream Agriculture**: Enhancing productivity through the Marab system for barley and other crops.

The Vallerani system is also suitable for establishing forest and fruit trees in areas receiving 150 to 250 mm of annual rainfall. It can be applied on slopes between 11% and 19%, with a minimum soil depth of 80 cm, excluding sandy soils, sandy loams, and loamy sands due to their poor water retention capacities[32].

3.1.2. Key Features of the Technology

1. **Mechanized Plowing**: The Vallerani tractor plow (Delfino 50 MI/CM) creates intermittent water-harvesting pits along terrain contours. These pits are spaced 4 to 10 meters apart, with lengths adjustable according to tractor speed. Typical pit lengths range from 3.2 to 4.5 meters.
2. **Planting Capacity**: Each pit accommodates several native shrub seedlings (commonly two per pit) to optimize vegetation cover.
3. **Soil Requirements**: Fine-textured soils with depths exceeding 60 cm are ideal for implementation.

3.1.3. Objectives and Ecosystem Benefits

The primary purpose of this technology is to interrupt the cycle of land degradation by retaining surface runoff and promoting deep infiltration. This enhances soil moisture, supporting the growth of both planted seedlings and native vegetation. Over time, as the pits naturally degrade, the established vegetation assumes hydrological functions such as rainfall interception, runoff deceleration, and infiltration facilitation. The resulting shrublands provide numerous ecosystem services, including[33]:

- **Soil Moisture Retention**: Sustains vegetation growth and prevents desiccation.
- **Erosion Control**: Reduces soil loss and captures organic matter and sediments.
- **Carbon Sequestration**: Increases organic carbon storage in soils.
- **Biodiversity Enhancement**: Supports diverse flora and fauna.

- **Flood Mitigation**: Reduces peak runoff and flooding risks.
- **Agricultural Support**: Enhances livestock grazing opportunities and reduces inputs for low-input barley farming.

3.1.4. Land User Perspectives

Land user perceptions of the Vallerani system are mixed. In the short term, skepticism is common due to the required recovery period, which involves resting or excluding grazing for at least two rainy seasons. Sustainable management practices are essential to maintain the rehabilitated lands. However, as vegetation is established and the benefits become evident, landowners generally acknowledge the technology's economic and environmental advantages. Adoption depends significantly on social and cultural contexts, as many farmers prefer traditional barley monoculture due to established practices and a lack of rangeland management alternatives. Targeted awareness campaigns can play a crucial role in overcoming resistance and promoting acceptance[34].

3.2.Marab Water Harvesting Technology

The Marab system is a traditional downstream water harvesting technique implemented within an integrated watershed management framework. This approach ensures that upstream and midstream land management practices significantly influence the effectiveness and sustainability of the Marab. Suitable for land slopes of less than 2% and deep, fine-textured soils, this technology is designed to optimize water use in flood plains for agricultural production[35]

3.2.1. Key Features of the Technology

The Marab system works by diverting and spreading excess runoff over flood plains with deep soils. Its core components include:

1. **Gully-Filling**: Filling local gullies to reduce erosion and manage runoff flow.

2. **Grading and Leveling**: Preparing seedbeds to ensure uniform water distribution.

3. **Bund-and-Spillway System**: Constructing bunds with spillways to create compartments for controlled flood irrigation.

This combination of features enables flood-irrigated agriculture, allowing previously unproductive arid lands to support high-yield crops effectively. The system is particularly well-suited for barley cultivation, which serves as fodder for livestock such as goats and sheep owned by local agro-pastoralists.

3.2.2. Purpose and Benefits

The primary aim of the Marab technology is to achieve high-yield agricultural production in arid environments that are typically unsuitable for field crops. By capturing and utilizing floodwaters, the system[36]:

- Boosts barley yields, reaching approximately 5-6 t/ha compared to the 0.05-0.30 t/ha typically achieved in rainfed systems without macro-catchment water harvesting.
- Provides grains for fodder and reseeding, supporting local livestock production.
- Promotes soil fertility through sediment deposition from upstream, improving the productivity of flood plains.

Applied within an integrated watershed management framework, the Marab system:

- Reduces extreme runoff through water retention, mitigating downstream flooding.
- Traps fertile sediments, enhancing soil quality and reducing erosion.
- Encourages sustainable dryland ecosystem management in uplands by balancing water use across the watershed.

