Green Water Harvesting in Jordan's Um Naa'am Watershed: Assessing Suitability for Climate Change Resilience

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DOI: https://doi.org/10.14796/JWMM.C580

ABSTRACT

Water scarcity is a critical challenge in Jordan, intensified by its arid climate, limited water resources, and growing demand across different sectors. The Um Naa'am watershed, located in a water-stressed area, requires sustainable solutions to enhance water availability and address climate change. This study aims to assess the suitability of Green Water Harvesting (GWH) interventions—including contour ridges, runoff strips, and marabs—in the Um Naa'am watershed using Geographic Information Systems (GIS) technology. GWH has shown promise in supplementing water resources, increasing soil moisture, improving vegetation cover, boosting crop productivity, and enhancing groundwater recharge. Spatial analysis, data reclassification, and multi-criteria evaluation were used in ArcGIS, taking into consideration topography and soil characteristics to analyze the suitability for GWH. In the present study, it was found that 42.46% of the watershed is suitable for runoff strips, 29.30% for contour ridges, and 1.64% for Marabs. The results may indicate that techniques for GWH can effectively act at deeper levels regarding water scarcity management, increasing resilience for more sustainable agriculture in this region. The integration of GWH and GIS thus provides a data-driven

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Abuhamoor, D., L. Al Mahasneh, F. Ziadat, M. Mudabber, M. Haddad, and A. Sweity. 2026. "Green Water Harvesting in Jordan's Um Naa'am Watershed: Assessing Suitability for Climate Change Resilience." *Journal of Water Management Modeling* 34: C580. https://doi.org/10.14796/JWMM.C580 www.chijournal.org
ISSN: 2292-6062

approach toward solving water-related problems, which is very important in terms of food security and sustainable development in semi-arid regions.

1. INTRODUCTION

Water harvesting (WH) is the process of collecting, diverting or storing, utilizing, and managing runoff water from the land surface that flows due to rain and floodwater, in useful applications such as enhancing soil moisture and groundwater recharge for agricultural and ecological sustainability as well as for potable uses, mainly during scarcity seasons (Critchley et al. 2013; Oweis et al. 2001). It includes the collection of rainwater from various surfaces or channels like seasonal valleys, rooftops, fields, or natural catchments. This improves the recharge of groundwater, optimizes full use of all water and land resources to meet the ever-fast-growing demand for both water and food, increases biodiversity in dryland areas, restores vegetation cover, raises agricultural productivity and its stability, while reducing the demand on natural resources (Mekdaschi Studer and Liniger 2013). This practice, therefore, helps in the effective management of water resources in arid and semi-arid zones around the world where water scarcity has limited agricultural activities (Abu-Awwad and Shatanawi 1997; Oweis et al. 2001).

Green water harvesting (GWH) is defined as the capture and use of rainfall water through vegetation, soils, and other natural mechanisms to enhance soil moisture and recharge groundwater resources (Dile et al. 2013). GWH techniques can be applied to improve agricultural and pasture land productivity by enhancing rain-fed crops production, reducing crop failure risks, reducing soil erosion in combating desertification through the development of pastures and vegetation cover, supporting the development of livestock with water supply for drinking purposes, and supplying water for domestic uses and drinking purposes for the local population (Abd-Elaty et al. 2024; Mahmoud et al. 2016; Oweis 2017). GWH has received global attention as a green technology to help cope with water scarcity, especially in arid and semi-arid countries like Jordan, commonly facing acute rainfall and groundwater scarcity (Eludoyin et al. 2021; Strohmeier et al. 2021; Yazar and Ali 2016). The country faces severe water scarcity amidst an arid setting that provides huge challenges for its rapidly growing population, who depend on very limited rainfall and shallow or depleted groundwater (Al-Addous et al. 2023). As climate change intensifies, Jordan's water security becomes even more vulnerable, with increased chances of further aridity and warmer temperatures accelerating the demand for water supply (Talafha et al. 2024). Research on GWH indicates that it has a range of benefits beyond just the augmentation of available water quantity. Hence, some of the essential outputs of GWH, which are also of equal significance in meeting agricultural sustainability, include reduced soil erosion, improvement in soil fertility, and recharge in groundwater, apart from reducing negative impacts of drought (Molajou et al. 2023). GWH will play an important role in the water-energy-food nexus, as it takes into consideration the interdependence of water and energy with the production of food. That approach, by minimizing the demand for external water supply and the energy needed to transfer the water, will enhance efficiency in the use of resources, build resilience to climate variability, and improve food security (Dile et al. 2013).

GWH can be categorized into micro-catchment systems, small-scale used on trees, and macro-catchment systems, which are large-scale runoff used in farming that involve the diversion of natural streams or wadis (Boers and Ben-Asher 1982). Many micro-catchment techniques, such as contour ridges and contour strips, focus on augmenting soil moisture by preventing surface runoff and are ideal for areas receiving less rainfall annually, mostly between 100–300 mm (Tatsumi et al. 2021). *Runoff Strips* are narrow, level strips constructed along the contour lines of sloped terrain. These strips are designed to intercept and slow surface runoff, allowing more time for water infiltration and reducing soil erosion. They are especially effective in semi-arid areas with gentle to moderate slopes and fine to medium-textured soils. Runoff strips are widely used in dryland agriculture to improve soil moisture retention and support crop productivity, especially under rainfall variability (Oweis and Hachum 2006). These techniques rely on small changes in land, like the application of soil or stone barriers along contour lines, which would hamper the flow of water and increase infiltration (Eludoyin et al. 2021).

In contrast, macro-catchment techniques are more appropriate for larger areas, incorporating check dams and water-spreading systems (Mekdaschi Studer and Liniger 2013), also known as Marabs. In Arabic, a "Marab" was described as a naturally occurring depression where runoff collects and spreads. Agro-pastoralists from the Middle East who reside in or travel across semiarid and desert rangelands are credited with inventing the so-called "Marab" (Strohmeier et al. 2021). They were designed to catch runoff from a wider catchment area and direct it toward defined zones where it can be stored or utilized for crops and livestock (IUCN 2022; Renzi et al. 2023).

The application of geographic information systems GIS and remote sensing technologies marks a ground-shifting era in assessing and implementing GWH, particularly in the fields for water management and conservation planning (Boroomandnia et al. 2021; Tsihrintzis et al. 1996). GIS offers a robust framework for spatial analysis, enabling the evaluation of critical factors such as slope, aspect, soil type, and land use, which determine the effectiveness of water harvesting techniques (Sayl et al. 2016). Remote sensing data further complement this with information on vegetation cover, land use changes, and rainfall patterns (Mashala et al. 2023). Together, these technologies enable the approach to be very precise and data-driven in decision-making on areas most suitable for GWH implementation. Integrating green-water harvesting techniques into a GIS tool enables more sustainable and resilient agricultural systems while managing water resources effectively and fostering long-term ecosystem health, especially in regions vulnerable to water scarcity. This study integrates updated, site-specific biophysical field data into a GIS-based multi-criteria framework to assess the suitability of green water harvesting (GWH) techniques in a semi-arid watershed. The approach refines suitability thresholds—such as slope, soil depth, and texture—based on local expert consultations and field validation. Additionally, it introduces a stream network buffering technique to accurately delineate zones suitable for Marabs, which has not been applied previously in this region.

