



Improving the efficiency and sustainability of
water harvesting technologies in Sudan:

Representative water harvesting technologies assessment

Executive summary

This report presents an in-depth review and contextual analysis of representative water harvesting technologies implemented across diverse agroecological zones in Sudan. It serves as a technical reference and strategic planning tool for practitioners, policymakers, and development partners working in water resource management, climate resilience, and sustainable land use.

Twelve key water harvesting technologies are examined in detail: *hafirs, water spreading weirs, half-moon terraces, sand dams, road water harvesting, percolation dams, subsurface dams, recharge basins, check dams, rocky catchments, and terraces*. For each intervention, the report provides standardized chapters covering introduction, adoption, hydrogeological considerations, structure design, water quality, challenges, and a new section on uniqueness and comparison, which outlines the strategic niche of each technology relative to others in the same portfolio.

To ground this information in reality, the report evaluates each intervention at a specific site, using field data on catchment size, land use, elevation, and rainfall. For example, the Tahella Hafir operates in an extremely arid zone with only ~100 mm of annual rainfall, while the Umsenibra Check Dams function in a much wetter setting receiving over 768 mm per year. These cases illustrate how hydrological suitability, land cover, and topography interact to determine the effectiveness of each technology.

Interventions are compared to clarify how design intent and environmental fit differ across technologies. For instance, subsurface dams and sand dams both store water in riverbeds but vary in visibility, sediment reliance, and suitability depending on geology and evaporation risk. Similarly, recharge basins depend on controlled inflow and infiltration conditions, while percolation dams function opportunistically by enhancing seepage from seasonal flow events.

The environmental suitability sections explicitly relates each structure to its surrounding rainfall regime, land cover, and geomorphology, aiding replication and planning in similar contexts. These site-specific insights can guide future siting, design, and scaling of water harvesting investments under Sudan's climate adaptation strategies.

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Abbreviations

CTCN	Climate Technology Centre and Network
ILM	Integrated Landscape Management
IWRM	Integrated Water Resources Management
MoIWR	Ministry of Irrigation and Water Resources
OECD	Organization for Economic Co-operation and Development
SWC	State Water Corporation
UNFCCC	United Nations Framework convention on Climate Change
WASH	Water, Sanitation and Hygiene
NAPA	Sudan National Adaptation Program

Introduction

Climate projections for Sudan indicate a future marked by increased rainfall variability, reduced seasonal predictability, and significantly higher average temperatures. These changes are expected to intensify evapotranspiration, reduce soil moisture, and increase the frequency and severity of droughts. The erratic distribution and shifting intensity of rainfall are already diminishing the reliability of both surface and groundwater resources, with major implications for domestic water supply, livestock, and agriculture.

Water harvesting has long been integral to Sudan's water management strategies. Traditional systems such as floodwater harvesting and hafirs, some of which date back to the Merowic kingdom, were developed to store, infiltrate, or retain water from seasonal rainfall. Today, these systems continue to serve as critical tools in adapting to climate change, enhancing resilience in rural communities, and addressing challenges across the water–agriculture–livelihoods nexus.

In response to these challenges, the Higher Council for Environment and Natural Resources, acting as Sudan's National Designated Entity to the United Nations Framework Convention on Climate Change (UNFCCC), submitted a request for technical assistance to the Climate Technology Centre and Network (CTCN). Hosted by the United Nations Environment Programme, the CTCN is the implementation arm of the UNFCCC Technology Mechanism. It provides countries with tailored support on technology solutions, capacity building, and advice on enabling frameworks to support climate adaptation and mitigation.

This technical assistance project, implemented in collaboration with the Water Research Institute of the University of Khartoum and the Dryland and Water Harvesting Research Centre of the Agricultural Research Corporation, aims to enhance the efficiency and sustainability of water harvesting technologies in Sudan. Its objectives include diagnosing the current status of rainwater harvesting technologies, evaluating their effectiveness, introducing alternative or improved methods, and building the capacity of relevant stakeholders—government officials, researchers, engineers, technicians, farmers, and community members—through training and demonstration.

This report contributes to that process by providing an in-depth analysis of twelve representative water harvesting technologies currently in use across Sudan. Each intervention is examined through a common analytical framework that includes its introduction, design, hydrogeological setting, water quality implications, adoption trends, and challenges. Further sections assess what makes each technology unique in comparison to others, and how well it fits within its environmental context based on site-specific data including rainfall, land use, catchment characteristics, and elevation.

By combining technical analysis with spatial and environmental assessment, this report aims to inform evidence-based planning, improve the targeting of water harvesting interventions, and support Sudan's broader efforts to strengthen resilience to climate change.

Methodology

Mapping the infrastructure.

To delineate the catchment areas and assess land use characteristics for each water harvesting structure, a combination of digital elevation and land cover datasets was used alongside hydrological modelling and GIS analysis tools. The methodological steps were as follows:

1. **Digital Elevation Model (DEM) Acquisition**
The Shuttle Radar Topography Mission (SRTM) DEMs were downloaded to provide base elevation data for hydrological modeling.
2. **Catchment Delineation in QGIS**
Catchments were delineated using the `r.watershed` and `r.watershed.outlet` tools in QGIS via the GRASS GIS plugin. These tools allowed for computation of flow direction and accumulation, and for determining upstream contributing areas based on defined outlet points.
3. **Accuracy Improvements in Flat Areas**
In regions with limited topography, such as expansive wadis, DEM-derived delineations were prone to inaccuracies. In these cases, the TanDEM-X (TDX) Hydro DEM dataset was used instead, as it provided hydrologically corrected elevation data, enabling more accurate delineation in flat terrain.
4. **Stream Network Identification**
Stream networks were extracted using either the `r.watershed` tool from the DEMs or obtained directly from the global TDX hydrography dataset. This ensured alignment between catchment boundaries and surface hydrology.
5. **Land Use Classification**
Land use within each delineated catchment was determined using the IO Global Land Use Land Cover (LULC) 2023 dataset. This dataset provided detailed, globally consistent classification of land cover types, which were spatially overlaid with the catchment boundaries to assess dominant land uses and support further hydrological and ecological analysis.
6. **Rainfall Analysis**
To assess the average monthly precipitation over each catchment, data from the CRU CL Global Precipitation dataset was used. The dataset was spatially intersected with each delineated catchment to calculate average monthly rainfall values, which were then visualized in precipitation graphs and maps for each structure. This information provides important context for understanding the seasonal availability of water and the potential for harvesting.
7. **Visualization and Map Production**
The outputs, including catchment boundaries, stream networks, and land use overlays, were visualized using GIS software and compiled into a series of maps and figures for inclusion in the deliverable.

Climate projections

To evaluate future changes in precipitation, projections from the CMIP6 (Coupled Model Intercomparison Project Phase 6) ensemble were used. These projections were analyzed to assess expected trends and shifts in precipitation patterns across Sudan under various climate scenarios. This analysis informed long-term planning and adaptation considerations for water harvesting infrastructure, especially in regions expected to experience increased variability or changes in seasonal rainfall.

Location and climate of the technologies

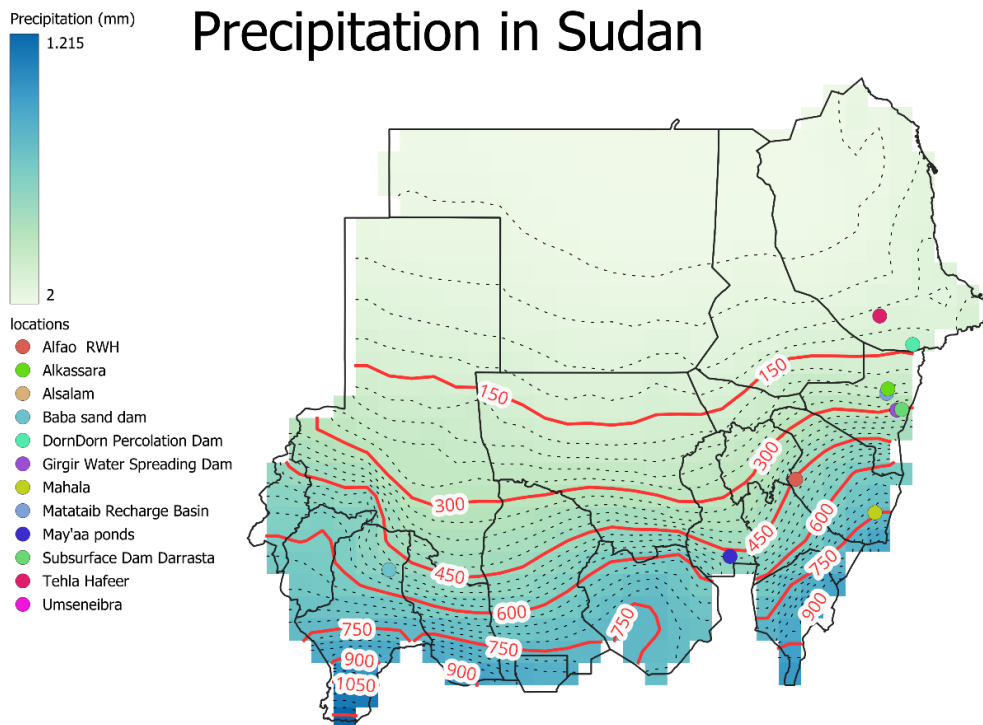


Figure 1, Precipitation in Sudan. The red- (150mm) and black dotted (30mm) lines represent the isohypses. The coloured dots show the representative technologies presented in this Report. Precipitation data from CRU CL 2.0.

Figure 1 above illustrates the spatial distribution of average annual precipitation across Sudan, overlaid with the locations of various water harvesting infrastructures evaluated in this study. The precipitation gradient increases from north to south, ranging from less than 100 mm/year in the northern deserts to over 1,000 mm/year in the southern and south-eastern regions.

Key isohyets (e.g., 150 mm, 300 mm, 600 mm, 900 mm) are marked to indicate general climatic zones:

- Arid and semi-arid zones dominate the northern and central parts of Sudan, where rainfall is low and highly variable, posing challenges for rain-fed agriculture.
- Sub-humid zones in the south and south-east receive significantly higher rainfall, enabling greater potential for groundwater recharge and more diverse cropping systems.

Implications for Water Harvesting Projects:

This spatial variability has important implications for the selection and design of water harvesting technologies:

- In areas receiving less than 300 mm/year technologies need to prioritize maximizing capture efficiency and minimizing evaporation losses.
- In transitional zones (450–750 mm/year); intermittent but substantial rainfall events can be effectively harnessed for both storage and soil moisture enhancement.
- In the higher-rainfall southern regions, projects can benefit from more reliable runoff and may focus more on flood control and longer-term storage strategies.