3.2.3. Impact on Livelihoods

By significantly increasing agricultural yields, the Marab system enhances the livelihoods of local communities. High and stable barley production reduces dependence on external inputs and improves food security for agro-pastoralists. Additionally, the system’s ability to mitigate downstream flooding and sediment loss contributes to broader ecosystem stability[37].

3.2.4. Challenges and Social Dynamics

While the Marab system is highly effective, its success can lead to social tensions between upstream and downstream users. As water is retained in the watershed for agricultural use, downstream users may perceive a reduction in water availability. Addressing these tensions requires participatory planning and equitable water-sharing agreements to ensure the long-term sustainability of the technology[38].

3.2.5. Farmers’ Perspectives

Local farmers express high levels of satisfaction with the Marab system due to its ability to increase yields drastically. However, implementing the system requires coordination and support to manage upstream-downstream dynamics effectively and integrate Marab practices into broader watershed management strategies.

3.3.Soil and Stone Bunds Water Harvesting Technology for Olive Farming

3.3.1. Soil Bunds

Soil bunds are earthen embankments constructed along contour lines to manage water and soil resources in olive farming systems. These structures are designed to intercept surface runoff, allowing water to infiltrate the soil and be retained in the root zones of olive trees.

- **Construction**: Soil bunds are formed by excavating soil from upslope areas and depositing it downslope to create semi-permeable barriers. The dimensions and spacing of the bunds depend on the slope gradient and rainfall intensity. Typically, bunds are spaced 10–20 meters apart on gentle slopes of up to 8%.
- **Application**: Soil bunds are most effective in areas with clay loam or silty clay loam soils, as these retain water well and promote infiltration. They are suitable for regions receiving annual rainfall of 250–450 mm, which aligns with many olive-growing areas in Jordan.
- **Functionality**: Soil bunds minimize erosion, enhance water infiltration, and maintain soil moisture by reducing the velocity of surface runoff. This promotes healthier root development and improved olive tree productivity.
- **Advantages in Jordan**: Given Jordan’s arid conditions, soil bunds are particularly valuable for stabilizing soil on gentle slopes and capturing limited rainfall to sustain olive orchards.

3.3.2. Stone Bunds

Stone bunds are dry-stone barriers constructed along the contours of sloping terrain. These structures are specifically designed to slow down water flow, capture sediment, and reduce soil erosion, particularly in areas with rocky soils or steeper slopes.

- **Construction**: Stones are collected from surrounding fields and arranged to form continuous or intermittent barriers along contour lines. The gaps between stones allow for some water passage while trapping sediments and organic matter.
- **Application**: Stone bunds are best suited for steeper slopes ranging from 8% to 15% and rocky or shallow soils. They are commonly used in areas where rainfall is insufficient to sustain crops without efficient water management, such as Jordan's semi-arid olive farming regions.
- **Functionality**: By reducing runoff velocity, stone bunds facilitate water infiltration and protect soil from degradation. They also stabilize the terrain, creating favorable conditions for olive tree growth.
- **Advantages in Jordan**: In Jordan's hilly and rocky areas, stone bunds are an effective solution for preventing soil loss and enhancing water availability for olive trees. They align well with the country’s topographical and climatic conditions.

3.3.3. Integration into Olive Farming Systems

Both soil and stone bunds are integral to sustainable water management in Jordan’s olive farming systems. These techniques are adapted to local conditions, leveraging limited rainfall to maximize water availability and reduce soil degradation. Their ability to enhance soil moisture and stabilize the land ensures long-term productivity in olive orchards, particularly in the semi-arid and arid zones of Jordan, where water scarcity and erosion pose significant challenges.

Soil and stone bunds play a critical role in supporting olive farming by improving water retention and reducing erosion. They contribute to agricultural resilience and sustainability under Jordan’s challenging environmental conditions.

4. TECHNOLOGY MAPPING AND SUITABILITY FOR SCALING

Scaling up water harvesting technologies in Jordan requires an in-depth understanding of regional suitability based on land use, topography, soil type, and rainfall conditions. The mapping of these technologies shows distinct regional variations in suitability percentages, emphasizing the need for tailored implementation strategies across Jordan's significant basins.