This represents the first comprehensive GWH suitability mapping study in the Um Naa'am watershed and offers locally relevant insights that can inform water resource planning and climate adaptation strategies in similar arid environments. The paper aims to evaluate the potential and acceptability of green water harvesting techniques in the Um Naa'am watershed in Jordan by employing (GIS) technology. Several recent studies have utilized GIS and remote sensing technologies to enhance green water harvesting (GWH) planning and implementation. These tools enable precise spatial analysis by integrating biophysical data such as slope, soil properties, vegetation cover, and rainfall distribution. For example, Sayl et al. (2020) employed GIS and remote sensing to identify optimal sites for rainwater harvesting in the western desert of Iraq, highlighting the role of spatial tools in dryland water management. Likewise, Haddad et al. (2024) applied a GIS-based spatial Multi-Criteria Evaluation (MCE) framework to delineate areas suitable for implementing GWH techniques in degraded arid zones of Jordan. These studies underscore the critical role of spatial technologies in identifying site-specific opportunities for GWH interventions, particularly in semi-arid and arid environments where resource allocation must be optimized.

While GIS-based multi-criteria evaluation is an established method in water harvesting studies, this research introduces several methodological refinements and region-specific innovations. First, the study incorporates updated, high-resolution field data—such as soil depth, surface stoniness, and vegetation cover—collected specifically for the Um Naa'am watershed, which enhances the accuracy and local relevance of the suitability analysis. Second, refined suitability criteria were developed and applied, reflecting the unique biophysical conditions of northeastern Jordan, and validated through expert consultations and field verification. Third, the study uses hydrological stream network buffering to improve the spatial identification of suitable zones for Marabs, a macro-catchment technique rarely assessed with this level of precision. Collectively, these contributions represent the first GIS-based green water harvesting suitability assessment for this watershed, providing a replicable approach for sustainable water management in other data-scarce semi-arid regions. This study will involve analyzing key factors including soil type, topography, and vegetation cover to provide comprehensive insights into the effectiveness of these water harvesting methods in the region. The findings from this study will contribute to addressing water scarcity challenges in Jordan and support global efforts towards promoting sustainable water management practices.

2. MATERIALS AND METHODS

2.1 Study area

The Um Enna'am watershed is located in the northeastern part of Jordan; its catchment area is 86.2 km^2, facing all the complexities typical of a semi-arid setting. The area has a semi-arid climate with annual rainfall of approximately 200–250 mm. This indicates severe water availability problems for agriculture and domestic purposes. However, a large variability in the quantum of rainfall dictates the importance of water management strategies to focus their efforts on GWH techniques for better retention of soil moisture. Topographically, altitudes around the watershed vary within a range from 622–923 m and are highly variable; this presents a variety of conditions affecting runoff, erosion, and water distribution. This may provide suitable sites for large-scale water harvesting techniques such as check dams or retention ponds, which could reduce runoff velocity, decrease erosion, and substantially increase the infiltration rate in the downstream areas. Thus, the geographical and climatic factors combine to make effective water management necessary for the long-term sustainability of this semi-arid environment. Figure 1 shows the Location of Um Enna'am watershed in Al Mafraq, Jordan.

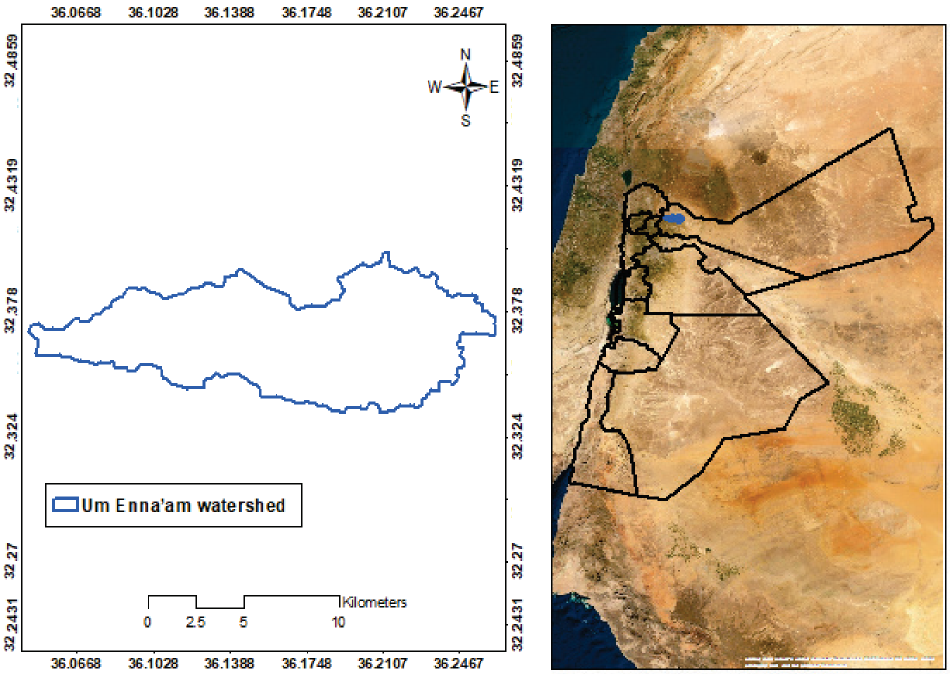

Figure 1 Location of the Um Enna'am watershed in Al Mafraq, Jordan.

2.2 Methodology overview

Land suitability evaluation and mapping were developed to integrate soil and climatic data to assess the land suitability only for green water harvesting techniques (GWH). This approach utilizes a number of sequential steps, as shown in Figure 2. The flowchart outlines the sequential process used to identify suitable areas for GWH interventions, beginning with the selection of techniques and biophysical criteria, followed by data collection, thematic map generation, reclassification, and GIS-based overlay analysis. This visual framework enhances the transparency and reproducibility of the multi-criteria evaluation approach applied in the Um Naa’am watershed.