Climate change projections

Precipitation

Projected climate models indicate notable shifts in precipitation patterns across Sudan toward the end of the 21st century. The two figures below present insights from the CMIP6 multi-model ensemble under various Shared Socioeconomic Pathways (SSPs), focusing particularly on SSP1-2.6 (low emissions) and SSP5-8.5 (high emissions) scenarios.

Figure 2 shows the projected monthly precipitation anomaly for the period 2080–2099 relative to 1950–2014. Under the high-emissions scenario (SSP5-8.5), Sudan is expected to experience significant increases in rainfall during the core of the rainy season (July–September), with peak anomalies reaching +50 mm in August. In contrast, under the low-emissions scenario (SSP1-2.6), rainfall increases are modest and more consistent throughout the year. The broader shaded areas indicate the uncertainty range among models, which is especially wide during the rainy season.

Figure 3, Past, current and future monthly Precipitation anomalies for Sudan according to the SSP5-8.5 ensemble. World Bank, Climate Change Knowledge Portal (2025)Figure 3 presents a time series heatmap of precipitation anomalies across months and decades from 1951 to 2100 under the SSP5-8.5 scenario. It highlights a historical drier July–September, especially during the 1970s and 1980s, followed by a steady projected increase in precipitation throughout the late 21st century. August, in particular, is expected to see the strongest positive anomalies, potentially exceeding +25 mm by the 2090s.

Implications:

These projections suggest a future characterized by more intense rainy seasons, which could lead to both increased water availability and heightened risks of flash flooding, Simultaneously increasing the potential and importance of water harvesting in Sudan. For water harvesting interventions, these trends reinforce the importance of designs that can capture peak rainfall volumes during the short wet season, while also managing the associated runoff and erosion risks. Climate-informed planning will be critical to ensure the resilience and

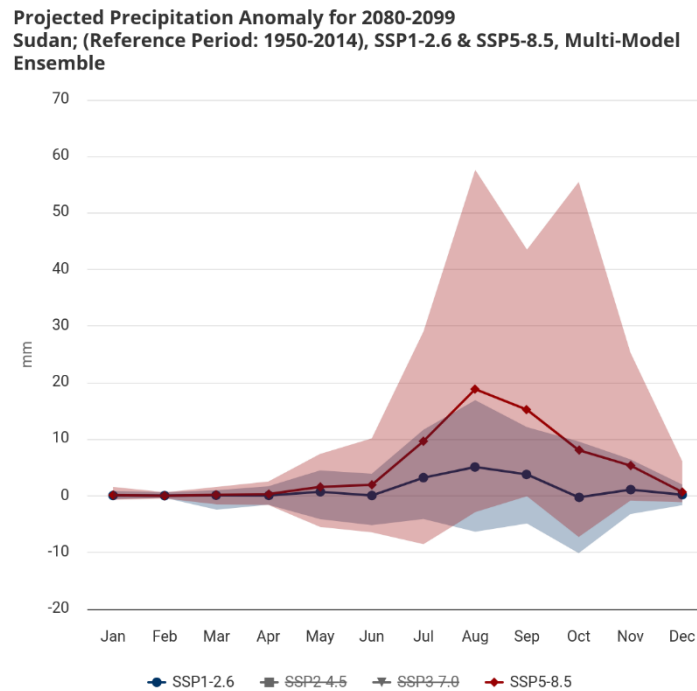


Figure 2, Projected monthly precipitation anomalies for the period 2080-2099 in Sudan according to ensemble models. The red represents the SSP5-8.5 and the blue represents the SSP1-2.6. World Bank, Climate Change Knowledge Portal (2025)

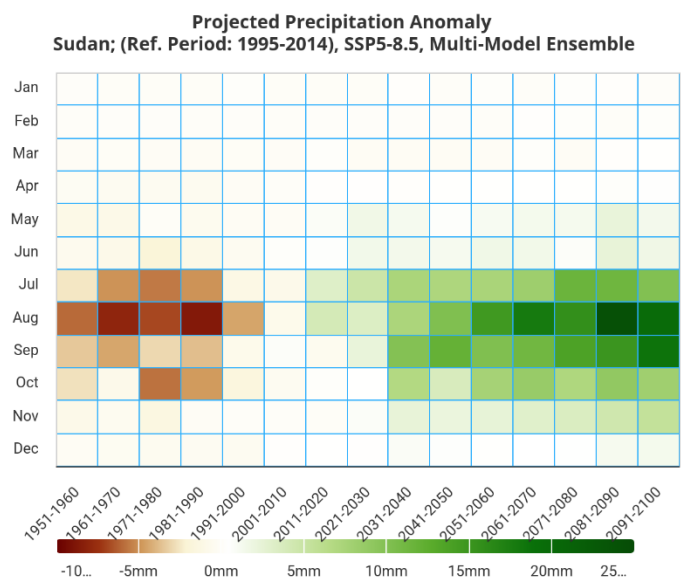


Figure 3, Past, current and future monthly Precipitation anomalies for Sudan according to the SSP5-8.5 ensemble. World Bank, Climate Change Knowledge Portal (2025)

effectiveness of infrastructure investments over time.

Temperature

Climate projections from the CMIP6 models indicate that Sudan is expected to experience substantial warming throughout the 21st century. Under high-emission scenarios such as SSP5-8.5, average annual temperatures across the country are projected to increase by 2.5°C to 4.5°C by the end of the century (2081–2100) relative to pre-industrial levels. The warming will be more intense in the northern and central regions, which already experience arid conditions, further exacerbating heat stress and evaporation rates. Seasonal temperature extremes—especially maximum daily temperatures—are also expected to rise, with more frequent and intense heatwaves in both dry and rainy seasons. Even under lower-emission pathways (e.g., SSP2-4.5), Sudan will still face significant warming, underscoring the need for robust adaptation measures.

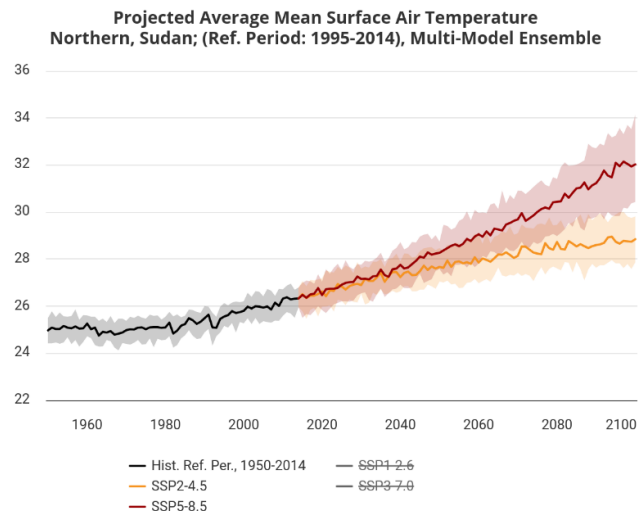


Figure 4, Past current and future Temperature trends in Sudan according to two different climate scenarios. World Bank, Climate Change Knowledge Portal (2025)

Implications for Water Harvesting Projects:

Sudan's climate is expected to undergo significant changes throughout the 21st century, characterized by rising temperatures and shifting precipitation patterns. Projections indicate a substantial increase in average surface air temperatures, particularly under high-emission scenarios, which will lead to much higher evaporation rates. This increase in atmospheric demand for moisture will further strain already limited water resources, particularly during the long dry season, when water availability is already critically low. At the same time, rainfall is expected to increase, but this increase may overlap with more intense downpours occurring over fewer months. This emerging climate pattern presents a paradox: greater overall precipitation, but also greater difficulty in capturing and using it effectively. The intensification of rainfall will increase the volume and speed of surface runoff, making it more challenging to store water without appropriate infrastructure. Additionally, the growing mismatch between when water is available (in brief, intense rainy periods) and when it is most needed (across long, hot, dry seasons) underscores a fundamental vulnerability in Sudan's current water management systems. These dynamics elevate the importance of water harvesting as a critical adaptation strategy. The ability to collect and store rainwater during high-intensity wet periods and retain it for use during the dry season will be vital for ensuring year-round water access. However, traditional systems may be overwhelmed by increased rainfall volumes, if not updated or properly maintained. Climate-informed planning, robust infrastructure, and context-specific design will be essential to maximize the benefits of increased rainfall while mitigating the risks of flash floods, erosion, and water loss through evaporation. In this context, water harvesting in Sudan is no longer just a supplementary practice, it is a strategic necessity for building resilience in agricultural systems, protecting livelihoods, and adapting to the realities of a changing climate.

Representative technologies

Hafir (Hafeer)

Introduction

Hafir, also written hafeer, is one of the oldest water-harvesting technologies practiced across Sudan since Meroitic civilization, nearly 2500 years. The structure typically consists of an off-stream artificially constructed water storage ponds with varying depths attached to a conveying system to divert flows into the hafir inlet. Hafirs are used to capture rainy season run-off in arid and semi-arid for later use in winter and summer.

The oldest operational hafir is located in Muswarat (Figure 5) dating back to 350 AD. Till today, hafirs are considered a main water supply source, in areas where groundwater is scarce, in regions away from the river Nile and its tributaries.



Figure 5, the Great Hafir, Muswarat, River Nile State. Dates 2500 years ago harvesting water from Wadi es-Sufra and has a capacity of 260,000 m³.

Source: <https://www.musawwarat.com/about-musawwarat/the-great-hafir/>

Adoption

There are currently more than 1,500 Hafirs in Sudan with the majority being constructed by local community to serve both human and livestock drinking water. Despite the questionable water quality standards, in states like Al-Gadarif, Blue Nile, White Nile, Hafirs are the primary source for water supply. There have been recent attempts in Al-Gadarif and Kassala state to utilize hafirs for both winter irrigation and supplementary/emergency irrigation source in the occurrence of dry spills, especially for horticulture smallholder farmers.

Hydrogeological considerations

Hafirs are constructed across the country from the far north, where rainfall averages 100mm annually, to the southern region, where rainfall reaches 800 mm annually. Hafirs can also be located at different locations within a catchment area in the upstream hilly areas or in downstream basin mouth or in river and wadis deltas. Clay and stiff silt soils are the most favorable for Hafir construction as they provide minimal seepage, thus increasing durability of stored water. However, in some cases, Hafirs are also constructed in sandy soils supported by lining Hafir bed with either clay material or manufactured lining products e.g. geomembrane.

Structure Design

Hafirs are typical in lowland areas in the vicinity of a wadi or a creek (khowr) and small stream ephemeral rivers or the foot of small hills. Hafirs are, often, dug below ground level to depths ranging from 1.5m down to 5 meters with surface areas ranging from 1,000 m² up to 10,000 m². Haffer dimensions are decided based on several factors including the depth of impermeable layer e.g. clay, available funds, method of construction and water availability. However, many haffirs are built according to a standard design and not sufficiently adapted to the local circumstances. The dimensions of the current typical standard design for a 28320m³ capacity Hafir are: top width: 118m, top length: 48m, depth: 5m, bottom width: 45.5m, bottom length: 113m and slopes: 2:1 for the length and one of the widths and 4:1 for the remaining width.