4.1.Vallerani WHT Technology

Vallerani contour plowing, a micro-catchment technique for planting saltbush (Atriplex halimus) and other native shrubs, is most effective on hillslopes with moderate gradients (2–8%) and shallow to moderately deep soils. The mapping reveals:

- **Highly Suitable**: Hammad, Hasa, Disi, and Mujib basins, which have the appropriate slope and soil characteristics for saltbush establishment.
- **Lower Suitability**: Jafar, South Rift Side Wadis, and Yarmouk basins have less favorable conditions due to either steep terrain or unsuitable soil types.

Scaling up Vallerani systems in suitable basins can rehabilitate degraded rangelands, improve vegetation cover, reduce soil erosion, and provide fodder for livestock, contributing to sustainable rangeland management.

4.2.Marab WHT Technology

Marab systems, designed for macro-catchment water harvesting and barley production, are particularly effective in flood-prone plains with low slopes (less than 2%). Suitability mapping highlights the following basins as favorable:

- **Highly Suitable**: Mujib, Azraq, Jafer, and Yarmouk basins, characterized by their extensive flood plains and deep soils, provide optimal conditions for Marab-based barley cultivation.
- **Lower Suitability**: South Rift Side Wadis, South Wadi Araba, and Disi basins exhibit less favorable conditions due to steeper slopes or limited soil depth.

Scaling up Marab systems in highly suitable basins can significantly enhance barley production, improve soil fertility through sediment deposition, and mitigate flash floods. These benefits contribute to food security and resilience for local agro-pastoralist communities.

4.3.Soil and Stone Bunds WHT

Soil and stone bunds, suitable for small-scale rainwater harvesting and olive farming, are effective in managing water and soil resources in regions with gentle to moderate slopes:

- **Soil Bunds**: These are most suitable for slopes up to 8% in areas with loam or clay loam soils. Regions with deep soils and annual rainfall between 250 and 450 mm, such as parts of the Mujib and Yarmouk basins, are ideal for scaling up soil bunds.
- **Stone Bunds**: Suitable for steeper slopes (up to 15%) and rocky soils, stone bunds are well-suited for areas like the South Rift Side Wadis and Disi basins where terrain stabilization is crucial.

Scaling up these technologies in targeted regions will enhance water retention, reduce erosion, and support sustainable olive farming, contributing to agricultural productivity and climate resilience.

4.4.Integrating the technologies

A combined approach using Marab, Vallerani, and soil and stone bunds can maximize the benefits of water harvesting in Jordan. For example:

- **Mujib Basin**: The high suitability of all three technologies makes it a prime location for an integrated approach. Marab systems can be implemented in the lowlands, while Vallerani and bund technologies can be deployed in the uplands and sloping areas.
- **Azraq Basin**: Favorable for Marab barley systems and soil bunds for orchard establishment, leveraging the basin's extensive plains and gentle slopes.
- **Hammad Basin**: Best suited for Vallerani systems targeting saltbush cultivation to rehabilitate degraded rangelands.

Scaling up Vallerani, Marab, and soil and stone bund technologies in Jordan presents an opportunity to address land degradation, enhance agricultural productivity, and improve water resource management. The suitability mapping underscores the importance of basin-specific strategies to optimize the benefits of these technologies. By leveraging the unique characteristics of each basin, Jordan can achieve sustainable development in its rainfed agricultural systems, ensuring resilience against climate variability and water scarcity.

5. ECONOMICS VIABILITY OF WATER HARVESTING TECHNOLOGIES

5.1.Economic Viability of Vallerani Water Harvesting System

5.1.1. CAPEX and OPEX of Vallerani

The implementation of the Vallerani water harvesting system involves a series of structured activities. These activities ensure both biophysical and social suitability, fostering sustainable management and community involvement. The timing for each activity is critical to align with environmental conditions and seasonal rainfall patterns.

Table 1: Required activities for the Vallerani water harvesting system

Activity	Timing (Season)
Site selection (biophysical suitability)	At least 1 year prior to implementation
Site inspection and community consultation	Around 1 year prior to the implementation
Ploughing of micro water harvesting pits	Late dry season (at least 1 month before the rainy season onset)
Out-planting of native shrub seedlings	After the first substantial rainfall (> 5 mm event)
Sustainable community management	Approximately after 2 years (including grazing/resting plans)

Source: Author's elaboration (2024).

