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Enhancing Groundwater Recharge Through Comparative Analysis Of Rainwater Harvesting Solutions In Arid Region Of Southern Afghanistan: A Review

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A B S T R A C T

Purpose:
The objective of this study is to examine the efficacy of rainwater harvesting (RWH) methods in enhancing groundwater recharge and water security in Afghanistan's arid and semi-arid areas, which are increasingly affected by climate change and water scarcity.

Method:
A comparative analysis of rainwater harvesting systems employed in analogous meteorological circumstances worldwide was done. The research utilised Geographic Information System (GIS) and spatial analysis methods to assess various environmental factors—including precipitation patterns, elevation, soil composition, geology, land cover, and water scarcity—to determine ideal sites for Rainwater Harvesting (RWH) deployment throughout Afghanistan.

Results:
The spatial analysis identified particular areas conducive to groundwater recharge via rainwater harvesting. Among the assessed techniques, sand dams, infiltration pits, rock catchments, and percolation ponds were recognised as the most successful owing to their water retention capabilities, adaptation to arid conditions, and potential for sustainable groundwater augmentation.

Practical Implications:
The findings offer a framework for policymakers and development organisations to use cost-effective and contextually suitable rainwater harvesting technologies in Afghanistan, thus enhancing sustainable water management and bolstering resistance to water scarcity.

Originality/Novelty:
This study is one of the initial efforts to integrate global rainwater harvesting knowledge with high-resolution spatial analysis specifically designed for Afghanistan's distinct environmental and climatic conditions, providing a scientifically robust framework for planning groundwater recharge through rainwater harvesting in arid and semi-arid regions.

Keywords: *Rainwater harvesting (RWH), Water shortages, groundwater recharge, Spatial analysis, Comparative analysis.*

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1. Introduction

Afghanistan is grappling with a significant water problem caused by a mix of reasons, including decades of violence, the repercussions of climate change, insufficient water management techniques, and a fast population increase (Alliance for Water Efficiency, 2023; Teams, 2024). The nation's dry and semi-arid climate, combined with low yearly precipitation and high evaporation rates, further increases the issues of water shortages (Biswas et al., 2023; Farid et al., 2023). Consequently, over-extraction of groundwater resources, inefficient irrigation systems, and insufficient investments in water infrastructure have contributed to the depletion and misuse of available water (Spera et al., 2018). This deplorable condition has far-reaching repercussions, harming access to clean drinking water, agricultural production, economic growth, and deepening social inequality, especially for vulnerable populations such as women and children(Oskam et al., 2021).

The escalating water crisis in Afghanistan needs immediate and creative strategies to increase water security and resilience. Rainwater harvesting (RWH) seems like a feasible alternative to tackle these issues, enabling decentralized and effective means to gather and use accessible precipitation (Vienna et al., 2019). Yet the diverse climatic, topographical, and socio-economic characteristics throughout Afghanistan need a nuanced knowledge of permissible RWH tactics suited to local settings(Damkjaer & Taylor, 2017; Sediqi et al., 2022). While current research reveals the potential advantages of RWH, there is a significant need to determine the most successful solutions for Afghanistan's semi-arid areas and analyse their feasibility and scalability (Campisano et al., 2017; Nandi & Gonela, 2022). Moreover, effective RWH case studies from similar areas must be carefully adapted and used to guarantee their relevance within the Afghan context (Nidhi Pasi et al., 2014).

This study intends to discover viable rainwater collection techniques for Afghanistan's arid climate zones, offer recommendations for their implementation, and assist in formulating sustainable water management regulations. Through comparison analysis and GIS technology, the project intends to promote water security and resilience for communities, addressing the water crisis's impacts.

2. Literature review

Rainwater harvesting has a rich history stretching back to ancient civilizations such as the Indus Valley Civilization, Mesopotamia, Egypt, Rome, the Byzantine Empire, and the Arab World (United Nations, 2024). Ancient civilizations used sophisticated methods like rooftop collecting and storage in tanks, whereas modern civilizations have witnessed growing interest in rainwater harvesting due to water scarcity concerns, ecological solutions, and technical improvements. Examples of historical rainwater collection systems include Sigiriya in Sri Lanka, Jaipur in India, and Hampi in India (Bozorg-Haddad et al., 2021; Hosseiny et al., 2021; Masoumeh et al., 2021). These systems illustrate the necessity of water management and the usage of subterranean tanks and canals for agriculture and drinking water (Kumar et al., 2022). Water scarcity concerns, environmental solutions, and technology breakthroughs drive the modern era of rainwater gathering. Water scarcity concerns, environmental solutions, and technology breakthroughs drive the modern era of rainwater gathering. It acquired popularity in Europe and North America in the 18th and 19th centuries, particularly in rural areas (Shemer et al., 2023). The 20th and 21st centuries have seen a resurgence of interest in rainwater gathering due to environmental sustainability concerns. Historical examples include Sigiriya, Sri Lanka's 5th-century rock stronghold, Jaipur's 18th-century underground tanks, and Hampi, India's UNESCO World Heritage Site (Chunyang, et al., 2021).