Conveying structures are used to divert surface water flow into the hafir reservoir e.g. self-catchment setup in the case of Hafirs in the mountainous, diversion weirs, or wadis deltas and catchment month. Following that, the diverted water collected in pre-sedimentation siltation trap is used to reduce turbidity with sizes ranging from 25 by 25 to 50 by 50.

Water quality

Water collected in a hafir has high level of suspended sediment, despite the settling process. Turbidity levels could range from 50 to as high as 5000 NTU. Over the past 50 years, a modified Hafir design has been introduced, where a treatment unit was added to the outlet well with a purpose of reducing water turbidity. Generally, slow sand filters are the most adopted treatment system. In less than 10% of the cases, chlorine tablets are added.



Figure 6 Broken outlet well and treatment unit of a Hafir in Al-gadarif. Source: field work

Sample design

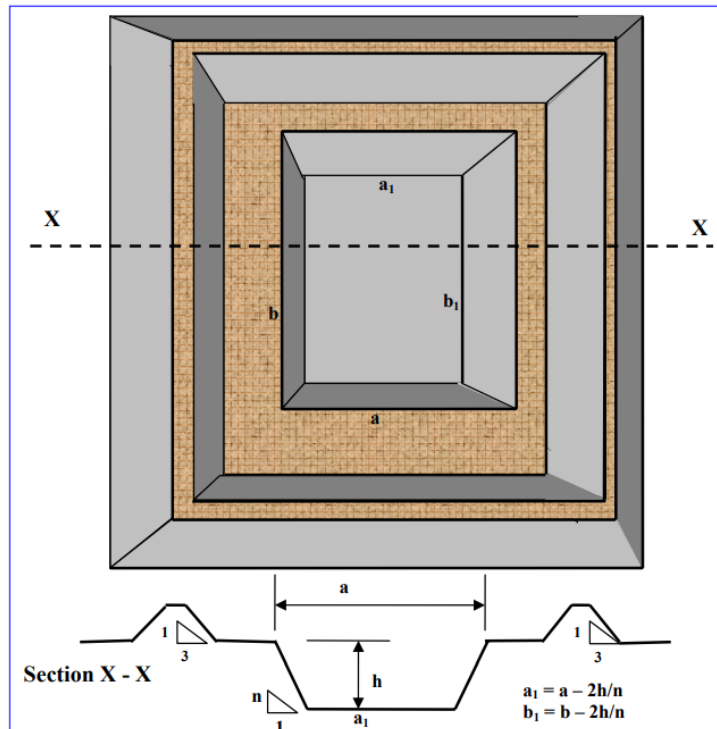


Figure 7, Sample design of an (improved) hafir. Figure from MetaMeta (2009).

Challenges

- **Sediment control:** In most hafirs, the levels of suspended sediment are higher than the approved WHO and Sudanese Ministry of Health standard. Despite the pre-sedimentation basin attached to most hafirs, turbidity reaches up to NTU 2,000. Beside water quality concerns, high sediment load leads to clogging of inlet and outlet well pipes, complicating regular maintenance. Similarly, filters are overloaded with over-capacity sediment loads are more prone to failure.
- **Hydraulic design:** Proper rainfall runoff calculations are provided in some Hafir design reports. However, almost in all hafirs, there was no proper hydraulic design provided for the water conveying structures, which are typical wide-open channels. In some locations, inlet wells are located the riverbank of seasonal stream without proper protection or diversion structures.



Figure 9 Excessive sedimentation in A Hafir in Al-Gadarif. Source: Consultant



Figure 8 Damage inlet system in A Hafir, Al-Gadarif. source: Field work

Uniqueness and comparison

Hafirs are unique because they are large, manually excavated open ponds designed primarily for livestock and domestic water storage in flat, clay-rich terrains. Unlike recharge-focused structures (e.g., recharge basins, percolation- or check dams), hafirs prioritize volume and surface access over infiltration. Compared to tanks or cisterns, they are less protected from evaporation or contamination, but offer much greater capacity. Their suitability is highest in areas with no shallow groundwater and seasonal water access needs, particularly in pastoralist communities where water mobility is essential.

Climate change

Hafirs play a moderately strong role in enhancing climate resilience, particularly in regions where groundwater is inaccessible, and rainfall occurs in short, intense events. Their ability to store large volumes of runoff provides a buffer against seasonal drought, allowing for emergency irrigation and sustained livestock watering. However, their contribution to long-term resilience is limited by high evaporation rates, sedimentation, and water quality challenges. In Sudan's eastern and central states, where the NAPA identifies increasing rainfall variability and dry-season stress as major risks, Hafirs offer a vital, though imperfect, adaptation tool. Improving sediment control, water treatment, and integration with land use planning would enhance their resilience function.

Feature infrastructure

Tahella Hafeer

Tahella Hafeer was constructed in 2012 by Humanitarian Organization and it is used to store water during floods as to cover water shortage during drought season.

The hafir is positioned in the downstream area of the 9,095 ha catchment. Out of this, a total area of 225 square kilometers is covered by in-situ water harvesting.

The hafir was constructed on top of a sandy soil foundation using clay, sand, gravel, cement, stone and brick with dimensions of internal areas of 142 by 71 square meter and an excavated depth of 4 meters. The topography of the area consists of Durdaib mountains, which serve as a natural divide of watershed and as a result, some small rivers that come from hilly areas can lead to floods during the rainy season.

The purpose of the Hafir is to improve production and it has successfully increased water availability, reduced downstream siltation and caused changes in river flow patterns which reduced floods occurrence. However, the technology resulted in an increase in pests and diseases, waterlogging, change in surface water quantity and sediment deposition.



Figure 10 Tehlla Haffer on December 2024

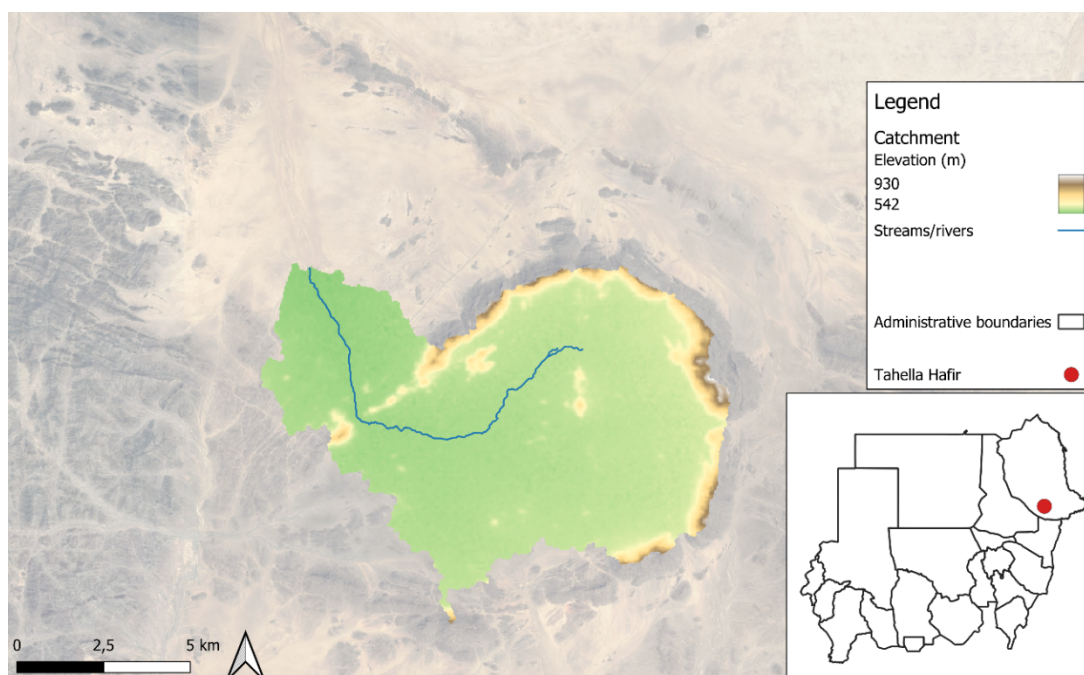


Figure 11, Map showing the catchment of the Tahella Hafir

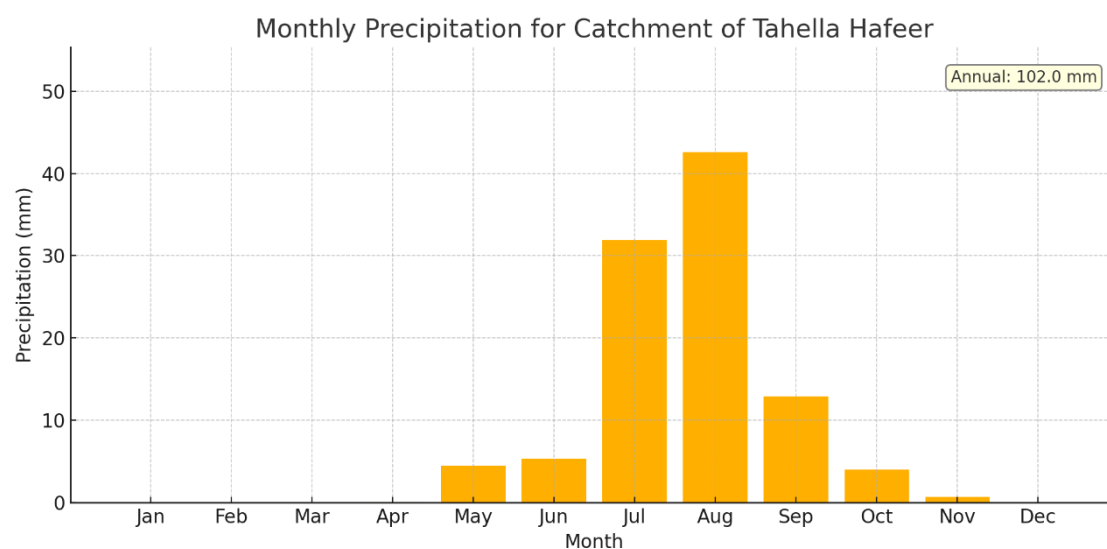


Figure 12, Monthly precipitation in the catchment of the Tahella hafir. Data from cru cl2

Environmental suitability

Tahella Hafir is located in the eastern semi-desert zone of Sudan, within an area receiving only ~100 mm of annual rainfall, according to the project's precipitation map. Despite this low rainfall, the catchment is expansive — around 100 km² — and consists largely of bare land and rangeland, which promotes high runoff during rare but intense rainfall events. This is a key factor making the Hafir viable, as runoff yield is amplified by low infiltration and sparse vegetation cover.