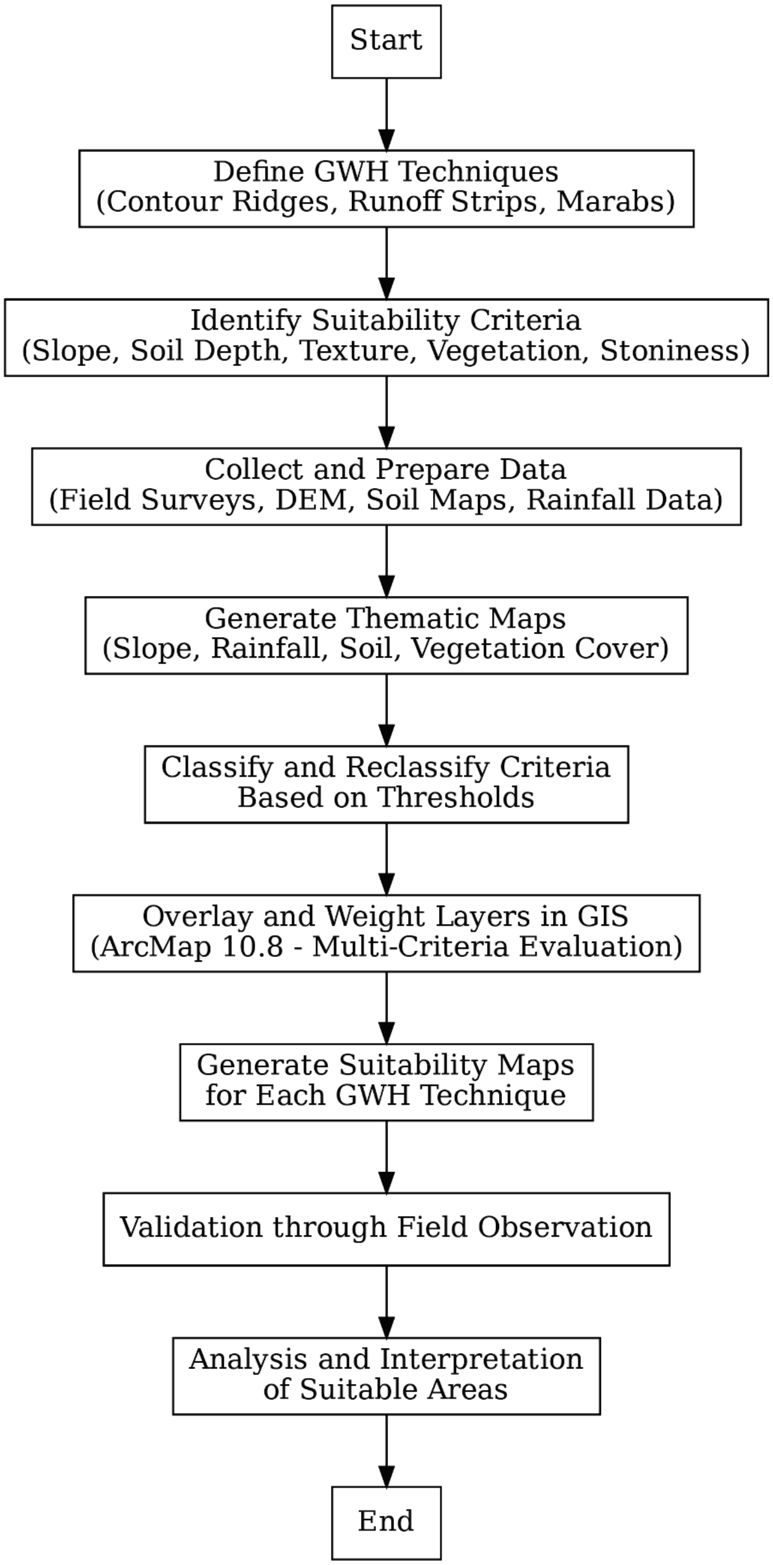

Figure 2 Methodological flowchart illustrating the steps used to assess the suitability of green water harvesting (GWH) techniques in the Um Naa'am watershed using GIS-based multi-criteria evaluation.

2.3 Selection of rainwater harvesting technique

The three selected water harvesting techniques—contour ridges, runoff strips, and Marabs—were adapted to the biophysical characteristics of the Um Naa’am watershed.

Contour Ridges consist of parallel embankments constructed along contour lines, typically spaced 10–15 m apart, designed to slow runoff and improve infiltration on sloped rangelands.

Runoff Strips are narrow, leveled, or slightly sloped bands of land (1–2 m wide) placed across gentle slopes. They can be left bare or planted and are commonly used in cereal cultivation, especially barley, to enhance water retention and reduce drought risk.

Marabs are natural or semi-structured depressions located in low-slope zones (0–1%), often reinforced with small stone barriers to retain water and trap sediments. These are especially suited for supporting field crops or trees and allow for post-harvest grazing.

The most suitable GWH techniques for the study area were determined by performing an assessment at the sub-watershed scale, which embraces three principal stages. It first identified the possible rainwater harvesting techniques, limiting the practices to those that are more common with proven success in similar climatic conditions and topography. Then, climate, soil condition, and topography data were gathered as inputs to assess the suitability of the site, while information on local practices was also obtained from the community to ensure that the implementation of rainwater harvesting would be aligned with community familiarity. Finally, regional experts’ consultations based on the feasibility of the selected techniques were narrowed down to the three GWH techniques chosen in this work, namely contour ridges for rangeland, Marabs, and runoff strips.

2.4 Identifying the key biophysical requirements for each water-harvesting intervention

Expert knowledge was used to identify the requirements for RWH interventions, adopting criteria for classifying areas as suitable or unsuitable for a particular intervention. The key parameters used were slope, soil depth, soil texture, vegetation cover, and soil surface stoniness (Oweis et al. 2001). Slope influences the amount of runoff and is important because the RWH technique adopted is dependent on slope, since each GWH technique has appropriate and maximum limits of runoff they can stand (de Winnaar et al. 2007). Soil depth and texture were fundamental in the approximation of the water-holding capacity of the soil, and its suitability for crop survival, especially in areas that receive episodic rainfall (Veblen et al. 2022). Vegetation cover and soil stoniness can be used as an indication of the potential of the land to support RWH. Rainfall was also considered an important factor, although it was not treated as a variable since it was the same throughout the study area.

The biophysical information needed was partly gathered from existing sources, and through a dedicated field survey. A 30-m resolution Digital Elevation Model (DEM) was generated from the contour lines and spot heights to develop a slope map through the ArcGIS command known as (SLOPE), which was then utilized for the delineation of slope units to serve as basic land mapping units for the suitability analysis. A field survey was conducted to collect additional relevant biophysical data, including stone surface cover, (percentage stoniness), type and cover of vegetation, soil surface texture, and depth of soil. These field measurements were then used to produce suitability maps based on previously developed expert-based criteria (Table 1). This was done by comparing RWH requirements to physical land conditions using the aid of GIS. The spatial data was stored, analyzed, and displayed using GIS tools; hence, it was very apt for studies in site selection during RWH.

Field verification confirmed the accuracy and reliability of the GIS-based methodology by identifying suitable locations and selecting appropriate water harvesting techniques, particularly micro-catchments/contour ridges and other systems such as cisterns and pits. Given that water harvesting is highly site-specific, assessing land suitability requires integrating various related criteria. GIS, with its capability to merge diverse types of information, greatly facilitated and expedited the analysis process. For broader applicability, this methodology can be used for other suitability studies in arid and semi-arid regions, and rainfall should be included as a variable. GIS also supports the integration of both biophysical and socio-economic factors, which improves the selection process for GWH techniques.

Table 1 Biophysical requirements for different rainwater harvesting techniques.