The table below summarizes the costs and inputs required to establish the Vallerani system, expressed in US$ per hectare.

Table 2: Costs and inputs needed for establishment

Input	Unit	Quantity	Cost per Unit (US$)	Total Cost (US$)
Labour				
Tractor plough operation	Labour Day/ha	0.2	25.0	5.0
Technical assistance	Labour Day	0.2	50.0	10.0
Seedling planters (community)	Labour Day	5.0	20.0	100.0
Equipment				
Tractor + Vallerani plough	Day	0.2	200.0	40.0
Field equipment	Day	1.0	20.0	20.0
Plant Material				
Atriplex halimus seedlings	Seedling	100.0	0.5	50.0
Retama seedlings	Seedling	100.0	0.5	50.0
Salsola seedlings	Seedling	100.0	0.5	50.0

Other Costs				
Transportation and storage	Lumpsum/ha	1.0	20.0	20.0
Total Costs (US$)				**345.0**

Source: Author's elaboration based on field data (2024).

Operational Costs

Operational costs for the Vallerani system are minimal post-establishment. The primary focus lies on community-based sustainable management practices, such as rotational grazing and resting periods, to maintain the system's functionality and ecological benefits.

5.1.2. Benefits and Physical Outputs

- **Shrub Biomass Production**: Establishing native shrubs such as *Atriplex halimus*, *Retama*, and *Salsola* provides essential fodder for livestock, supporting agro-pastoralist communities.
- **Runoff Reduction and Soil Stabilization**: The Vallerani system significantly reduces runoff and prevents soil erosion, enhancing water retention and promoting vegetation growth.
- **Grazing Benefits**: The biomass produced is converted into feed units (FU) for livestock. With proper grazing management, feed unit production stabilizes over time, providing long-term benefits to local communities.

Results from previous studies related to feeding *A. halimus* to livestock indicated good nutritive value. The chemical composition of *A. halimus* shows that the leaves are rich in protein, as they contain 19–25% of their dry weight in nitrogenous compounds and provide 0.56 feed unit (FU)/kg of DM[39] and 1 kg of DM of annual herbaceous plants provide 0.33 FU [40]. From these results and our estimation of biomass production, we estimated the FU provided during each season. The additional biomass dry matter production is estimated at 200 Kg/ha, equivalent to 66 Feed Units of barely equivalent with a price of USUS$ 0.55 per kg.

The Vallerani water harvesting system represents an effective and cost-efficient approach to combating land degradation, improving soil moisture, and enhancing fodder production in Jordan. While initial establishment costs are moderate, the long-term benefits of increased productivity and sustainable ecosystem management outweigh the initial investment, making it a scalable solution for arid and semi-arid regions.

The Vallerani water harvesting technology demonstrates economic viability, which is supported by the financial indicators and broader ecosystem benefits observed in its implementation. Below is a detailed discussion of its economic performance based on the provided data.

5.1.3. Financial Indicators

The financial analysis of the Vallerani water harvesting system highlights its strong economic performance and suitability for sustainable water management in arid and semi-arid regions. With a total investment of US$245 per hectare, the system represents a moderate-cost solution, and its payback period of 6 years aligns with the long-term horizon typical for land management technologies focused on gradual ecosystem recovery. The average incremental cost (AIC) for capital expenditure is US$0.184 per unit, with negligible operational costs, resulting in a total AIC of US$0.184 per unit. The updated net present value (NPV) of US$435 indicates a robust return on investment, supported by a benefit-cost ratio (BCR) of 2.78, showing that every dollar invested yields US$2.78 in benefits. The internal rate of return (IRR) of 30.3% further emphasizes the system's profitability and efficiency, while a profitability index (PI) of 1.78 confirms its financial attractiveness. These indicators collectively underscore the Vallerani system's viability as a cost-effective and profitable investment for enhancing water management and ecosystem productivity.