The site lies in a natural lowland depression, a preferred topographic setting for hafirs, allowing efficient water collection from surrounding ephemeral flow paths. The presence of clayey to silty soils, as noted in the project documentation, contributes to water retention but also poses sediment management challenges, especially with high sediment loads from bare slopes.

Given these factors, the Hafir is well-suited for livestock watering and seasonal use under current land use and hydro-climatic conditions. However, sedimentation risk and evaporation losses are major limitations. Supplementary measures such as sediment traps and partial shading or lining may improve long-term reliability in this hyper-arid environment.

Water Spreading Weirs

Water Spreading Weirs (WSW) are low height retaining and spreading structures built in small wadis and creeks (khors) with the purpose of redistributing the rainfall surface. WSWs are typically used in rainfed and grazing areas where they help to increase irrigated areas by expanding inundation and water recharge in the rootzone. Additionally, retaining effects reduce water velocity in the small streams which mitigate erosion effects. Farmers utilize WSW to prevent oversaturation of soils, known as waterlogging, which hinder plant growth.

Adoption

Several WSWs have been implemented in the last 20 years, especially in Kassala and North Darfur states. Surveyed WSWs ranged in length from 500 meters to 2 km length and in height from 0.5 meters up to 2.5 meters. In general, WSW are utilized as drought resilient structure, erosion control and soil water conservation measure. Its impact on resolving upstream and downstream water sharing is disputed especially in multi-use area e.g., farmers and pastoralist sharing.



Figure 13 Water Spreading Structure in North Darfur. Source: UNEP and Practical Action

Hydrological consideration

WSWs have been constructed in wadi and khors with maximum discharge capacity of 30 m³/sec with upstream catchments ranging from 50 km² to 400km² with relatively gentle slopes 1%<slope<3%. WSW primarily alter the hydraulic parameters of flood water by enforcing inundation into areas with higher roughness (off-stream floodplains), thus reducing flow velocities. In return, groundwater recharge is enhanced in both, upstream and downstream. A subsequent damping effect of flood peak increases flow duration yet increases evapotranspiration and upstream sediment deposition.

Structure Design

WSWs often consist of earth embankments, which retain water flows and help redirect water flows to the gates, the gates, are often built of mortared masonry or reinforced concrete and control structures, which allow management of flows quantities and allocation across targeted areas.

- Embankment: Upstream and downstream slopes 1:2 to 1:4 depending on soil characteristics e.g. cohesion, internal angle of friction. Protection is applied in

the vicinity of river streams where early floods subject higher energy into the structures.

- **Gates:** Gates are designed to allow passages of 50 to 100 return period flood. In some cases, energy dissipation structures are attached to the downstream side.
- **Control structures:** Control structures are typically made of steel sluice gates or wood locks depending on the availability of operators.

Sample design

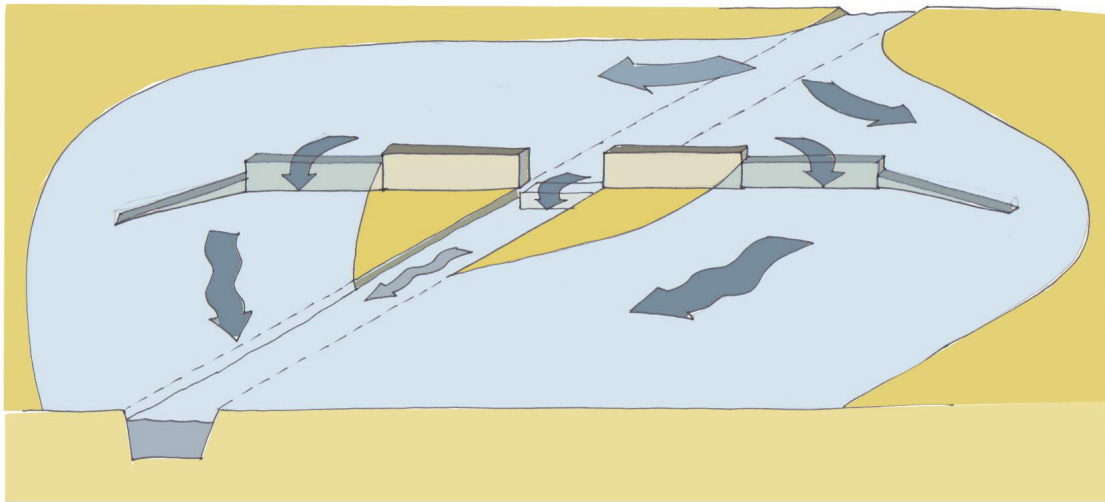


Figure 14, Simplified schematic overview of a water spreading weir. Photo from: Heinz Bender

Water quality

Although WSWs do not treat water directly, they contribute to improved water quality indirectly through sediment deposition and infiltration. As water spreads and seeps into the soil, turbidity and contaminant loads are naturally reduced. This process is especially beneficial when groundwater is later abstracted for domestic, or livestock use. However, in initial stages after flood events, water may remain turbid and should not be consumed without filtration or basic treatment.

Challenges

- **Sediment control:** In most cases, the WSWs are designed with the premise of that water discharge distributed equally across the multiple gates. In reality, most of the structures are sensitive to sediment deposition which alter the water path resulting in one gate receiving more discharge. Continued alternation in upstream morphology, especially in loose soil, could change the topography of the reservoir, hence, limiting the water distribution downstream and, consequently, the overall impact.
- **Hydraulic design:** In many cases, WSWs are found to cause negative impact on downstream users due to overdesign fixed spillway levels that block low flows. Low water volumes are important for the sustainability of downstream users, especially farmers during in dry years. Spillway should allow for varies operation considering both dry and wet year scenarios.
- **Operation conflict:** Competing interests between farmers and pastoralists can complicate flow regulation.

- Construction: Design requires skilled engineering and proper site assessment.

Uniqueness and comparison

Water Spreading Weirs (WSWs) are unique in transforming destructive flood pulses into broad, productive infiltration over floodplains. Unlike structures such as sand- or check dams that block or slow water within a channel, WSWs guide it laterally across landscapes. They are ideal in wide, low-gradient catchments where sediment spread is beneficial (such as the large Wadi landscapes in Sudan). Compared to bunds or terraces, they operate at a much larger valley-wide scale, and are most appropriate where livelihoods depend on rangeland rehabilitation or extensive agriculture.

Climate change

WSWs are particularly well-suited for enhancing landscape-scale resilience in dryland regions prone to flash flooding and rangeland degradation. Their ability to slow and spread surface runoff increases infiltration, stabilizes soils, and supports vegetation recovery, an approach directly aligned with Sudan's NAPA focus on restoring degraded land and improving multi-user water access. In conflict-prone zones, WSWs also play a socio-ecological role by mediating water distribution between farmers and pastoralists. Their capacity to support groundwater recharge and rangeland productivity during increasingly erratic rainy seasons makes them a high-potential tool for climate adaptation, especially when designed with equitable governance mechanisms.

Feature infrastructure

Girgir water spreading structure

The girgir water spreading dam was constructed in 2008 through external interventions and it consists of a small dam designed to collect rainwater, along with a network of three small channels to distribute water to the targeted areas. The small dam stores water for utilizing it in irrigating agricultural projects. The dam was constructed using cement, sand, rocks and gates' steel over a clay soil foundation with these dimensions: 1.5m height, 25m length, and 2.5m side extensions.

The construction of the dam has led to increased agricultural production, which contributes an added value to the local economy. The main purposes of dam construction are improving production, prevent land and water degradation. The dam has successfully increased water availability, increased vegetation growth, increased crop fields and waterlogging.



Figure 15 Gates of Girgir WSW. Source: Field work 2024



Figure 16 Embankments of Girgir WSW. Source: Field work 2024

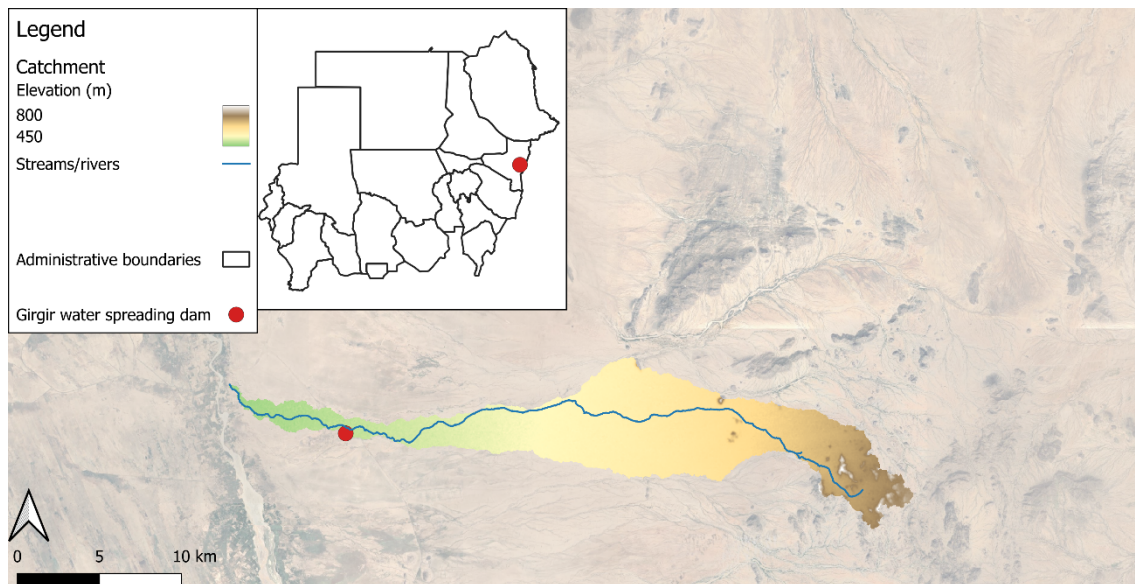


Figure 17. Map showing the catchment of the Girgir water spreading weir

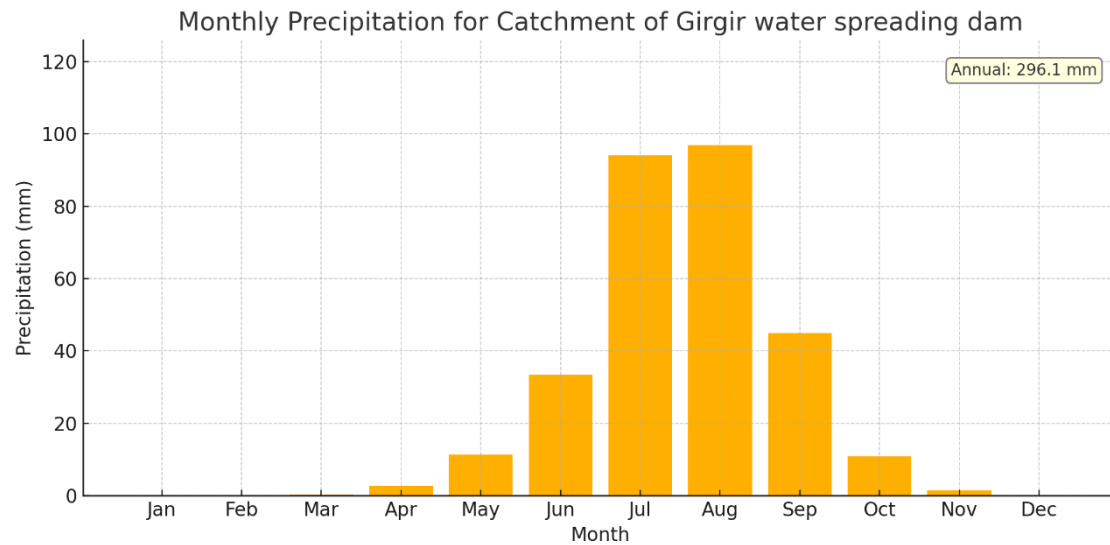


Figure 18 Monthly precipitation in the catchment of the Girgir dam. Data from cru cl2

Environmental suitability

The Girgir Water Spreading Weir is located in North Darfur, within a semi-arid landscape that receives an average annual rainfall of 296.1 mm, as indicated by site-specific climate data. The rainfall is strongly seasonal, with nearly all precipitation concentrated in July and August, making the area highly dependent on effective management of short, intense flood events.