Rainwater harvesting is a sustainable and resilient option for managing water scarcity, environmental protection, and economic development. It lowers dependency on municipal water sources, improves water quality, and ensures access to sufficient water for basic requirements (Qi et al., 2019; Waseem et al., 2023). Water security is vital for human health, economic prosperity, and environmental well-being. Rainwater collection provides a steady source of water during droughts, minimizing dependence on overexploited groundwater and stressed municipal supplies. Additionally, it increases water availability by capturing and utilizing rainfall that would otherwise flow off (Bennett et al., 2024; de Sá Silva et al., 2022; Raghava Rao et al., 2024).

Rainwater harvesting is a sustainable way of managing water resources, notably in aquifer recharge. Recharge is the transfer of water from the unsaturated zone to the saturated zone, contributing to understanding large-scale hydrologic processes (Bremer et al., 2021; Richards et al., 2021). Estimating recharge rates helps anticipate solute transport and can induce a rise in the water table. Recharge rates vary in time and space, and temporal focus promotes recharge. Research demonstrates that a bigger fraction of water becomes recharged if concentrated in narrow channels, as it hastens passage through the unsaturated zone and occupies less soil volume (Bremer et al., 2021; S. He et al., 2021).

2.1 Need for rainwater harvesting

Rainwater harvesting is a crucial solution to the world's water scarcity problem, which is exacerbated by rising population, urbanization, and climate change (Khanal et al., 2023). Afghanistan is facing water supply shortages in both urban and rural areas due to factors such as population, inadequate infrastructure, climate variability, poor water policies, and misappropriation of funds (Shokory et al., 2023; USAID, n.d.). Rainwater harvesting is not new in water resources management and is being promoted in countries like China, Brazil, Australia, and India. It offers numerous benefits, such as providing free water with only storage and treatment costs, augmenting groundwater, reducing stormwater runoff, reducing erosion and pollution, and providing natural soft water for non-potable indoor usage (Z. Huang et al., 2021; Naik et al., 2015). Rainwater harvesting also results in decentralized water collection, making it less expensive than well drilling and public taps. Expanded use of rainwater harvesting and other innovative technologies could reduce greenhouse gas emissions and contribute to climate change (Słyś & Stec, 2020).

2.2 Methods of aquifer recharge

Check dams are transverse engineering structures built across torrents, gullies, and streams to prevent soil erosion, moderate water and sediment flows, and enhance land. They control erosion by slowing water flow, preventing gullies, and protecting the topsoil (Abbasi et al., 2019; Lucas-Borja et al., 2021; Nichols & Polyakov, 2019). Check dams also promote water quality by retaining silt and contaminants, promoting cleaner water flow downstream (Li et al., 2019; Zema et al., 2018). They promote water infiltration, provide habitat for wildlife, replenish groundwater reserves, and decrease flooding. They also assist in replenishing groundwater by absorbing and holding rainwater, guaranteeing sustainable water supplies. Check dams also lessen flooding concerns after severe rainfall events (T. Huang et al., 2021; Khonkaen & Cheng, 2011; Mongil-Manso et al., 2019).

Khadin structures are a traditional method of retaining rainfall in agricultural fields. They consist of an earthen wall, sluices, and spillways that capture and store rainwater during the monsoon season. We then use this water for irrigation, drinking, and residential needs (Prasad et al., 2004; Sarah & Rodeh, 2004). Khadin also aids soil and water conservation by slowing down precipitation flow, reducing soil erosion, and preventing gullies. They also help replenish groundwater aquifers, maintaining agricultural production and food security. Khadin water can be treated for drinking and domestic use, improving public health. Additionally, Khadin provides a habitat for diverse plant and animal species, promoting biodiversity and habitat. (Kolarkar et al., 1983)

Percolation ponds are small ponds in Poramboke lands that retain rainfall runoff and allow it to percolate downward and sideways. They help replenish depleted groundwater aquifers, enhance water quality by trapping silt, pollutants, and toxins, and minimize flooding danger (Wadhwa & Kummamuru, 2021). They also generate habitats for varied creatures, leading to enhanced biodiversity and a healthy ecology. Percolation ponds can be effective up to 1000 meters distant, benefiting downstream areas and wells (Christy & Lakshmanan, 2017; Raj et al., 2006).

Check basin farming is a traditional agricultural technique that uses earthen embankments to gather and preserve rainwater. These embankments produce mini-reservoirs around plants or crops, holding water in the root zone for extended durations (Kang et al., 2021; Mati, 2012). This approach offers benefits such as greater water usage efficiency, enhanced crop yields, and less reliance on external water sources. It also minimizes soil erosion, promotes water infiltration, and enhances crop output.

This technique fosters self-sufficiency and water security (Chawla et al., 2023; Grinshpan et al., 2021; Vafaei et al., 2021).

Recharge wells are constructions designed to inject water into underground aquifers to restore stocks and alleviate overexploitation (Luyun et al., 2014). They serve an important role in sustainable water management, especially in places confronting groundwater depletion. Recharge wells increase water quality, manage the amount of water injected, reduce dependence on surface water, and mitigate ground subsidence, which can harm infrastructure and alter ecosystems. They also help prevent oversaturation and pollution of aquifers (Kumar et al., 2002).

Fog nets are enormous mesh structures used to trap water droplets from fog, providing a sustainable alternative for water harvesting in frequent fog zones. They effectively catch water droplets, improve water quality, and are highly efficient. Once constructed, fog nets require minimum maintenance, making them a cost-effective and sustainable solution (Bintein et al., 2023; Knapczyk-Korczak et al., 2020).