Water Harvesting Techniques	Rainfall (mm)	Slope (%)	Texture	Soil Depth	Stone at the Surface
Contour ridges range	100–300	16–18%	Variable	Variable	Variable
Runoff strips	100–300	<10%	Fine and medium	Medium-deep	Medium
Marabs	100–300	0–1%	—	—	—

NOTE: Soil Depth: shallow (<30 cm), medium (30–60 cm), and deep (>60 cm).
Soil Texture: coarse = sandy soils, medium = loam, and fine = clayey soils.

2.5 Analyzing biophysical requirements

The analysis focused on determining the biophysical requirements for each rainwater harvesting intervention, with soil information playing a critical role. Descriptive and geographic data of soil characteristics were important for identifying suitable locations for implementing water harvesting techniques. In this research, soil data covering all parts of the watershed were used, sourced from the National Soil Survey Project by the Ministry of Agriculture (MOA 1994). The parameters included GPS coordinates (easting and northing), land surface cover (stoniness percentage), vegetation type and coverage (percentage for selected sites), surface horizon texture (estimated by sight), and soil depth (cm). For runoff strips, soil depth specifically needed to be medium to deep. Figure 3 shows these factors spatially across the watershed. The study area topography is undulating to rolling; low, rounded hills formed in Tertiary calcareous rock formations with slopes less than 0% and well over 20%.

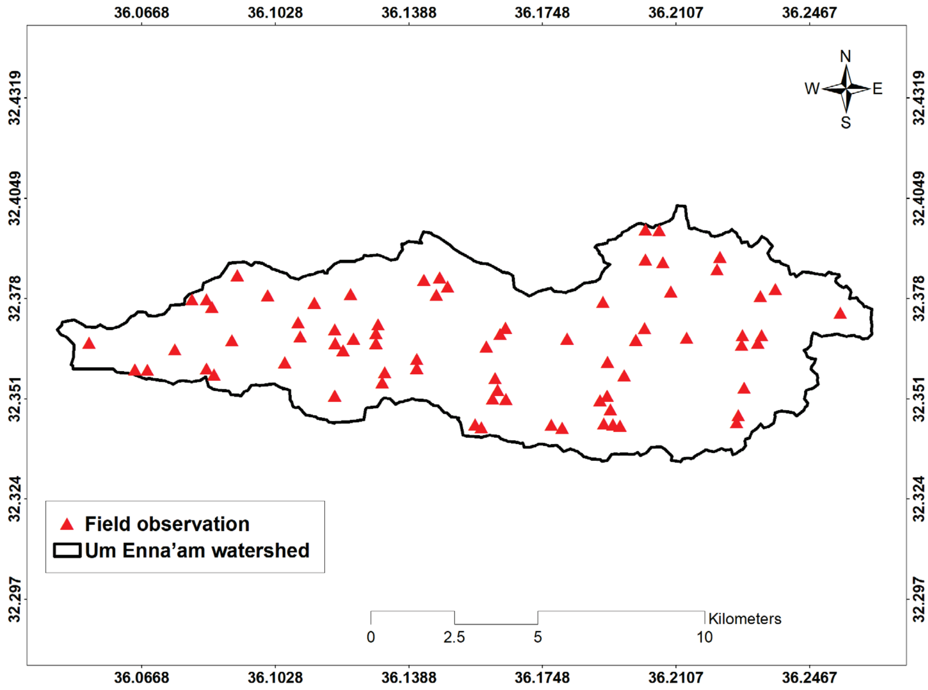

Figure 3 Field observation locations in the Um Enna'am watershed, Al Mafraq, Jordan.

2.6 Data integration and analysis

The modeling process consisted of the integration and processing of several layers of data collected using the assistance of Geographic Information System software, to identify major zones suitable for various water harvesting techniques. In this study, spatial analysis and suitability mapping were carried out using ArcMap 10.8 by (ESRI, Redlands, CA, USA). The software was employed to process a Digital Elevation Model (DEM) with a 30-m resolution, derive slope maps through the Slope tool, and to conduct spatial overlays and map algebra operations critical for the multi-criteria evaluation process. ArcMap also facilitated the integration of field survey data with various biophysical layers, enabling the development of suitability maps for the implementation of GWH techniques. This was achieved by overlaying spatial datasets on climate, topography, and soil characteristics and then applying defined suitability criteria to find areas suitable for different water-harvesting interventions: contour ridges, runoff strips, and Marabs. Other spatial analysis techniques used include overlay analysis, which was performed using ArcGIS to overlay and analyze the different data layers. Climate data, topographic features, and soil properties were all collected and pre-processed before being imported into ArcGIS—a basic tool when running the Suitability Analysis model—and overlaid against one another to retrieve an overall rating of suitability for each one of the water harvesting interventions. Adopting the Suitability Analysis model, the computation of the most suitable area with potential where specific techniques of water harvesting techniques should be applied was done. The analysis, based on ArcGIS, was performed considering biophysical factors and spatial relationships between various data layers to ensure that the chosen locations would meet the requirements of the proposed interventions. Moreover, the computable areas for each technique—contour ridges, runoff strips, and Marabs—were quantified, giving very important information to decision-makers on implementation strategies for water harvesting.

3. RESULTS AND DISCUSSION

Biophysical Suitability for GWH was based on interpolations for all biophysical requirements. The overlay of these layers with the slope units provided biophysical characterization of each slope unit (polygon-based overlay). Matching the requirements for various GWH techniques with the characteristics of each slope unit generated biophysical suitability maps. The results of the GIS analysis revealed the suitability of different green water harvesting techniques in the Um Naa'am Watershed. The suitability analysis results were used to understand the distribution and spatial patterns of suitable areas for each water-harvesting intervention and then produce thematic maps indicating the suitability classes for each intervention. These maps provide visual representations of areas where specific GWH techniques are likely to be successful.

3.1 Biophysical requirements analysis

The amount and distribution of rainfall are an important factor for the suitability of specific rainwater harvesting techniques in any given location. In designing effective rainwater harvesting systems, it is necessary that the catchment region receives adequate rainfall to ensure sufficient water storage for future use. In this study, the suitability of GWH techniques was assessed using long-term annual rainfall data, which was collected from 1990 to 2014, sourced from the Jordan Meteorological Department. The data showed that the annual rainfall in the study area ranged between 200 and 250 mm, as shown in Figure 3. Recent literature emphasizes the significance of rainfall quantity and its temporal distribution for the effectiveness of GWH techniques. Rainfall data are essential in determining the type and scale of rainwater harvesting systems that can be implemented effectively (Darabi et al. 2021; Adham et al. 2016a). This region, receiving moderate rainfall of less than 200-300 mm a year, is suitable for different types of intervention, like runoff strips and micro-catchments designed to capture and maximize the use of rainfall (Abdelkareem et al. 2024; Adham et al. 2016a). The temporal pattern of rainfall distribution, instead of the amount of rainfall alone, is very important in delineating the reliability of the GWH system, especially in arid regions characterized by rainfall variability (Liuzzo et al. 2016). In fact, rainfall management, as part of RWH techniques, contributes to the supplementation of irrigation, minimizes runoff, and decreases soil erosion (Gatot et al. 2001). The stability of crop yield is directly affected by effective rainfall harvesting owing to the prolonged soil moisture availability, especially during the normally dry months experienced in Jordan. Figure 4 presents an analytical summary of rainfall over a 24-year period, thereby laying a foundational understanding into the potential effectiveness of applying RWH techniques in the study area.