The catchment area for the weir is approximately 120 km², primarily composed of rangeland and sparse vegetation cover, conditions which favor rapid runoff and flash floods during storm events. These hydrological conditions are ideal for the functioning of water spreading weirs, which are designed to intercept and spread these short-lived, sediment-laden flows laterally onto adjacent floodplains.

Topographically, the structure is well positioned in a low-gradient alluvial fan area, allowing floodwaters to be evenly dispersed across agricultural or rehabilitating rangeland. The intervention enhances soil moisture, facilitates shallow groundwater recharge, and supports regeneration of degraded land. Compared to structures like sand or subsurface dams that target water storage within the streambed, Girgir's WSW design offers a landscape-wide benefit, helping to stabilize land use systems and build climate resilience across a broad valley floor. This makes it particularly well-suited for regions like North Darfur, where pastoralism, agro-pastoralism, and dryland farming all coexist within fragile environments.

Sand dam

Sand dams are retaining structures built in seasonal streams to collect coarse sand which capture stream flows during wet season creating sand reservoir with a high-water content. Currently, there are more than 160 sand dams reported with the majority being constructed in during the last 15 years. Water is usually collected from both upstream and downstream nearby open dug wells and water yards. In grazing area livestock corridors, water is provided to livestock by digging temporary shallow dug wells inside the sand reservoir, locally named “Jammam”.

Adoption

Uptake of sand dam in Sudan is recent in relative to other technologies. Many sand dams were constructed initially as check dam or as roads crossings with proper erosion protection in sandy rivers then repropose as sand dam after coarse sand accumulated in the upstream reservoir. Sand dam ranges in size from 25 meters up to +100-meter width and material with mortar masonry being the most common. South Kordofan and Sea states has the highest number of sand dams due to scaled projects from local NGO SOS Sahel, who are the pioneers of community-led sand dam construction.



Figure 20 Reinforced concrete sand dam. Red Sea State. Source: SOS Sahel Sudan



Figure 19 low level Sand dam in Kabkabya. Source: Consultant

Hydrological Conditions

In most cases, sand dams in Sudan are built on top of faults and shallow aquifers. Unlike its counterparts in most of east Africa, the bottom of the sand reservoir is usually permeable, allowing water to seep and recharge the underground cracks and shallow aquifer. Similar to subsurface dams, the sand reservoir would function as a buffer providing a consistent and slow recharge in compared to a no-dam scenario where the high-water velocity reduces the recharge. Additionally, less evaporation is permitted, and a considerable purification is witnessed in most the surveyed locations. Typically, increase water table was reported in both upstream and downstream boreholes. A thorough geophysical and hydrogeological studies are important to provide close insights and robust results on Sand dam impact in Sudan.

Structural Design Consideration

The sand dam structural design is similar to small to mid-size check dams. The main dam body consist of impervious retaining wall typically design as a gravity. Dam spillway is designed to pass 25 to 50 years returned period peak flow. Side abutments and wings are usually built from the same dam body material. Spilling over to the riverbank is not permitted, thus earth embankment is rarely considered. Sluice gates are not considered as now water flow is only permitted through the spillway. Simple energy dissipation structures are usually provided in the shape of inverted water basin. The majority of the surveyed structure are built using mortared masonry, with fewer dams being built with reinforced concrete or with mixed material combining, reinforced concrete, mortared masonry,

Sample design

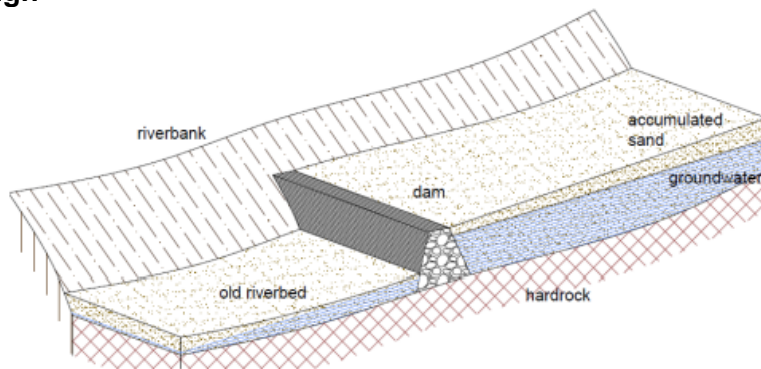


Figure 21, Schematic cross section of a typical sand storage dam (Borst & de Haas, 2006)

Challenges

- Operation and maintenance: Despite the relatively low cost of repair, most of existing structures receive low to no maintenance funding. Infrastructure built by federal agency have their O&M responsibility transferred to State level authority which are often underfunded. Structure built humanitarian partners are mostly community managed, yet little attention is paid to the sand dam in compared to the water collection facilities attached to it e.g. shallow well.
- Improper spillway design: Most of the community structure, largely funded by humanitarian actors, shows improper spillway design. When interviewing the contractors, they stated in many cases, there was no detailed technical design provided. Instead, a set of drawings with standard spillway dimensions. This is attributed to the lack of enforcing design review procedure by state level authorities, in compared to federal level authorities which ensure a robust review is applied before approving design for construction.

Uniqueness and comparison

Sand dams are built above ground across seasonal rivers, trapping coarse sand during floods to create a subsurface reservoir. Their key uniqueness lies in combining physical storage with natural filtration. Compared to subsurface dams (which are below ground), sand dams are easier to monitor, cheaper to construct, but depend on consistent sand deposition. They are ideal in arid riverbeds with high sediment load and active community labor participation, but less suitable in fractured or saline environments.

Climate change

Sand dams offer a robust and highly climate-resilient solution in Sudan's arid and semi-arid regions, particularly where prolonged dry spells follow brief, intense rains. They combine effective water storage with groundwater recharge, minimizing evaporative losses and supporting water availability well into the dry season. This directly addresses NAPA's priority of improving water access for pastoral and agro-pastoral communities vulnerable to rainfall failure. Field experience in South Kordofan and Red Sea states shows that, despite limited initial uptake, sand dams have strong potential when combined with shallow well access and community-based management. Their resilience value is high, especially if spillway designs are improved and maintained.

Feature infrastructure

Baba sand dam

Baba sand dam is located in Baba village, which is situated in small branches of Wadi Talata downstream of Andur Basin. Prior to dam construction a change in the wadi course has directed flows away from the mainstream to a smaller stream, which reduced surface flows and groundwater recharge leading many farmers to abandon vegetable and fruits cropping resulting in a poor diet and deteriorating food security.

The purpose of constructing the dam was for the dam to serve as a diversion weir and sand dam as well. The design included 3 small open gate allowing better control of water allocation and diversion between main wadi and irrigation canal. In the first season, flash floods deposited layers of coarse sediment upstream of constructed weir leveling up bed level and causing desirable partial dredging in Baba irrigation canal. In the following season, additional increase of 0.4m on top of weir level was added.

The construction of the dam resulted in redirecting the water back in the irrigation channel, which led to irrigating over 40 gardens by surface water and an increase of shallow groundwater recharge. A total of 120 farmers have resumed winter irrigation in the Baba gardens area. In addition to stabilizing khor wadi banks, the structure created a hydraulic jump that has significantly dissipated flood peaks energy that erodes banks in baba village downstream.