5.1.4. Benefits Beyond Financial Indicators

The Vallerani water harvesting system offers substantial contributions to ecosystem services, livestock support, climate resilience, and community development, making it a vital technology for sustainable land management in arid regions like Jordan. By increasing soil moisture retention, reducing runoff and erosion, and improving vegetation cover, the system enhances ecosystem services, indirectly supporting agricultural productivity and mitigating land degradation costs. The growth of shrubs such as Atriplex halimus, Retama, and Salsola provides high-quality fodder, reducing feed expenses for agro-pastoralist communities and improving livelihoods and food security. Additionally, the system bolsters climate resilience by stabilizing degraded lands and enhancing water infiltration, which is crucial in the face of unpredictable rainfall patterns. Community inclusion is a core feature, with local labor and quality seedlings fostering ownership and long-term sustainability despite slightly higher establishment costs. Challenges remain, including a long payback period and modest profitability index, which could be addressed through cost reductions, such as using more affordable seedlings and achieving economies of scale. Enhancing fodder yields can further improve economic returns and reduce the payback period. Policy support, including financial incentives or subsidies, can play a critical role in offsetting initial costs and promoting widespread adoption of the technology.

5.2. Economic Viability of Marab Water Harvesting Technology

5.2.1. Capital Expenditure (CAPEX)

The Marab water harvesting system requires a total capital investment of US$12,930, translating to US$918 per hectare. This higher initial investment reflects the complexity of the

Marab system, which includes extensive labor, machinery, and materials for construction. Key cost components include:

- **Labor Costs**: Significant labor input is required for activities such as local workforce engagement, land surveys, engineering supervision, and operation of heavy machinery.
- **Equipment Costs**: The use of graders, loaders, plows, and tractors accounts for a substantial portion of the CAPEX. These machines are essential for shaping and preparing the flood plains.
- **Material Costs**: Construction materials, primarily stones, are used to build the earthen bunds and spillway systems.
- **Transportation and Other Costs**: Transporting heavy machinery to the site and ensuring site security are additional cost drivers.

The substantial CAPEX reflects the need for durable infrastructure to manage floodwaters effectively and support agricultural productivity in flood plains.

Table 3: Costs and inputs needed for establishment

	Specify input	**Unit**	**Quantity**	**Costs per Unit**	**Total costs per input (US$)**
Labour	Local Workers	person-days	50.0	35.0	1750.0
Labour	Land Survey	person-days	6.0	35.0	210.0
Labour	Engineer (+assistance)	person-days	15.0	50.0	750.0
Labour	Drivers of heavy machinery	person-days	12.0	35.0	420.0
Equipment	Grader	machine-days	3.0	250.0	750.0
Equipment	Loader	machine-days	10.0	250.0	2500.0
Equipment	Deep Plow	machine-days	3.0	200.0	600.0
Equipment	Tractor (to pull the shallow and deep plow)	machine-days	5.0	200.0	1000.0
Equipment	Shallow Plow	machine-days	2.0	200.0	400.0
Equipment	Water Tank Truck	Tank	1.0	50.0	50.0

Equipment	Small Equipment (Shovel, pickaxe, buckets)	Equipment	1.0	200.0	200.0
Construction material	Stones	Kubic Metre	200.0	10.0	2000.0
Other	Transportation of heavy machinery		1.0	2000.0	2000.0
Other	Security		1.0	300.0	300.0
Total costs for the establishment of the Technology					12930.0
Total costs for the establishment of the Technology in US$					12930.0

Source: Author’s elaboration based on field data (2024).

5.2.2. Operational Expenditure (OPEX)

The Marab water harvesting system incurs relatively low annual operational costs of US$66 per hectare, primarily attributed to routine maintenance activities such as minor repairs to bunds and spillways, labor costs for engineers, workers, and equipment operators, and material expenses for replenishing stones and conducting small repairs. These minimal operational costs underscore the system’s efficiency and cost-effectiveness in maintaining functionality over the long term, making it a sustainable solution for water management in arid regions.