Micro-catchment rainwater harvesting (MCWH) is a low-cost, sustainable water management approach that gathers and stores rainwater in small, localized regions. It boosts water availability, improves soil moisture, lowers soil erosion, and is accessible and economical because of its minimal materials and local resources. This strategy is particularly effective in arid and semi-arid countries confronting water constraints (Ali et al., 2010; Tumbo, 2010).

Sand storage dams are modest constructions placed across streams or riverbeds in arid and semi-arid environments to absorb and store rainwater for later use (Ritchie et al., 2021). They serve numerous objectives, including catching and retaining rainwater during the wet season, enabling irrigation and raising agricultural output, conserving groundwater resources, improving soil quality and land management, and preventing downstream flooding (Schreiner et al., 2013). The impermeable wall across the stream fills up sand, producing a natural reservoir for water storage (Maddrell, 2018). This assists communities confronting dry seasons with uncertain rainfall patterns, increases food security, and contributes to poverty alleviation and economic development (Wang et al., 2024). Sand storage dams also contribute to sustainable land management practices and environmental health (Ndekezi et al., 2023).

2.3 Rainwater harvesting in Afghanistan

Rainwater harvesting (RWH) is a growing field in Afghanistan, with research focusing on specific regions or applications. This limited but growing body of research highlights the potential of RWH as a valuable tool for water management in dry-climate areas of Afghanistan. Research has shown that households with rainwater harvesting systems in Bamyan province had 50% more water during dry periods; farmers in Herat using harvested rainwater for irrigation experienced a 30% yield increase; and rainwater harvesting in Ghazni province raised groundwater levels, increasing wellbore water availability (Aliyar et al., 2022; Aliyar & Collins, 2022; Tahera et al., 2022).

RWH systems can save up to 42.9% of non-potable water demand in Kabul New City, particularly during dry periods. However, due to potential contamination concerns, proper treatment and filtration of road water before use are essential (Rahman, 2021).

3. Material and Methods

3.1 Study Area

The study area consists of the Kandahar, Helmand, Nimroz and Zabul southern provinces in Afghanistan. Kandahar Province in southern Afghanistan experiences a semi-arid climate with hot summers and mild winters, causing low annual precipitation and water scarcity. Surface water sources include the Helmand River, with groundwater used for irrigation and domestic purposes. Zabul Province experiences a continental climate with hot summers and cold winters, further exacerbating water scarcity. Helmand Province, the largest in Afghanistan, has a desert climate with hot summers and mild winters. Nimroz Province in Afghanistan, with a desert climate, low precipitation, and significant evaporation losses, supports agriculture and human settlements with groundwater reserves from the Helmand River.

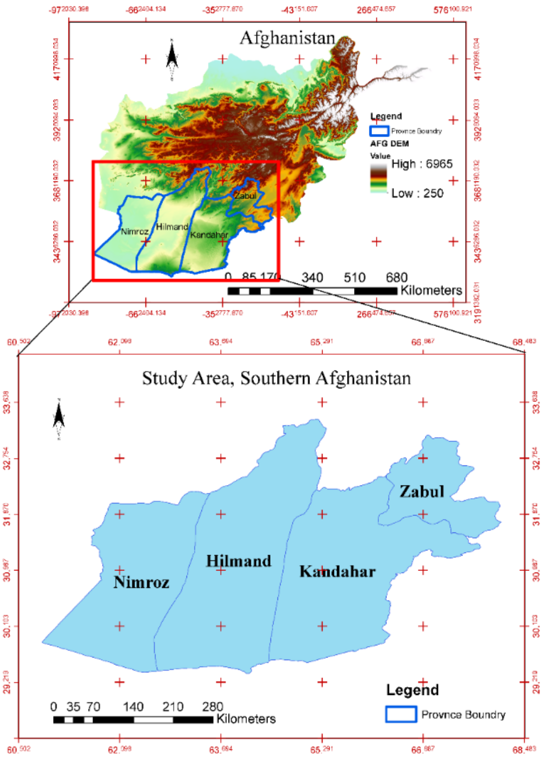

Figure 1. The figure above presents the study area map, highlighting the elevation levels in meters. The subsequent figure below illustrates the sub-districts within the study area, providing a detailed spatial delineation for the analysis.

The data collected is used to evaluate the feasibility of rainwater harvesting in Afghanistan's Kandahar, Zabul, Nimroz, and Helmand regions. It includes rainfall, climate, hydrological, and socio-economic data. These data help determine water collection capacity, evaporation losses, storage locations, and the region's water needs. The data helps identify the physical characteristics of the area and determine if rainwater harvesting is a viable solution.

3.2 Datasets

Data was collected from various sources, including the DEM, USGS Earth Explorer, SoilGrid.org, and CHRS (Table 1). The datasets utilized in this study were sourced from diverse and reputable platforms, ensuring comprehensive and accurate data for the analysis. The Digital Elevation Model (DEM) was obtained from the USGS Earth Explorer platform, which provides high-resolution elevation data essential for analysing terrain characteristics such as slope, drainage density, and geomorphology. Users can access DEM data by visiting https://earthexplorer.usgs.gov/, creating an account, and specifying the area of interest using geographic coordinates or shapefiles. The DEM is instrumental in hydrological and topographical studies due to its fine spatial resolution and reliability (Mohammadi et al. 2021; Shah et al. 2021).