Figure 22 Baba sand dam, Nyala South Darfur. Source: ZOA International

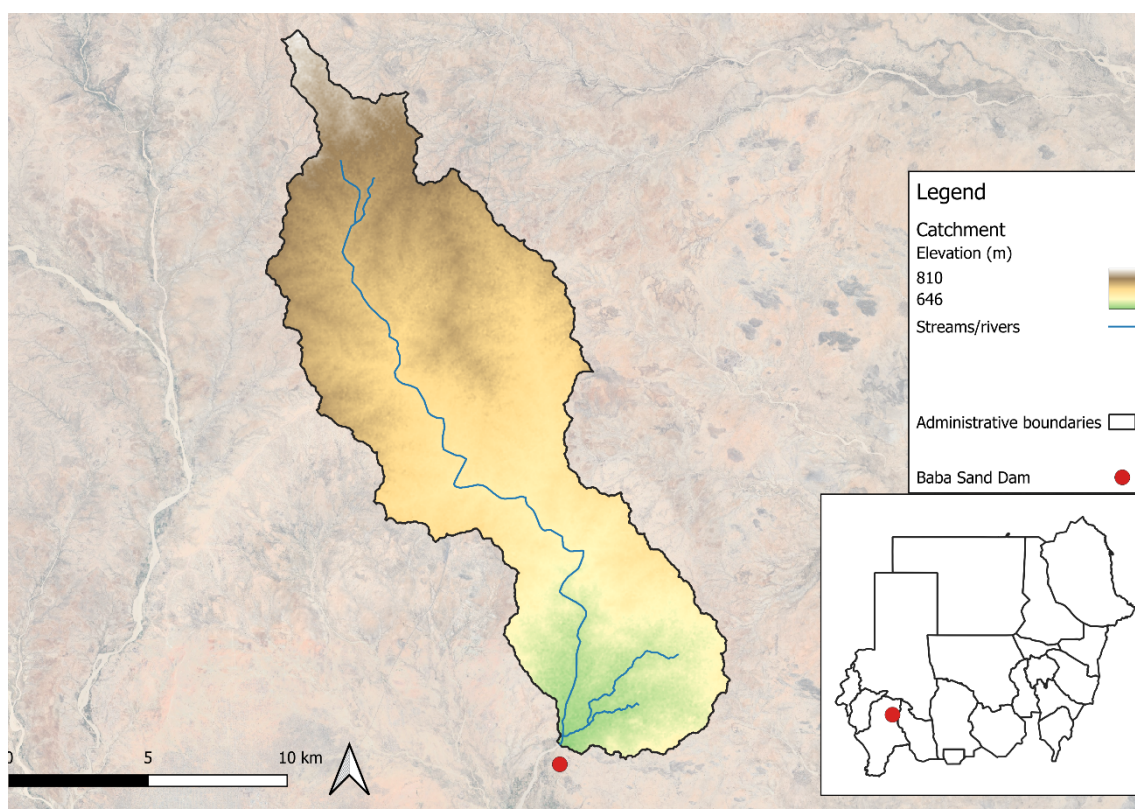


Figure 23 Map showing the catchment of the Baba Sand Dam

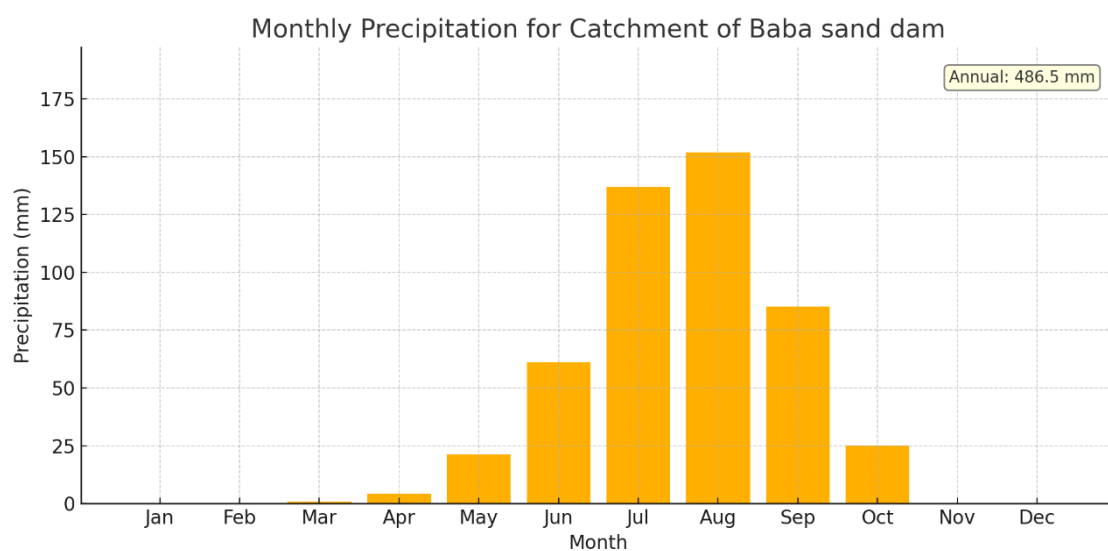


Figure 24, Monthly precipitation in the catchment of the Baba Sand Dam. Data from cru cl2

Environmental suitability

The Baba Sand Dam is located at 12.3912°N, 32.6590°E, in South Kordofan, within a semi-arid zone that receives approximately 316.5 mm of annual rainfall, according to the project's site-specific precipitation graph. The rainfall is highly seasonal, concentrated mainly in July and August, with isolated storm events typical of Sudan's

sandy wadi systems. The catchment size is approximately 175 km², and the land use is entirely classified as rangeland, which contributes minimal interception and encourages rapid runoff, ideal for filling the sand reservoir behind the dam during flood events. The seasonal stream that feeds the site carries coarse sand and sediment, a critical requirement for sand dams, as this material builds up behind the dam to form the subsurface water storage.

Road water harvesting

Road water harvesting technologies are secondary structures typically connected to national roads with high embankment level. Eldest structures are likely linked to the expansion of national roads in the 1980's across Sudan. Fewer structures were also spotted in the proximity of culverts built along railway station dates back to more the 100 years ago. The structure collects excess seasonal rainfall along rural road infrastructure which reduces rain-related road damage and reduce risk of erosion and landscape degradation.



Figure 25, Improved road water harvesting, Haya, Red Sea

Adoption

The majority of road water harvesting structures are re-purposed structures initially constructed as burrow pits to collect construction material along national roads. Burrow pits excavated close to seasonal streams, wadis or khors that shows signs for good water retention capacity e.g., Collected rainfall water for an extended period of time, are repurposed by increasing and unifying its shape and adding proper inlet and outlet system. Another type of road water harvesting are artificial bonds created as a result of improper roads drainage design specially in remote areas. Temporary ponds created by flash floods and retained by road embankment, or the limited road culvert discharge capacity are repurposed into small Hafirs serving water supply and protecting road embankment for erosion, excess seepage and increase hydrostatic pressure.

Hydrological consideration

Road water harvesting is considered an artificial pond created by either seasonal flows and flash floods retained by roads or by diversion canals. The inflow is depended on rainfall runoff process in the upper catchment, the conveying capacity of the diversion canal and/or the drainage structure (usually culvert) design.

Structure design

Road Water Harvesting systems include one or a combination of the following elements:

- Diversion channels that guide runoff from the road or adjacent drainage ditches to the storage pit.
- Borrow pits repurposed into ponds by reshaping and lining to optimize storage volume and stability.
- Retention embankments built along the downstream side of roads to temporarily impound runoff.
- Spillways reinforced with stone pitching to prevent erosion during overflow events.

Design must ensure that the structures:

- Withstand peak flood events without breaching.
- Include overflow structures to prevent undermining of road embankments.
- Are equipped with sediment traps upstream to minimize siltation

Water quality

While RWH improves water availability, quality concerns are significant:

- Runoff from roads may carry hydrocarbons (e.g., oil, fuel) and heavy metals, particularly from asphalted surfaces.
- Sediment loads can be high (especially from dirt-roads) if drainage systems are not well maintained.
- Water from RWH ponds is typically suitable for livestock but not directly for human consumption unless properly filtered and treated.

Simple filtration measures like sediment traps and constructed wetlands can enhance water quality, but careful site selection, preferably away from heavily trafficked roads, is crucial

Challenges

- Road protection: In most of the repropose structures, little attention is given to the protection of the road's embankment. Sufficient analysis should be conducted to ensure that stored water doesn't impact the structural integrity of the road structure.
- Flood management: Similar, hydraulic analysis should ensure proper measures in place in case of flood event where water discharge exceeds Road Water Harvesting storage capacity

Uniqueness and comparison

Road water harvesting repurposes infrastructure runoff, making it unique among passive systems. It does not require a new catchment but rather diverts existing water flows from roads into useful basins or pits. Unlike traditional harvesting systems, it is low-cost and opportunistic, often leveraging borrow pits. It is particularly suitable in areas where formal water systems are lacking and where roads intersect flood-prone rural zones, offering dual benefit for infrastructure protection and water supply.

Climate change

While not traditionally designed for climate adaptation, road water harvesting can be a highly effective resilience measure when integrated into infrastructure planning. Sudan's NAPA encourages the multifunctional use of development assets, and road networks, especially in flat, erosion-prone zones like Butana they are ideal options. By diverting and storing runoff from road surfaces, this approach mitigates flood damage, reduces erosion, and enhances water availability for adjacent fields or recharge structures. The resilience potential of road water harvesting is strong, especially when combined with design features that prevent clogging and support infiltration. However, its benefits remain underutilized due to lack of planning integration.

Feature infrastructure

Alkassara Road Water Harvesting

Locality: Hamshkorieb

State: Kassala

Coordinates: [16.1575671](#), [36.2066599](#)

Alkassara road water harvesting is in Airbab area in North Delta Locality covering a length of 20 meters, a width of 20 meters a depth of and 2 meters. The main road serves as a barrier collecting rainwater from Hamashkoraib khors. The primary purpose of this technology is to provide drinking water for human and livestock. The structure consists of repurposed small pits, which were utilized for embankment material for the national road. The location also benefits from the buffering effect created by the road culvert. As a result, water is stored both upstream and downstream the road. The total storage reaches up to 27,000 cubic meters.

One of the key issues is the growth of Mesquite trees which are considered invasive species that consume water massively. Additionally, the absence of a proper water outlet caused the livestock to fitch directly from the storage pond which reduced water quality for human being use.



Figure 27 Downstream view of Alkassara road water harvesting. Source Field work 2024



Figure 26 Upstream view of Alkassara road water harvesting. Source Field work 2024

Percolation dam

Dams built in seasonal streams to retain water which percolates the permeable bed layer and recharges the underground shallow aquifer. Although it shows a similar recharge process to sand dams, percolation dams do not retain coarse sand purposely. All the surveyed percolation dams are repurposed from ordinary surface water storage dams. A percolation tank's effectiveness depends on how well water seeps through its bed and sides to recharge groundwater, boosting nearby well yields. Over time, silt buildup and crust formation reduce this efficiency by blocking water infiltration.

Adoption

The term percolation dam is not common in Sudan and in most cases, these types of dams are considered surface storage dams. The percolation effect is usually coming as a byproduct for the sudden water storage. In many cases, dams were accidentally constructed over faults, crack and lineament without employing proper grouting works leaving reservoir storage in direct contact with open groundwater recharge flow. As a result, the constructed increased water table in downstream boreholes significantly to the extend its purpose changed from surface to groundwater storage. In some locations, e.g. Gadiet dam in Red Sea state and Rashid dam in Al-Gadarif state.

Hydrological consideration

Effective percolation dam sites share key characteristics:

- Permeable subsoil (e.g., sand, gravel) and fractured rock formations to allow deep percolation.
- Shallow aquifers (within 5–10 m depth) for quick impact on water tables.
- Moderate channel slopes and narrow valleys, ideal for concentrating flow and maximizing recharge.
- Minimal fine sediment input, as silt reduces infiltration rates over time.

Inappropriate siting, e.g., on impermeable clays or with high sediment loads, can lead to waterlogging or rapid silting, undermining performance

Design consideration

Structural design of the dam follows normal design philosophy for surface storage dams. However, the major difference are site location and outlet work. Percolation dams are situated in-streams with low sediment load. Early flood flows, which typically carry in desired organic material, bring in silt and high consternation suspended solids. These materials typically settle and create an undesirable blanket reducing recharge rate. Outlet works will be operated with purpose of passing. For the re-purposed dam, modification of existing dam designs are usually applied with focus on enhancing sediment management.