5.2.3. Benefits of the Marab System

The Marab water harvesting system demonstrates significant benefits in agricultural productivity, water management, and climate resilience, making it an essential tool for sustainable development in arid regions. By generating an additional 2,000 kg/ha of barley annually, valued at US$0.55 per kg, the system provides substantial revenue of US$1,023 per hectare per year, while increased biomass production enhances fodder availability for livestock, supporting agro-pastoralist communities. Its efficient capture and redistribution of floodwaters mitigate flash flood risks and reduce soil erosion, while sediment retention improves soil fertility and promotes sustainable agricultural practices. Additionally, the system strengthens climate resilience by stabilizing flood-prone areas, enhancing water retention, and contributing to the restoration of degraded flood plains, ensuring long-term environmental sustainability and adaptability to climate variability.

5.2.4. Financial Indicators

The economic analysis of the Marab water harvesting technology highlights its strong financial viability and sustainability for arid regions like Jordan. The Average Incremental Cost (AIC) demonstrates affordability, with a capital expenditure (CAPEX) of US$0.057 per unit and minimal operational expenditure (OPEX) of US$0.002 per unit, resulting in a total AIC of US$0.096 per unit. The updated Net Present Value (NPV) of US$6,699 underscores substantial financial returns over the system's lifecycle, while the Benefit-Cost Ratio (BCR) of 5.33 indicates that every dollar invested generates US$5.33 in benefits, affirming the system's profitability. With an Internal Rate of Return (IRR) of 75.0% and a reduced payback period of 3.0 years, the Marab system offers exceptional investment efficiency and rapid cost recovery. The profitability index (PI) of 7.30 further reinforces its financial feasibility. Beyond financial returns, the Marab system provides ecological and social benefits, including enhanced agricultural productivity, improved climate resilience, and strengthened community engagement, making it a valuable tool for sustainable water and land management. Proper maintenance and active community involvement are critical to maximizing its potential and ensuring long-term success.

5.3.Economic Viability of Soil and Stone Bunds in Olive Farming Water Harvesting Technology

5.3.1. The capital expenditure (CAPEX)

The capital expenditure (CAPEX) for implementing soil and stone bunds in olive farming water harvesting systems is a critical factor in determining their feasibility and application. Soil bunds are a cost-effective solution with a CAPEX of US$76.3 per hectare, primarily driven by labor costs, which include 20 person-days for local workers (US$355) and 10 person-days for engineer assistance (US$355), along with minimal equipment costs (US$53.25 for small tools). The absence of construction materials like stones further reduces their total cost. Conversely, stone bunds require a significantly higher CAPEX of US$882 per hectare, reflecting their robust design and suitability for erosion-prone terrains. This cost includes labor for 30 person-days (US$532.5) and engineer assistance (US$355), as well as substantial equipment costs, such as loaders (US$568) and tractors (US$213).

Additionally, the use of 100 cubic meters of stones, at US$71 per cubic meter, adds US$7,100 to the total. While soil bunds offer a cost-effective option for water harvesting, stone bunds provide a more durable solution for areas with challenging slopes, high erosion risks, and the need for enhanced water retention. Site-specific factors, such as topography, soil type, and land degradation severity should guide the choice between these technologies.

5.3.2. Maintenance Costs of Soil and Stone Bunds in Olive Farming

The maintenance costs for soil bunds and stone and soil bunds in olive farming systems are minimal, consisting primarily of labor and small equipment, which ensures both cost efficiency and sustainability. Both technologies require 10 person-days per hectare annually for routine tasks such as repairing bunds and clearing debris, costing US$355 at a rate of US$35.5 per day, with no need for engineer involvement, further minimizing expenses. Additionally, small tools like shovels and pickaxes add US$17.75 per hectare annually, bringing the total annual maintenance cost for both technologies to US$37.3 per hectare. These low maintenance costs underscore the economic viability of soil and stone bunds for long-term implementation, highlighting their cost-effectiveness and scalability for olive farming in arid and semi-arid regions. The modest financial requirements make these water harvesting systems sustainable and feasible for widespread adoption.