Soil data was retrieved from SoilGrid.org, an online platform offering detailed soil properties and classifications at varying depths and resolutions. This dataset is valuable for assessing soil texture, structure, and suitability for agricultural or hydrological applications. Users can explore and download these datasets through https://soilgrids.org/, leveraging its user-friendly interface to select specific parameters like organic carbon, pH, or bulk density.

Precipitation data was sourced from the Climate Hazards Group InfraRed Precipitation with Station data (CHRS) database (Baqa et al. 2021). This dataset combines satellite observations with ground station data, offering high temporal and spatial resolution rainfall information crucial for analysing climatic and hydrological patterns. Accessible through http://chrsdata.eng.uci.edu/, the CHRS platform allows users to download historical and near-real-time precipitation data tailored to specific study requirements (Majeed et al. 2021).

Each dataset presents distinct advantages. DEM data provides essential elevation details for understanding topographic influences on hydrology. SoilGrid.org contributes vital information on soil properties, enabling precise land use planning and management. CHRS delivers accurate precipitation data critical for understanding climatic impacts on hydrology and vegetation. Together, these datasets form a robust foundation for environmental, agricultural, and hydrological studies, ensuring data-driven insights and sustainable decision-making.

Table 1: Various datasets used in this research

Dataset	Source	Acquisition Date	Sensors	Resolution	Path/Row	Cloud Cover	Details	Download Process
CRU Temperature Data	CRU (Climatic Research Unit)	2011-2020	Ground-based weather stations	0.5° x 0.5°	N/A	N/A	Global precipitation data based on satellite observations. Suitable for various hydrological studies.	Accessed via the CHRS Data Portal. Users log in and specify the region and time period. Data is available in formats like NetCDF and can be filtered by time steps.
CHRS Precipitation Data	CHRS Data Portal (PERSIANN)	2003–2021	Ground-based observations	4km	N/A	N/A	High-resolution global gridded precipitation dataset.	Data downloaded from CRU's official website, following registration and area specification
FAO Soil Data	FAO Soil Map	2015 (Global Soil Map)	(derived from soil surveys)	1 km	N/A	N/A	Global soil database providing information on soil types and properties.	Downloaded from the FAO website. Users can select the required geographic area and

Dataset	**Source**	**Acquisition Date**	**Sensors**	**Resolution**	**Path/Row**	**Cloud Cover**	**Details**	**Download Process**
								download format (e.g., shapefile or raster).
USGS Land Cover Data	USGS Earth Explorer	2016 (NLCD 2016)	Landsat 5 TM,	30 m	Path/row data dependent on location	< 20%	Provides global land cover classification based on satellite imagery.	Registered on USGS Earth Explorer. After selecting a geographic area of interest, data is downloaded in GeoTIFF format.
SRTM DEM	SRTM 30m (NASA Earth Data)	2000 (Data from NASA)	Shuttle Radar Topography Mission (SRTM)	30 m	N/A	< 20%	High-resolution digital elevation model suitable for hydrological and terrain analysis.	Registered at NASA Earth Data, logged into the website, and accessed through Tile Downloader for specific regions.

3.3 Spatial Analysis

The study used a systematic methodology to identify areas with high potential for groundwater recharge. The process involved determining the study area and selecting thematic layers, such as slope, drainage density, lineament density, land use and land cover, soil texture, geology, and rainfall. Data was collected from various sources, including the Digital Elevation Model (DEM), USGS Earth Explorer, SoilGrid.org, and CHRS. Creating thematic maps using these data to comprehend the spatial distribution and features of each element. The thematic maps were then reclassified and analysed using the Multi-Criteria Decision Making (MCDM) technique. The study identified potential zones for groundwater recharge based on optimal parameters across all thematic levels. This approach demonstrated the efficiency of combining different data sources and analytical tools in environmental and resource management research shown in Figure 2.