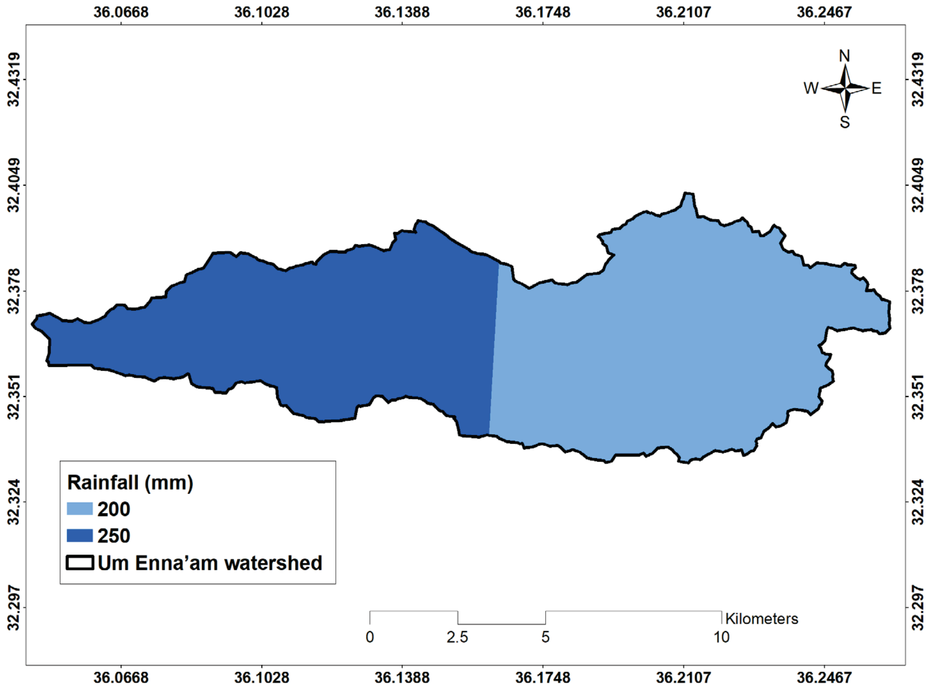

Figure 4 Annual rainfall map of Um Enna'am watershed, Al Mafraq, Jordan.

This complex study topography was analyzed using ArcGIS software to create an in-depth topographical representation to derive relevant slope data for the suitability analysis in RWH techniques. A DEM of 30-m resolution was prepared in ArcMap to delineate elevation variation across the watershed (Figure 5). This DEM was further processed for slope calculation at each pixel by using the "Slope" tool in ArcGIS, which delivered a thematic map showing all slope variabilities in the study area (Figure 6). The final slope map allowed the classification of topography into different slope classes, from flat areas to steep lands (>20%) (Figure 6). The slope classification was of great importance in the land suitability analysis, since each class was allocated according to the requirements that different RWH interventions have for the specific identification of areas capable of supporting runoff collection effectively and minimizing erosion risks. The detailed slope analysis is an important optimization strategy in the selection of suitable water harvesting techniques to ensure that the topographical features of each site align with interventions (Faisal and Abdaki 2021). Subsequently, the slope map was overlaid onto other biophysical data layers such as soil texture, soil depth, and vegetation cover using the multi-criteria analysis capability of ArcGIS. This integration could, therefore, facilitate a more holistic identification of areas where topography, in association with other biophysical conditions, favors certain methods of water harvesting. Similar approaches have been tested and verified by Tumbo et al. (2013), where the integration of topographical data together with other land characteristics ensured better orientation toward decision-making in the interest of sustainable land management in semi-arid environments. Slope data had to be integrated with other biophysical layers, which played an important role in the identification of suitable areas for different GWH techniques. The use of GIS and its resultant multi-layered analysis, therefore, made the land suitability assessment much more effective and swift to support sustainable agricultural development on such challenging terrains (Umugwaneza et al. 2022).

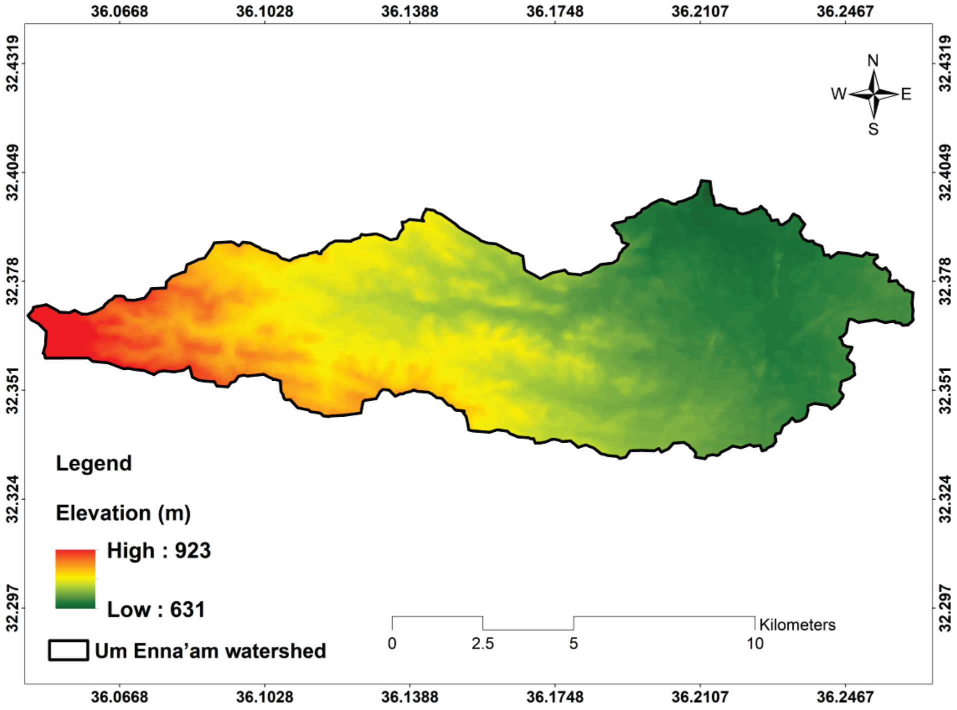

Figure 5 Elevation map of Um Enna'am watershed, Al Mafraq, Jordan.