5.3.3. Economic Viability for Olive Soil Bunds and Olive Stone Bunds

The financial analysis of olive farming water harvesting technologies, specifically soil bunds and stone bunds, highlights their robust economic viability and suitability for sustainable agricultural practices. Olive soil bunds stand out as a highly cost-effective option with an initial investment of US$76 per hectare and minimal annual operational and maintenance costs of US$17. The average incremental cost (AIC) for capital expenditure is US$0.011 per unit, and operational costs are US$0.002 per unit, resulting in a total AIC of US$0.060 per unit. With a net present value (NPV) of US$9,637, a benefit-cost ratio (BCR) of 23.36, and an internal rate of return (IRR) of 220.0%, soil bunds offer exceptional profitability. The payback period (PBP) of just three years and a profitability index (PI) of 126.26 further underscore their financial attractiveness and scalability. Conversely, olive stone bunds, while requiring a higher initial investment of US$882 per hectare due to the use of stones and heavy equipment, also demonstrate strong financial performance. The annual maintenance cost remains consistent at US$17, and the total AIC is US$0.172 per unit, reflecting cost efficiency despite the higher upfront costs. With an NPV of US$8,831, a BCR of 8.14, and an IRR of 68.1%, stone bunds provide substantial financial returns and are particularly suitable for erosion-prone terrains. Although the payback period for stone bunds is slightly longer at four years, the profitability index of 10.01 confirms their viability. Both technologies are crucial tools for sustainable water harvesting in olive farming systems in Jordan, with soil bunds excelling in cost-effectiveness and profitability and stone bunds offering durability for challenging conditions. Together, these systems validate their scalability and long-term benefits for arid and semi-arid regions.

CONCLUSIONS

The findings presented in this working paper underscore the economic, environmental, and social benefits of rainwater harvesting (RWH) technologies for sustainable water and land management in Jordan's arid and semi-arid regions. Technologies such as Vallerani RWH, Marab RWH, and olive farming systems (soil and stone bunds) demonstrate varying degrees of economic viability, driven by site-specific conditions and the scale of implementation. These systems address critical challenges, including water scarcity, land degradation, and agricultural productivity, while delivering substantial financial returns and ecological benefits. Economic analyses highlight the cost-efficiency and profitability of these technologies, as summarized in Table 4.

Table 4: Economic viability of water harvesting technologies in low rainfall areas in Jordan

Financial Analysis	**Vallerani RWH**	**Marab RWH**	**Olive Soil Bunds RWH**	**Olive Stone BundsRWH**
Total Investment (US$/ha)	245	918	76	882
Total AIC (US$/unit)	0.184	0.096	0.060	0.172
NPV (US$)	435	6,699	9,637	8,831
BCR	2.78	5.33	23.36	8.14
IRR	30.3%	75.0%	220.0%	68.1%
Payback Period (years)	6.0	3.0	3.0	4.0
Profitability Index	1.78	7.30	126.26	10.01

Source: Author's elaboration based on field data (2024).

Olive soil bunds emerge as the most cost-effective option, with exceptional financial metrics, including a Benefit-Cost Ratio (BCR) of 23.36, a Net Present Value (NPV) of US$9,637, and a short payback period of 3 years. Similarly, olive stone bunds and Marab RWH systems provide strong economic viability, with NPVs of US$8,831 and US$6,699, respectively. The Vallerani RWH system, although requiring a longer payback period (6 years), offers broader ecological benefits, such as ecosystem restoration and land stabilization, making it a valuable investment.

Beyond financial metrics, these RWH technologies contribute to enhanced ecosystem services, including reduced soil erosion, improved water retention, and increased agricultural productivity. They also bolster climate resilience and promote community inclusion through local labor engagement and benefit-sharing, ensuring long-term sustainability.

In conclusion, the economic viability of these technologies positions them as essential tools for addressing water scarcity and land degradation in Jordan. Scaling up these solutions, supported by strategic policies, financial incentives, and community participation, will amplify their impact, fostering sustainable agricultural development and resilience to climate variability. The choice of technology should align with site-specific conditions, investment capacity, and Jordan's broader sustainability objectives.

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Photo Gallery

Photo 1: Vallerani Water Harvesting System. Photo Credit (Mira Haddad, ICARDA).

Photo 2: Marab Water Harvesting. Photo Credit (Mira Haddad, ICARDA).

Photo 3: Soil Bunds Water Harvesting. Photo Credit (Mira Haddad, ICARDA).

Photo 4: Stone Bunds Water Harvesting. Photo Credit (Mira Haddad, ICARDA).

	
Photo 5: Semi-circular bunds. Photo Credit (Mira Haddad, ICARDA)	Photo 6: Semi-circular bunds. Photo Credit (Mira Haddad, ICARDA).