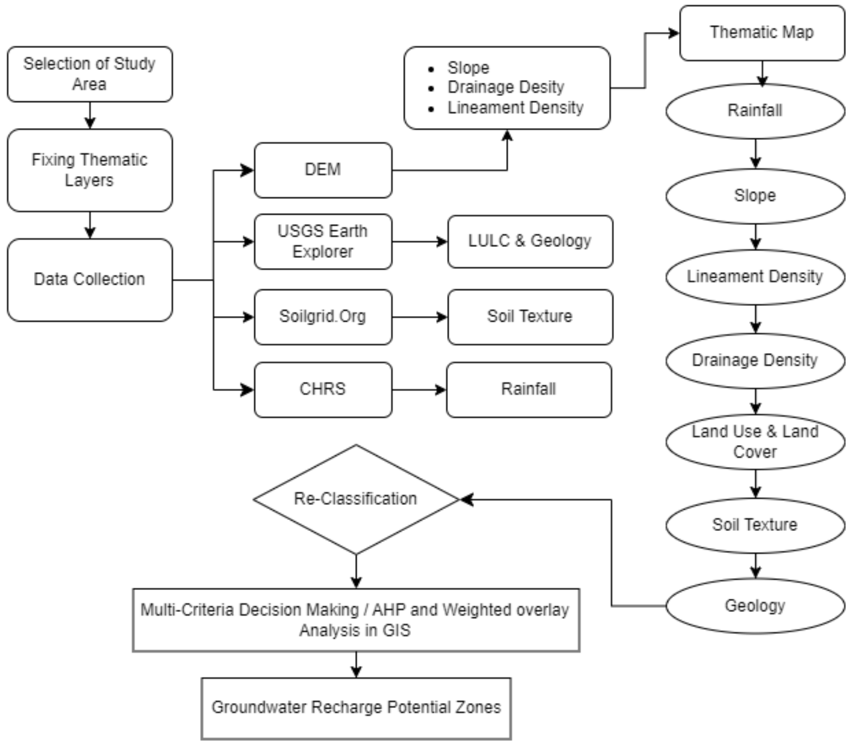

Figure. 2 Special analysis methodology used in this study

The investigation found places with significant potential for GWR due to their high rainfall and infiltration rates, making them suitable locations for rainwater collection systems Figure 3.

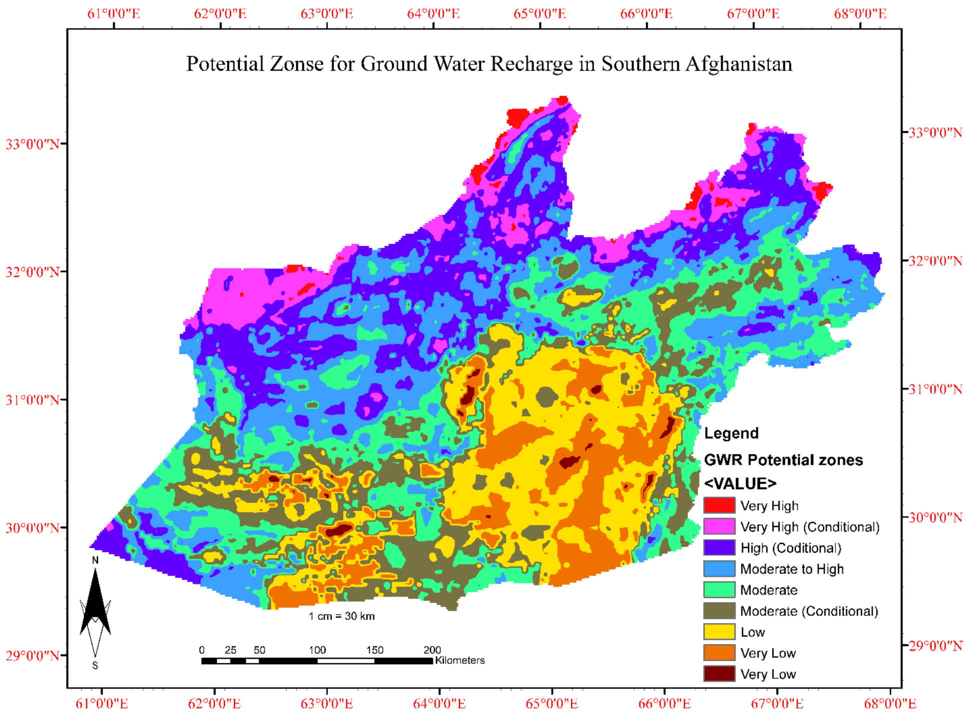

Figure. 3 Showing regions with high potential for GWR

3.4 Comparative Analysis

This research aimed to find rainwater gathering methods that would work in Afghanistan's dry environment and alleviate water shortage. The twenty-five methods were chosen from a wide range of case studies and scholarly articles after an exhaustive literature search. We compared each method according to its potential water output, resource needs, infrastructural complexity, environmental effect, and socioeconomic considerations. Key findings included rooftop rainwater harvesting (India), Jessour (Tunisia), check dam (Jordan), percolation ponds (Kenya), subsurface dams (Sudan), contour trenches (Nepal), infiltration pits (Mexico), sand dams (Kenya), micro catchment systems (Ethiopia), gabion structures (Zimbabwe), previous pavement (USA), earth dams (Afghanistan), rain gardens (Australia), water spreading (Tunisia), rock catchment systems (Namibia), pot storage (Iran), stone bunds (Mali), trenches and bunds (Sudan), swales (Morocco), hillside water harvesting (Uganda), gully plugs (Pakistan), swallets (South Africa), percolation pits (India, Australia, Africa), Khadin structures (Iran, North Africa), and recharge wells (Globally). To reduce water scarcity and increase water resilience in Afghanistan's arid regions, the most effective and feasible rainwater harvesting techniques were identified through a comparative analysis that considered the specific climatic and socioeconomic conditions of the area.

In Afghanistan, 24 different Rainwater Harvesting (RWH) methods were assessed using five basic criteria: efficiency (water capture potential), affordability (materials, labor, maintenance), environmental impact (sustainability), social acceptability (culture fit), and scalability (household to regional). A comparative analysis matrix in Table 2 was used to describe the data, giving a thorough overview of the advantages and disadvantages of each approach.

The research revealed five potential approaches for Afghanistan's dry regions: The following structures are used for surface runoff harvesting: check dams, percolation ponds, subsurface dams, contour trenches, infiltration pits, sand dams, micro catchment systems, gabion structures, previous pavements, earth dams, rain gardens, water spreading, rock catchments, pond storage, stone bunds, swales, hillside water harvesting, gully plugs, swallets, Khadin structures, rooftop rainwater harvesting, the JS system, and recharge wells.