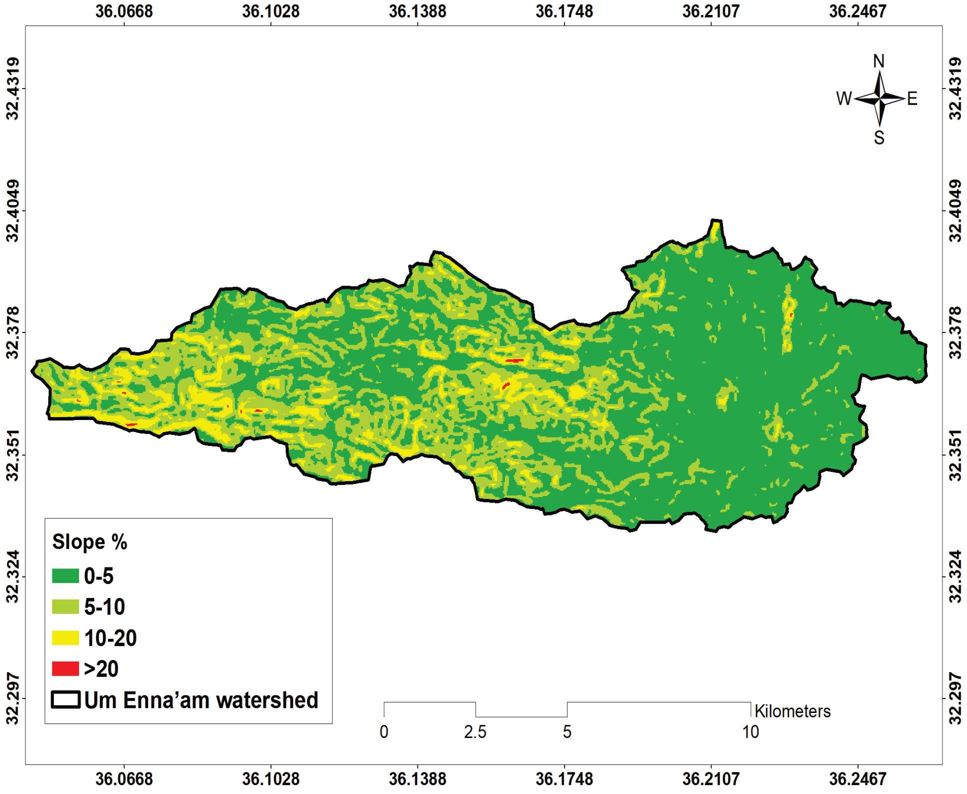

Figure 6 Slope map of the of Um Enna'am watershed, Al Mafraq, Jordan.

The DEM, with a 30-m resolution, was used in the delineation of the stream network of the wadis through a cumulative flow analysis. In this case, the stream network represents a regular movement of surface runoff from its source to the outlet, providing full details of the flow paths within the watershed. These flow paths are very important in the evaluation of water harvesting opportunities, especially for siting interventions like Marabs, which are suitable for various water-harvesting techniques. Marabs are designed to take advantage of natural depressions and stream flows to accumulate water and fertile sediments. A boundary buffer was hence applied to the derived wadi network to delineate areas highly suitable for the support of field crops and trees from Marabs (Ullah et al. 2024). The buffer delineated areas were adjacent to the stream network as highly favorable for the implementation of Marab-based water harvesting systems (Matomela et al. 2020; Haddad et al. 2024). It should be close enough to the wadi network so that the structural measures of the Marabs enhance their runoff capture and distribution capabilities for agricultural purposes. A buffer zone was used in the suitability analysis to identify zones where there is considerable potential for water harvesting (Adham et al. 2016a). Other recent works have used similar methods to identify proximity to flow pathways as an important factor in optimizing interventions for water harvesting. For example, stream network buffers were used as an effective way of delineating suitable zones for the placement of rainwater harvesting structures in arid and semi-arid areas by Ullah et al. (2024). These buffer zones intercept direct surface runoff, which increases water availability for crops by extending the retention period of water within the landscape (Abdelkareem et al. 2023). This integrative analysis approach is illustrated with the incorporation of hydrological flow path analysis and spatial buffering to develop an extended suitability assessment approach for water harvesting systems in Figure 7. This technique locates high potential for Marabs with high precision, by using tools from GIS, hence helping to provide sustainable water management and agricultural productivity in semi-arid regions.

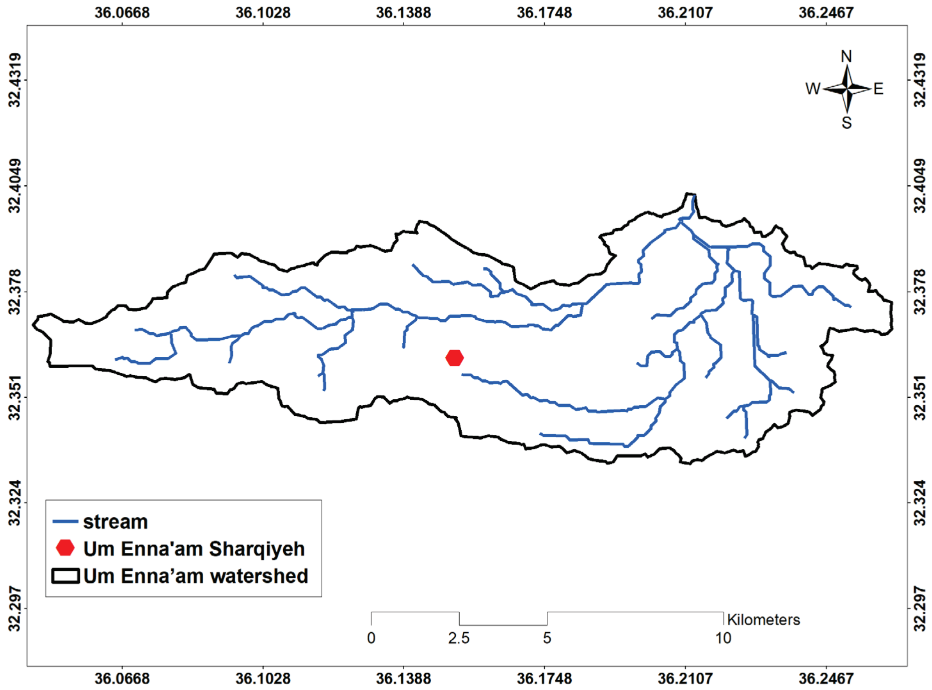

Figure 7 Stream networks and village location in Um Enna'am watershed, Al Mafraq, Jordan.