Sample design

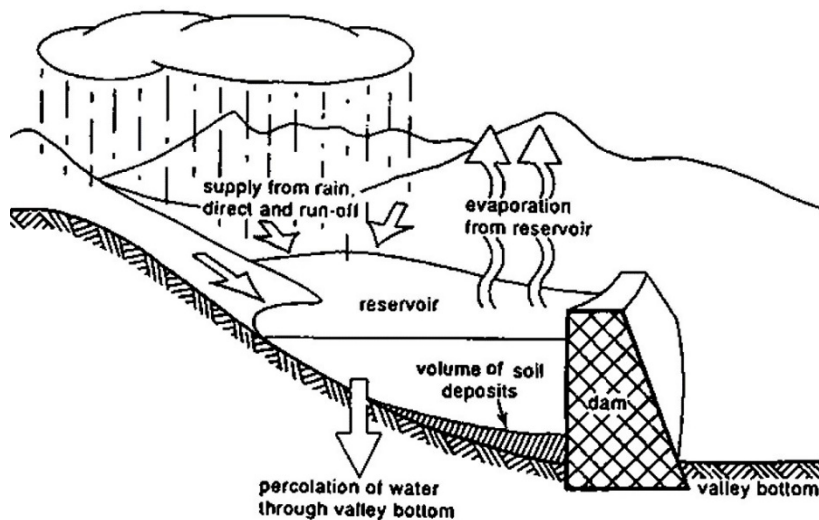


Figure 28, schematic overview of the workings of a percolation dam.

Water quality

Percolation through the soil naturally filters water, improving its clarity and reducing pathogen load. However, sediment-laden inflows can cause clogging. Over time, a silt layer or "sediment blanket" may form at the base of the impounded water, reducing infiltration and necessitating desilting operations. While the water quality of recharged aquifers is generally safe for livestock and domestic use, upstream pollution (e.g., from agriculture or waste dumping) should be avoided to prevent groundwater contamination.

Challenges

- **Sedimentation:** High sediment loads can reduce infiltration by forming an impermeable blanket at the base.
- **Improper siting:** Building on low-permeability soils or without assessing groundwater dynamics may result in negligible recharge.
- **Design limitations:** Many existing structures lack bottom outlets or sediment traps, complicating maintenance.
- **Institutional capacity:** Maintenance and monitoring are often minimal, especially where dams are managed at local or community level without technical support.
- **Terminological confusion:** Lack of awareness about the function of percolation dams leads to misclassification and underestimation of their benefits.

Uniqueness and comparison

Percolation dams uniquely prioritize infiltration over visible storage. Unlike hafirs or sand dams, they are designed to lose water to the ground, making them ideal for enhancing shallow groundwater recharge. They differ from recharge basins by combining embankment design with strategic seepage. Their suitability is highest where shallow aquifers are present, but direct abstraction is not feasible, and where evaporation losses from surface storage would be too high.

Climate change

Percolation dams provide a valuable contribution to resilience in areas where aquifers are shallow and rainfall is seasonal but intense. Their main benefit lies in enabling managed recharge of groundwater, particularly where conventional dams suffer from high evaporation or are unsuitable due to terrain. In Sudan, these structures are most effective in sandy or loamy soils found in parts of Sennar and Kordofan. NAPA

identifies aquifer recharge as a strategic need under climate stress. While percolation dams do not provide direct access to stored water, their role in stabilizing groundwater availability indirectly supports irrigation and domestic use, especially during the extended dry seasons now more common under climate change.

Feature infrastructure

Dorn Dorn Percolation Dam

Locality: Hamashkoraib

State: Kassala

Coordinates: 17.1585067, 36.7636771

The percolation dam was designed to recharge groundwater for the wellfields in the area and to contribute to flood control with a catchment area of 10 hectares. Cement, sand and rocks were used to construct the dam on the top of sandy soil. Adaptations were conducted after the initial construction of the dam. These involved raising the dam wall by an additional 2m, spillway rehabilitation and mesquite trees removal.

The dam area often experiences flooding events and the flood water occasionally exceeds the dam's capacity. However, the dam plays a crucial role maintaining the groundwater level for the wells that depends on it by ensuring consistent recharge of the water throughout the year. The main purposes for the dam construction were production improvement, reduce risks of disasters and prevent land and water degradation. The dam has successfully increased water availability, increased crop yields and elevated groundwater level.



Figure 30 Dorn Dorn during wet season. Source: Plan International



Figure 29 Dorn Dorn during dry season. source: field work 2024

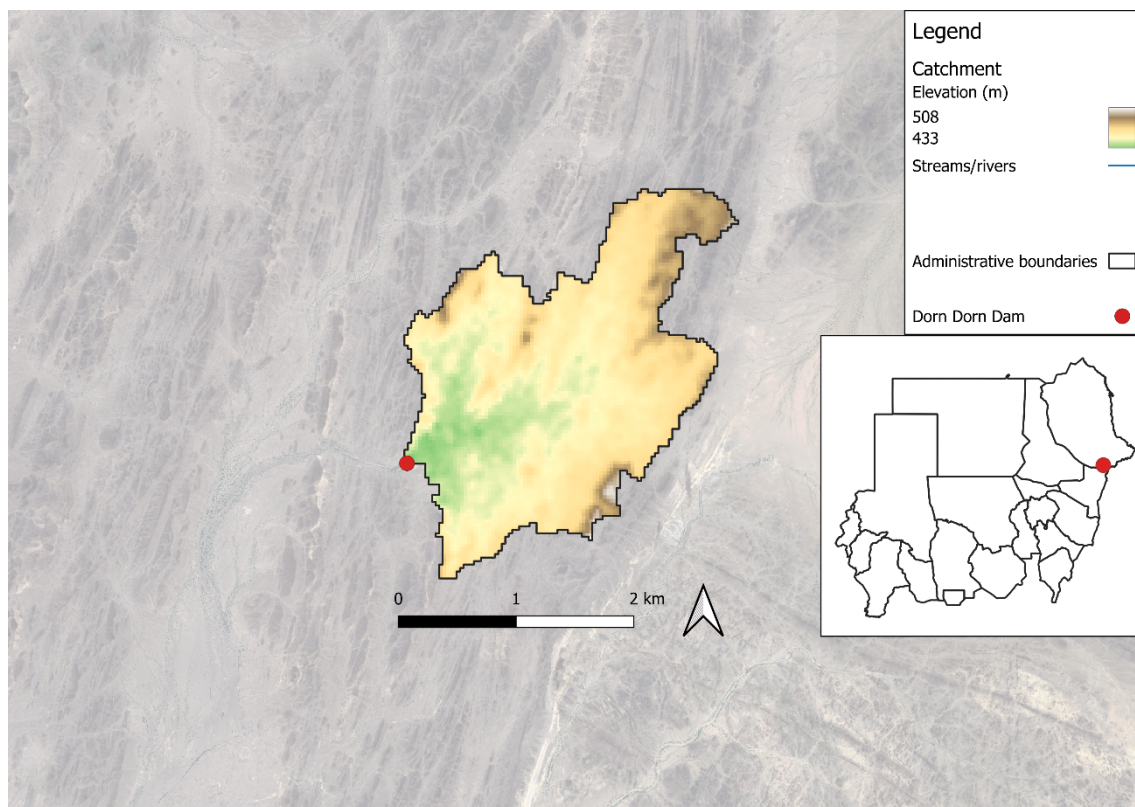


Figure 31, Map showing the catchment of the Dorn Dorn dam

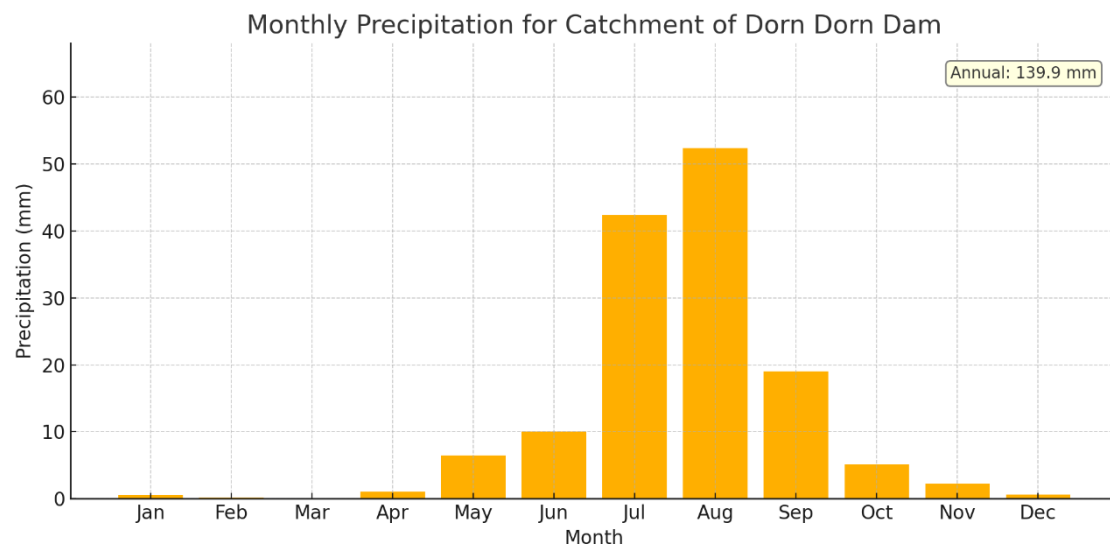


Figure 32, Monthly precipitation in the catchment of the Dorn Dorn dam. Data from cru cl2

Environmental suitability

The Dorn Dorn Percolation Dam, located at 16.7401°N, 36.0616°E, lies in a hyper-arid to semi-arid zone in North Darfur, receiving only 140 mm of annual rainfall, with nearly all precipitation falling during July and August. Despite this extremely low rainfall, the dam benefits from episodic flash floods during storm events, which are sufficient to trigger infiltration along short wadis and ephemeral streams.

The catchment area is small (~7.5 km²) but efficient, dominated by open rangeland (99%), which contributes to rapid runoff and minimal vegetative interception. These characteristics create conditions suitable for the percolation dam's purpose: to temporarily store floodwater and allow it to gradually seep into the fractured bedrock and shallow aquifers beneath the site.

Subsurface dam

A sub-surface dam consists of a vertical, impermeable barrier through a cross section of a sand- filled, seasonal riverbed. A ditch is dug at right angles across the river and into each bank, preferably where a rock dyke protrudes. This provides a solid, impermeable base onto which a simple masonry wall can be built within the trench. In some situations, the wall is raised gradually as sand from upstream accumulates behind the structure, forming a sand dam.

Water is taken out through a shallow well in the sand bed, or through a filter box, into a gravity pipe which runs through the dam to the point of use downstream. For water supply augmentation and soil conservation purposes, it is better to build a series of small dams along the same stream, rather than building one large dam. A sequence of small dams increases alluvial deposition and improves infiltration more than a single large dam.