Sand dams, infiltration pits, and rooftop rainwater collecting were found to be the most suited RWH approaches for Afghanistan's dry areas owing to their high efficacy, sustainability, and scalability, according to the comparative study. This research lays out a comprehensive plan for putting these potential RWH strategies into action to improve water resilience and reduce water shortage in the area.

The examination of Rainwater Harvesting (RWH) methods identified numerous potential possibilities with high recommendation percentages, over 80%. Sand Dams were the most highly recommended approach, particularly in places with sandy soils and seasonal rivers. Sand dams catch and store considerable volumes of water in subterranean aquifers, boosting water quality and lowering evaporation losses. Infiltration Pits are highly recommended owing to their simplicity, cheap cost, and proven success in boosting groundwater recharge. Rock catchments are a sustainable and cost-effective alternative for collecting runoff, with low environmental impact and compatibility with the region's climate and topography. Percolation ponds have comparable benefits to infiltration pits but demand more acreage and building work.

Table 2: Showing Shortlisted techniques for further analysis

Technique	Country	Advantages	Disadvantages	Temp Suitability (°C)	Rainfall Suitability (mm)	Reference
Rooftop Rainwater Harvesting	Jordan	Utilizes existing infrastructure	Limited by roof area	20-40	200-1000	(Abdulla and Al-Shareef 2009)
Gesssour	Tunisia	Captures runoff from land surfaces	Dependent on land slope and soil type	25-40	100-300	(Gasmi et al. 2018)

Technique	Country	Advantages	Disadvantages	Temp Suitability (°C)	Rainfall Suitability (mm)	Reference
Check Dam	Jordan	Temporarily stores runoff water	Requires maintenance and desilting	20-40	100-400	(Sepehri et al. 2019)
Percolation Ponds	Kenya	Recharges groundwater	Dependent on soil permeability	20-35	100-300	(Abraham and Mohan 2019)
Subsurface Run-off Harvesting	India	Stores water underground	Requires suitable geological conditions	25-45	100-300	(Salazar and Casanova 2011)
Contour Trenches	Malaysia	Collects surface runoff	Needs regular maintenance	20-35	100-400	(County 2010)
Infiltration Pits	Mexico	Allows water to infiltrate into soil	Requires proper design and spacing	20-40	100-400	(Mupangwa et al. 2012)
Sand Dams	Kenya	Traps water in sandy riverbeds	Dependent on seasonal river flow	20-35	100-300	(Neufeld et al. 2021)
Microcatchment Systems	Ethiopia	Collects rainwater from small catchments	Requires careful design and maintenance	20-35	100-400	(Ali et al. 2010b)
Gabion Structures	Zimbabwe	Controls erosion and stores runoff	Requires periodic maintenance	20-35	100-400	(Pathak et al. 2013)
Pervious Pavement	United States	Allows rainwater to infiltrate into soil	Requires proper installation and maintenance	10-35	200-1000	(Nnadi et al. 2015)
Earth Dams	Saudi Arabia	Captures rainwater in natural depressions	Requires suitable topography	20-40	100-300	(Al-Munqedhi et al., 2022)
Rain Gardens	Australia	Filters and stores rainwater	Requires regular maintenance	10-35	200-1000	(Dunnett and Clayden n.d.)
Water Spreading	Tunisia	Spreads water over land for infiltration	Requires suitable land and management	20-35	100-300	(Hashemi et al. 2015)
Rock Catchment Systems	Namibia	Collects rainwater from rocky surfaces	Dependent on rock type and slope	20-40	100-300	(Nissen-petersen 2006)
Pond Storage	Germany	Stores rainwater in artificial ponds	Requires suitable land and maintenance	20-40	100-300	(Khoury-nolde 2011)
Stone Bunds	Etiopia	Controls soil erosion and captures runoff	Requires maintenance and land preparation	20-40	100-300	(Nyssen et al. 2007)
Trenches and Bunds	Sudan	Collects runoff and prevents soil erosion	Needs regular maintenance	25-45	100-300	*(G. Taye et al. 2015)*
Swales	Morocco India	Redirects surface water for infiltration	Requires suitable land and maintenance	20-35	100-300	(Vargas 2009)
Hillside Water Harvesting	Uganda	Collects runoff from hill slopes	Requires proper land preparation	20-35	100-400	*(Ali et al., 2007)*
Gully Plugs	Pakistan	Prevents erosion in gullies	Requires maintenance and proper design	20-40	100-300	(D. Khan et al. 2022)
Swallets	South Africa	Collects rainwater in depressions	Requires suitable land and management	20-35	100-300	(David L Royster 1984)
Percolation Pits	India australia Africa	Simple and inexpensive construction. Reduces soil erosion and flooding. Can be built on individual or community scales	Limited storage capacity. Requires permeable soil for proper function. Can get clogged with debris over time.	20-40	150-300	(RK. Sivanapan 2006)