3.2 Suitability mapping for Contour Ridges Range (CCR)

Marabs are naturally occurring depressions with gentle slopes, through which watercourses pass, allowing for better catchment of water and deposition of fertile clay layers suited to farming. Further development by adding low stone barriers helps in the distribution and retention of water within the soil sector, giving rise to proper capture and storage during rainfall events. This technique is particularly useful in supporting field crops and trees to sustain soil moisture in dry regions. A suitability map for Marabs is depicted in Figure 8, which shows that the highly favorable locations for their implementation are based on specific biophysical conditions. Recent studies have identified the effectiveness of Marabs in optimizing water harvesting for agricultural productivity in arid and semi-arid areas. Oweis and Hachum observe that Marabs are suitable in areas where natural depressions can gather runoff naturally, creating a productive microenvironment for crops (Oweis and Hachum 2006). The deposition of fertile sediments in these depressions can significantly improve both the fertility and water-retention capacity of the soil, making it ideal for growing annual crops and perennial trees (Wolka et al. 2018). Moreover, the application of low stone barriers was discovered to enhance water retention by reducing runoff velocity and encouraging water infiltration into the soil. Marabs are successful in areas with gentle slopes, as water accumulation allows sediment to deposit, improving the soil conditions. The strategic use of Marabs can further increase crop yield and resilience by extending moisture availability beyond the rainy season, which is vital for agricultural productivity in water-scarce environments (Renzi et al. 2023). Additionally, stone barriers in Marabs help manage water flow across the field, ensuring even moisture distribution, which is essential for the successful cultivation of field crops and trees (Wolka et al. 2018).

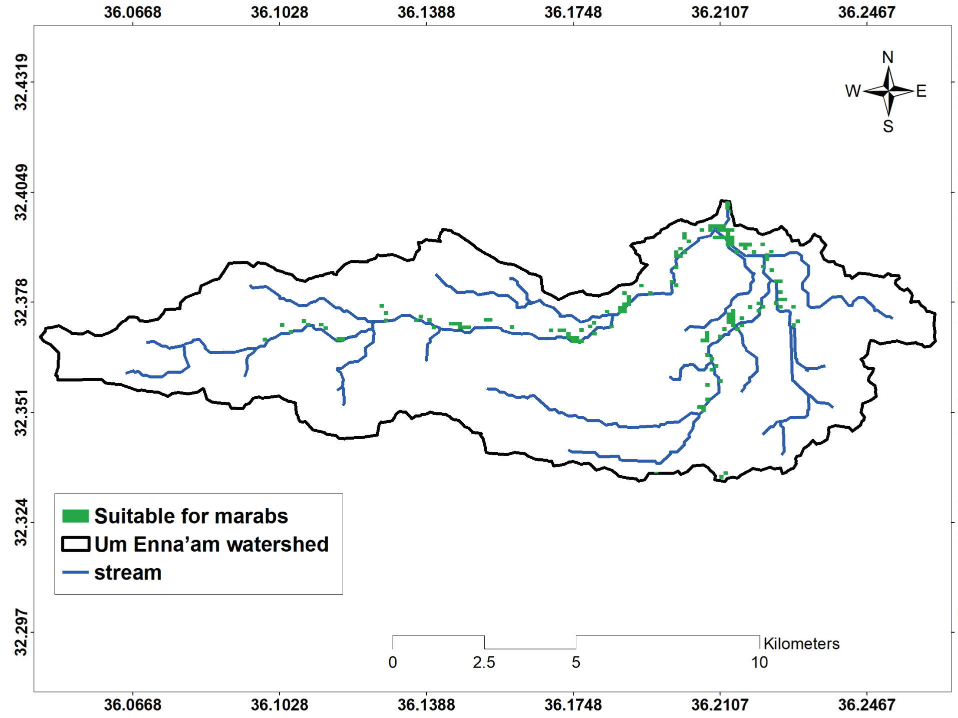

Figure 8 Suitability map for Marabs in Um Enna'am watershed in Al Mafraq, Jordan.

3.3 Runoff strips

Runoff strips are land management features built to slow surface runoff and maximize infiltration rate in rainfed areas. They are narrow, placed strips—either planted or bare—used to improve water availability for field crops like barley in dry steppe regions. These strips minimize drought risk, enhance yields, and allow post-harvest pastoral use. The runoff strips in this research were determined to be suitable for areas with moderate slopes and clay soils, as shown in Figure 9. The suitability of runoff strips in such areas is due to their effectiveness in collecting and directing surface runoff, ensuring that water is retained where adequate storage is available for irrigation. This becomes very important in semi-arid areas, such as the study area, where effective water management is crucial for agricultural productivity. Recent studies corroborate these findings, emphasizing the suitability of runoff strips for improving water availability in similar environments. Runoff strips with moderate slopes are highly effective in managing flow velocity, reducing soil erosion, and allowing more water to infiltrate into the ground (Martinez-Raya et al. 2006). Furthermore, the application of runoff strips, along with other sustainable land management practices, has shown an improvement in soil moisture content during water stressed conditions and increased crop yield under water-scarce conditions (Stroosnijder 2009). The application of runoff strips in areas with moderate slopes and clay soils contributes not only to the conservation of water but also to reducing the risk of soil degradation. By facilitating gradual water movement and maximizing infiltration, these runoff strips help to sustain soil health, which is essential for the long-term productivity of agricultural land in arid and semi-arid regions. This aligns with the findings of several recent works that highlight the role of strategic runoff management in sustainable agriculture (Shah and Wu 2019). Thus, runoff strips are a valuable technique for enhancing water management in areas with specific biophysical conditions, and their implementation, as indicated by the findings of this study, is supported by recent literature on best practices for rainwater harvesting and land suitability in challenging environments.

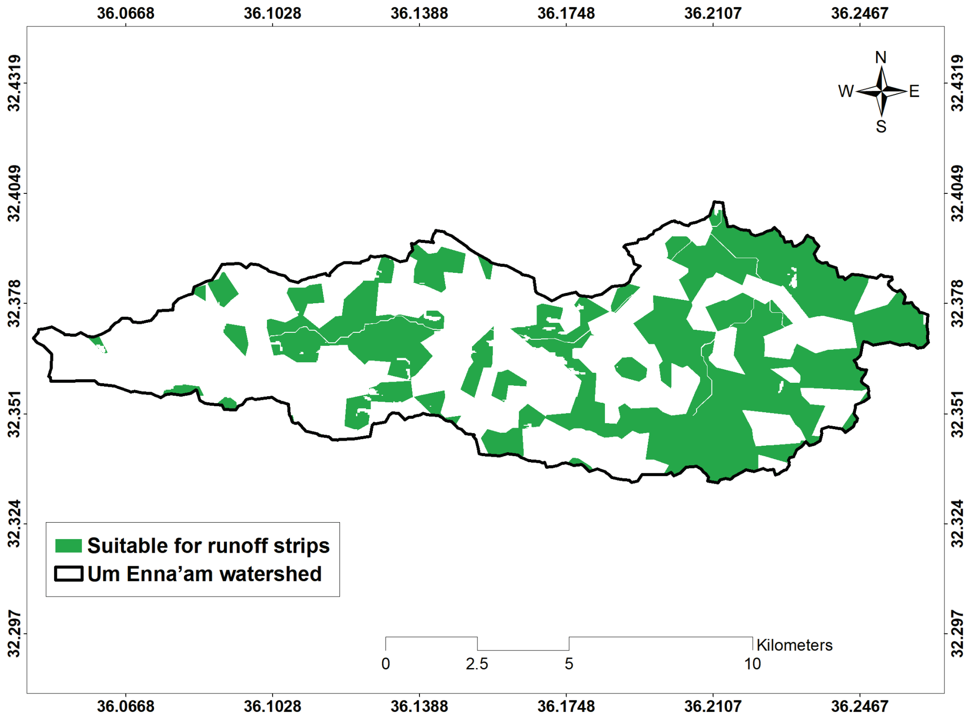

Figure 9 Suitability map for Counter Ridges Range (CCR).