Technique	Country	Advantages	Disadvantages	Temp Suitability (°C)	Rainfall Suitability (mm)	Reference
Khadin Structure	Iran North africa	Capture and store surface runoff for later use. Recharge groundwater and improve soil moisture. Mitigate desertification and promote vegetation growth. Can be used for multiple purposes like livestock watering.	Construction costs can be high for large structures. Siltation can reduce storage capacity over time. May require regular maintenance to remove sediment.	20-40	100-300	(Bassi and Vedantam 2013)
Recharge Wells	Globaly	Direct injection of water into the aquifer, maximizing recharge. Can be used for large-scale groundwater replenishment. Suitable for various water sources like rainwater, treated wastewater.	Requires drilling and construction expertise, making them expensive. Potential for groundwater contamination if not properly maintained. Can interfere with natural groundwater flow patterns.	20-40	Any rainfall amount	National Groundwater Association. "Artificial Recharge of Groundwater
Sand Storage Dams	Africa	Capture floodwater and store it behind the dam for later use. Recharge groundwater and increase soil moisture downstream. Reduce soil erosion and promote floodplain agriculture.	Construction costs can be significant, especially for large dams. Sedimentation can reduce storage capacity over time. May displace local communities or ecosystems.	20-45	100-300	(Lasage et al. 2015)

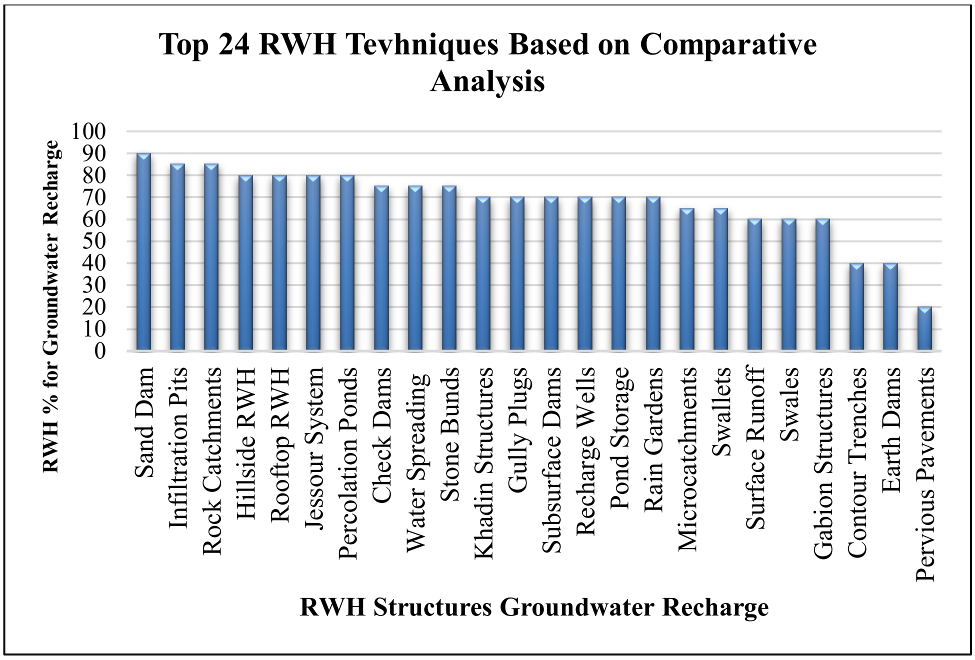

Figure. 4 Top 24 RWH Technique based on comparative analysis

Several generally suggested approaches exhibited moderate applicability (60-75%), with their efficiency relying on unique site variables and changes. Surface Runoff Harvesting, Check Dams, Water Spreading, and Stone Bunds may be efficient in catching and using runoff, although their efficacy varies depending on parameters including rainfall intensity, slope, and soil type. subsurface dams and Gabion structures have specialized uses in groundwater recharge and erosion control, but their overall performance is low owing to site-specific needs and limits.

Contour trenches and swales, pervious pavements, and earth dams are the least-suited methods. Contour Trenches and Swales have limited usefulness in absorbing runoff owing to the mostly flat topography in the research area. In contrast, due to their high cost and limited application, previous pavements are not suggested for rural desert locations.

Research assessing 24 rainwater collecting systems in Afghanistan revealed 10 of the most promising options based on efficacy, affordability, sustainability, social acceptability, scalability, and compatibility with the region's climate and soil characteristics.