Table 2 shows the distribution of suitable areas for most of the water harvesting techniques in the study area. Runoff strips have shown the highest coverage area, accounting for 42.46% of the total area, contour ridges cover around 29.30%, while Marabs account for 1.64%. These numbers indicate the suitability and feasibility of applying each technique based on the landscape characteristics and results from the suitability analysis. The larger coverage of runoff strips suggests that the region has extensive areas with favorable conditions for runoff harvesting, the potential of runoff strips in areas with moderate slopes and suitable soil conditions (Álvarez-Mozos et al. 2014). The relatively small area suitable for Marabs indicates that such zones are limited and effective only in natural depressions where Marabs are best suited to specific landscape features such as depressions or flat areas with the ability to capture and hold water efficiently (Haddad et al. 2024). These results highlight how integrating GIS-based analysis with land suitability assessments can effectively guide decision-making for water harvesting interventions in semi-arid and arid regions (Adham et al. 2016a). Such methodologies are essential for ensuring that water harvesting techniques are matched appropriately to land characteristics, ultimately maximizing agricultural productivity and sustainability in challenging environments (Adham et al. 2016a; Mahmoud et al. 2016; Shah and Wu 2019).

Table 2 Area coverage of different water harvesting techniques.

Water Harvesting Techniques	Total Area (km^2)	Area (%)
Contour Ridges Range	25.25	29.3
Runoff strips	36.59	42.46
Marabs	1.4	1.64

The findings of this study align well with existing literature on the suitability and performance of green water harvesting techniques in arid and semi-arid environments. For instance, Haddad et al. (2024) reported similar suitability patterns for runoff strips and contour ridges in Jordan’s Badia region, confirming that areas with moderate slopes and medium-textured soils are optimal for runoff harvesting. Likewise, Adham et al. (2016a) emphasized the importance of integrating slope, soil texture, and rainfall in selecting appropriate RWH techniques, consistent with our multi-criteria GIS approach. Our results showed that runoff strips covered the largest proportion of suitable land (42.46%), which is in agreement with Stroosnijder (2009), who found runoff strips particularly effective in reducing soil erosion and enhancing soil moisture in similar Mediterranean-climate conditions. In contrast, Marabs were found to be suitable only in a limited area (1.64%), echoing findings by Renzi et al. (2023) and Wolka et al. (2018) that conclude that Marabs are highly site-specific and perform best in low-slope natural depressions. The differences in coverage among techniques can be attributed to the topographic constraints of the watershed and the spatial distribution of key soil properties. These comparisons confirm that this study’s results are both methodologically robust and contextually consistent with regional and international findings, reinforcing the relevance of GIS-based GWH planning in water-scarce landscapes.

3.4 Uncertainties, limitations, and generalizability

While the study presents practical results for the spatial viability of green water harvesting (GWH) strategies, it must be mentioned that several uncertainties and limitations are encountered. First, as the model depends on the use of high-resolution spatial and field data, certain soil parameters (e.g., the infiltration rates or the subsurface hydraulic conductivity) were not available throughout the entire extent of the basin and were estimated through regional soil surveys. Second, the rainfall data used in the study are long-term historic means (1990–2014), which may not reflect the increasing variability associated with the climate change of the study area. Lastly, while the suitability criteria were narrowed down through the application of experts, the local socio-economic factors, e.g., the state of the land tenure, capability of maintenance, or adoption of society, were not included in the model and may impact the viability of GWH projects at the local scale.

Regarding generalizability, the methodology used herein can be replicated in other arid and semi-arid areas with comparable agro-ecological limitations. The combination of biophysical field data, expert-based attributes, and GIS multi-criteria assessment compares to those of Adham et al.(2016a; 2016b) in Tunisia and Morocco, respectively, that employed slope, soil texture, and rainfall as the essential parameters of RWH planning. Similarly, Haddad et al. (2024) and Renzi et al. (2023) employed comparable suitability frameworks in degraded semi-arid areas of Jordan and reported that even at the micro-scale, interventions like contour ridges can boost substantially the improved productivity under the threshold of 200–300 mm/y of rainfall. The relatively narrow area of suitability for Marabs in our case study also compares to the findings of Matomela et al. (2020), who reported that macro-catchment systems are greatly dependent upon natural depressions as well as stream flow geometry. On this basis, although the study has its foundation in the study area of the Um Naa'am basin, the methodology and implications, as learned, can be transferred to other dryland watersheds, which have comparable environmental and the associated water resource challenges.

While the research conducted here depends largely upon spatial analysis and GIS-based modeling, it includes a limited number of the field-based biophysical measurements to provide reliability. Field surveys were conducted to obtain measurements of soil depth, surface stoniness, texture, and vegetation cover, to be utilized for the validation and corrections of the spatial layers. However, due to resource constraint, accurate measurements of the soil moisture content and the infiltration rates of the whole of the watershed were not available to be used in the current model. Also, structured stakeholder comments regarding preferred use of land and intervention feasibility were not collected at the current level. It is understood that the use of such data would add reliability as well as site-specific usability of the results. Future studies should integrate soil moisture monitoring, stakeholder consultative processes, and post-implementation comments to evaluate the efficacy of the short-listed water harvesting measures and also provide support for adaptive management.

4. CONCLUSION

This study assessed the suitable area for implementing of different Green Water Harvesting (GWH) techniques, namely contour ridges, runoff strips, and Marabs, in the Um Naa’am watershed in Jordan, by using GIS technology for optimal water management strategies in a semi-arid environment. The results of the study showed significant potential for runoff strips (42.46%), contour ridges (29.30%), and Marabs (1.64%), based on key biophysical factors examined such as slope, soil depth, and texture. GIS proved to be a useful technique to enable the integration of these criteria, which allows a complete suitability analysis to identify areas best suited area for each technique. Applying GWH techniques in semi-arid watersheds can enhance water availability, improve agricultural productivity, and endorse environmental sustainability, contributing to resilience against water scarcity and to cope with climate change impacts. The study highlights the importance of matching water harvesting techniques with local land conditions and highlights the role of GWH in the broader future water-food-energy nexus, supporting sustainable development in arid and semi-arid regions. Nevertheless, execution is hindered by the constraints of land tenure, high installation cost, and technical skill requirements, more so on communal lands. Compromises between cultivation and land use for water harvesting also require planning at the local level. In the case of Jordan, scaling GWH involves incorporation at the basin planning level, supported by institutional reinforcement, capacity enhancement, and policy support. GWH suitability maps should integrate national drought planning and allocation of water policies. Future studies should encompass socio-economic and hydrological modeling, and field monitoring of GWH performance, to support inclusive and sustainable uptake.

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