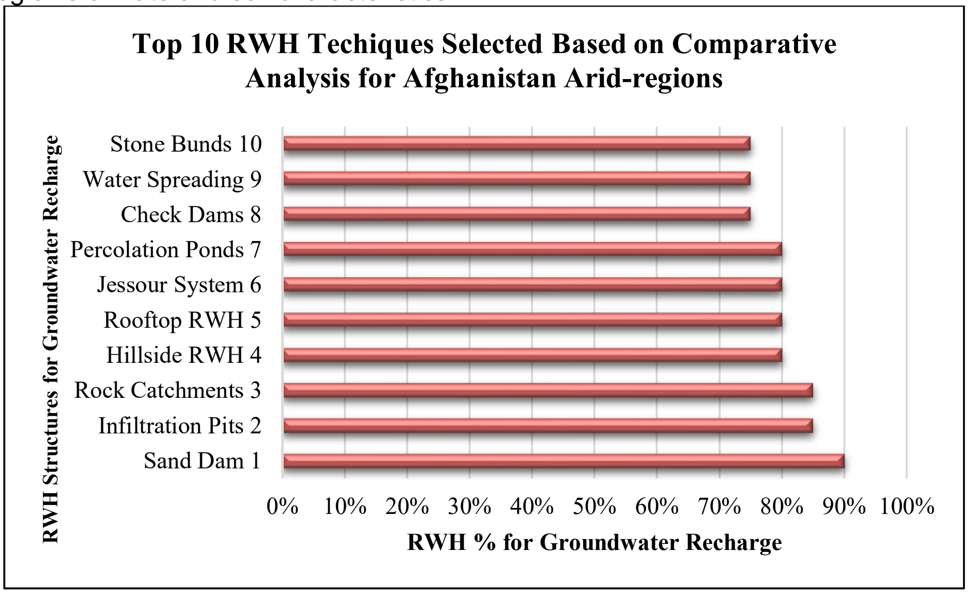

Figure. 5 Show the top 10 techniques and their recommended percentage

4. Discussion

Our results are consistent with research from Sudan and Kenya that shows how effective sand dams are at recharging groundwater. However, our study's restricted applicability of contour trenches and swales contrasts with their effective use in Ethiopia's hilly regions. Southern Afghanistan's flat terrain, which lessens runoff channelization, is the cause of this disparity. Surprisingly, this study revealed gabion structures to be less effective than those with considerable performance in other arid environments (Chaoyong et al. 2024).Afghanistan's soil makeup, which restricts water retention, is to blame for this. Similarly, contour trenches' subpar performance emphasizes the influence of the study area's modest slope and runoff dynamics (Duan et al. 2024). The present research shows how spatial analysis can successfully discover workable RWH strategies in arid climates, which adds to the theoretical framework of Integrated Water Resources Management (IWRM). These results practically aid in creating policies for installing RWH systems in areas with limited water resources. For example, infiltration pits can be encouraged at the community level for localized groundwater recharge, and sand dams can be strategically placed in regions with seasonal rivers (Tufail et al. 2025). A successful method of rainwater collection of surface runoff that leads it to the subsurface water and stored. This approach is vital where precipitation does not enter the soil but runs over the surface. Communities may absorb and store this runoff by erecting tiny check dams or retention basins. Subsurface dams, in particular, are very successful in Afghanistan's arid settings. These structures are created under the surface, catching water that would otherwise flow away and storing it below. The benefit of this technology is that it considerably minimizes evaporation losses, a typical concern in dry conditions.

Water stored in subterranean dams may be retrieved during dry years, providing a steady water supply for crops and cattle (N. Ahmad et al. 2024).

This study employs the MCDM strategy and GIS technology to identify suitable sites for RWH to recharge groundwater in southern Afghanistan. The research employs GIS and thematic analysis to identify regions with high potential for groundwater recharge. The study then reclassifies thematic maps and employs MCDM approaches to refine the identification of optimal spots. A comparative examination of 24 various RWH approaches indicated that sand dams, infiltration pits, and rock catchments best suit arid locations. These strategies successfully captured and stored water, improved groundwater recharge, and responded to local climatic circumstances (N. Ullah et al. 2024). The study's findings can help policymakers and stakeholders formulate strategic plans for water resource management in dry regions. However, problems include the accuracy of thematic maps, unpredictability in climatic circumstances, and the necessity for community involvement, proper funding, and regular monitoring. One of the study's limitations is its dependence on thematic maps, which might not reflect environmental changes in real-time. Furthermore, there was no thorough assessment of the socioeconomic viability of implementing the indicated RWH techniques. To improve the choice and application of RWH methodologies, future studies should concentrate on integrating cost-benefit evaluations, community involvement, and dynamic climate data. Additionally, broadening the study's scope to encompass several Afghan locations will improve its relevance.

5. Conclusion

Ultimately, this study emphasizes the crucial significance of (RWH) as a feasible solution to tackle the severe water shortage problems in Southern Afghanistan. With efficiency ratings above 80% based on sustainability indicators and water capture potential, this study finds that sand dams, infiltration pits, and rock catchments are the best RWH practices for enhancing groundwater recharge. GIS-based spatial analysis identified Southern Afghanistan's highest recharge potential areas to optimize resource allocation. These techniques showcase exceptional efficacy in catching and storing water and display remarkable flexibility in adapting to the area's specific climatic and geographical requirements, establishing them as sustainable alternatives for extensive water resource management.

GIS and MCDM approaches in spatial analysis have effectively identified the most suitable sites for implementing these RWH methods. Using thematic layers such as rainfall, soil texture, and land use, the research generates a comprehensive map indicating regions with the greatest capacity for groundwater recharge. By adopting this focused strategy, resources are allocated to the most favourable sites, optimizing the effectiveness of RWH projects and substantially contributing to water security in the area.

Overcoming obstacles, including antiquated maps, erratic weather, and little community involvement, is essential to the success of RWH techniques. To identify RWH sites more accurately, future studies should improve GIS mapping approaches to incorporate dynamic climatic data. Assessing the long-term feasibility of RWH technologies requires longitudinal studies on their socioeconomic and environmental effects. Furthermore, pilot projects investigating community-led modifications to infiltration pits and sand dams may offer scalable models for regional deployment. By tackling these obstacles, the results of this study may function as a strategy manual for policymakers, water resource managers, and local people in formulating and executing resilient water management strategies that improve resistance to water shortage in the arid areas of Afghanistan.

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