Adoption

Subsurface dams were introduced in several regions over the past + 60 years with some still serving its purposes. One of the oldest subsurface dams are located in Tokar and Agig localities in the southern region and were introduced by rural drinking water corporation in early 1980s to increase groundwater recharge in enhance water quality by reducing salinity level. Over the past 10 years more subsurface dams in introduced in Kassla e.g. Darrasta subsurface dam, north Darfur and south Darfur mainly under zero thirst program, by the Federal Dam implementation Unit and the rural water for Sudan program under EU and UKAID.

Hydrological consideration

Effective subsurface dam sites must meet key conditions:

- Presence of a shallow alluvial aquifer composed of sand or gravel.
- An impermeable layer (bedrock) close to the surface to anchor the barrier.
- Narrow, confined valleys to limit dam length and reduce leakage risks.
- Sufficient aquifer recharge through seasonal floods.

Ideal riverbeds consist of permeable materials overlying rock, allowing high infiltration and storage capacity. Dams built in cascade further upstream enhance total groundwater volume and minimize leakage.

Structure Design

A typical subsurface dam consists of:

- A vertical impermeable wall, built within a trench excavated across the wadi, often using concrete or masonry. It must reach the underlying bedrock and extend into both banks to fully obstruct subsurface flow.
- Upstream sediment traps, in some designs, help maintain water quality and reduce clogging.
- Wells or collector drains placed upstream in the alluvium allow for water abstraction.
- Overflow and spill protection is generally not needed as water does not visibly accumulate above ground.

Standard small dams may store up to 10,000 m³ of water, with dimensions of 4 m depth, 50 m width, and 500 m length. Larger installations can exceed 100,000 m³ of storage

Sample design

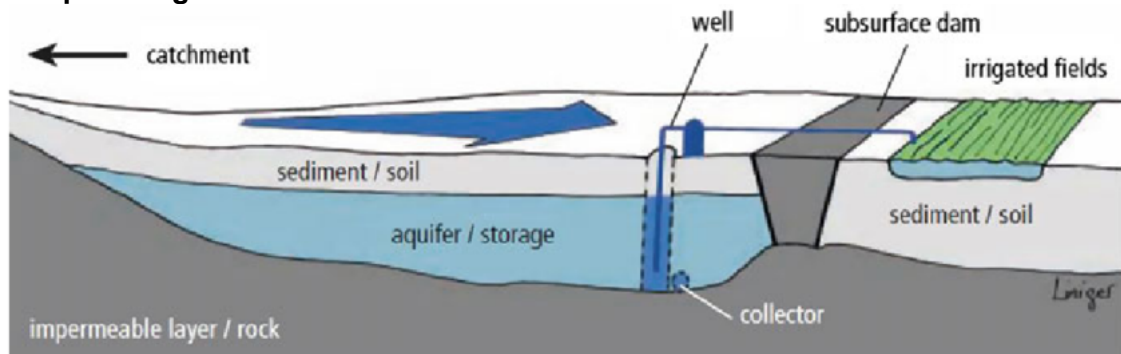


Figure 33, Schematic design of a subsurface dam. Source: Studer & Liniger (2013).

Water quality

Subsurface storage protects water from:

- **Contamination**, as water is less exposed to livestock or human activity.
- **Vector breeding**, since there is no surface pooling to host mosquitoes.

However, if improperly located in saline or contaminated aquifers, water quality may suffer. Periodic groundwater monitoring is recommended to avoid salinization or microbial contamination, especially where recharge is from polluted surface runoff

Challenges

- Site selection: Requires hydrogeological expertise to ensure sufficient recharge and to locate suitable impermeable strata.
- Construction complexity: Building below the surface and into rock demands more advanced engineering and sometimes heavy machinery.
- Low-yielding abstraction: Poor design may limit water delivery, especially without proper collector systems.
- Community engagement: Success depends on long-term use and maintenance; lack of ownership can reduce sustainability.

Uniqueness and Comparison

Subsurface dams are unique in being entirely below the surface, capturing invisible subsurface flows. Unlike sand dams, they do not depend on sediment deposition and can store water even in fine or variable soils. Compared to percolation dams, they do not recharge but retain existing baseflow. Subsurface dams are preferable where evaporation and contamination risks are high, or where communities lack water access, but the geology supports alluvial storage.

Climate change

Subsurface dams are among the most climate-resilient water harvesting options available for Sudan's sandy and gravel-filled wadis, particularly in northern and western regions where surface water retention is difficult. These structures create a hidden water buffer that avoids evaporation, protects quality, and maintains supply during droughts. Their strength lies in combining storage with minimal land disturbance, making them well-suited for mobile pastoral systems and dispersed rural settlements. Sudan's NAPA encourages the use of such low-visibility, low-loss structures in regions where climate variability undermines both aquifer recharge and water accessibility.

Subsurface dams may require more technical input initially, but they offer long-term resilience benefits where properly sited.

Feature infrastructure

Darrasta Subsurface dam

Locality: Telkok

State: Kassala

Coordinates: Located in 17.1585067, 36.7636771

The subsurface dam is located near Darrasta village and it holds the water coming from an upstream khor. The dam was built within the last decade through external interventions with a total area of 0.10 square kilometer covered by in-situ water harvesting. It was constructed on the top of sandy soil from cement with dimensions of 120m length and 2m depth. The construction of the dam successfully improved production, boosted water availability, elevated groundwater level and enhanced downstream water availability.



Figure 34 Darrasta Subsurface dam. Source: Field work 2024

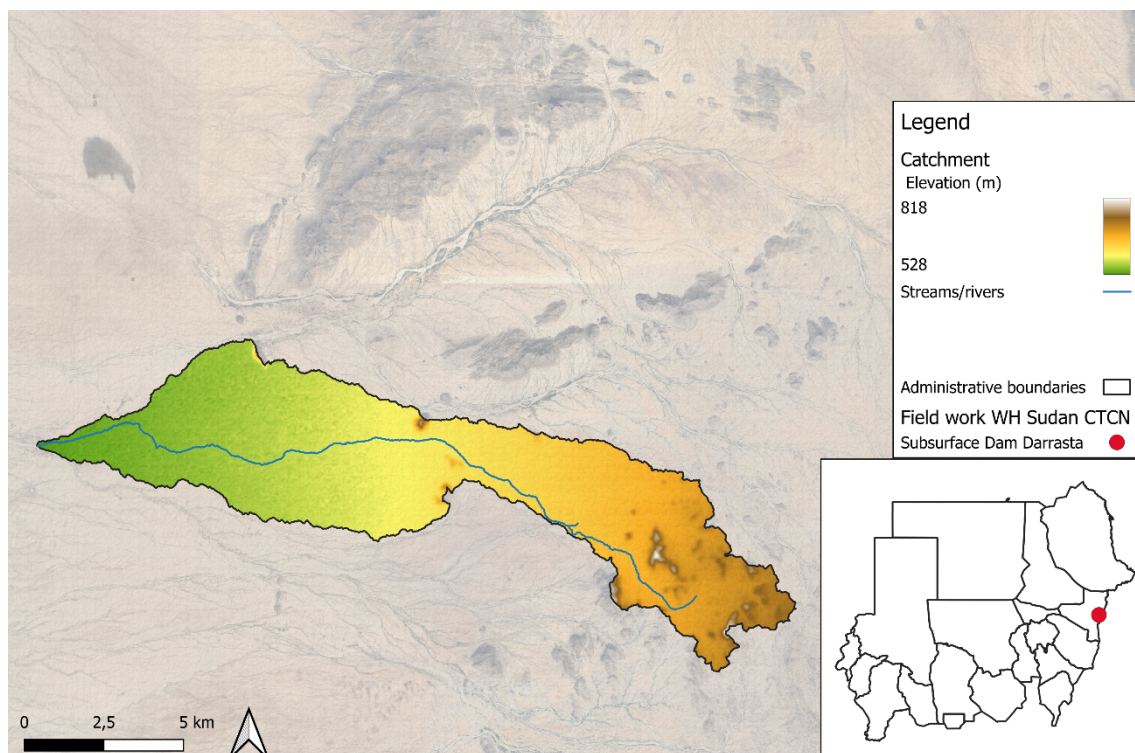


Figure 35, Map showing the catchment of the Darrasta subsurface dam

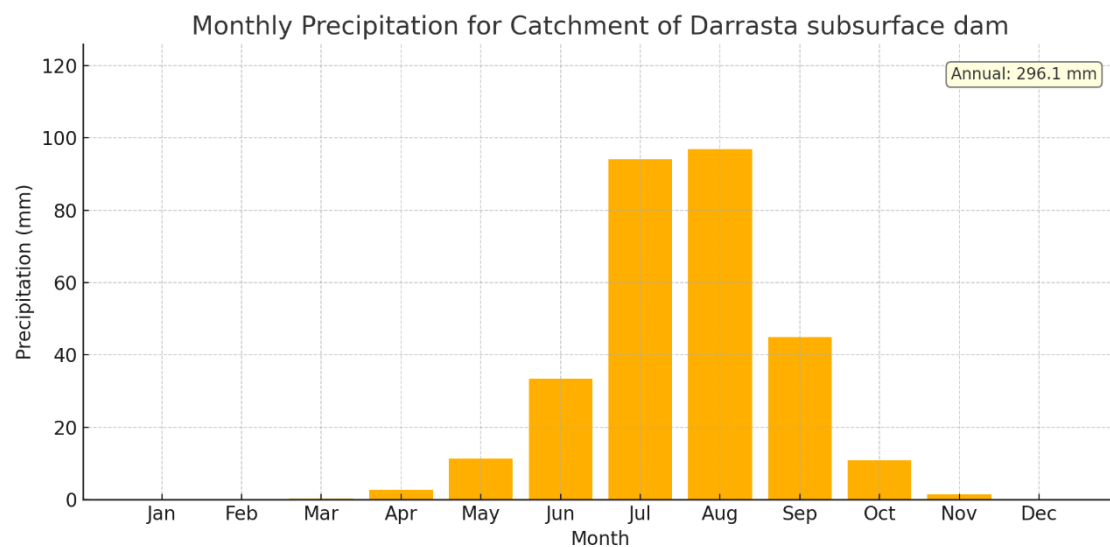


Figure 36, Monthly precipitation in the catchment of the Darrasta subsurface dam. Data from cru cl2

Environmental suitability

The Darrasta Subsurface Dam, located at 17.1585°N, 36.7637°E in Kassala State, receives an average annual rainfall of 296.3 mm, with the vast majority concentrated in July and August, as shown in Figure 36. This brief, intense rainy season is characteristic of eastern Sudan and supports episodic but substantial runoff flows in seasonal streams. The catchment area is approximately 82 km², and land use is predominantly rangeland (99%), which supports moderate runoff generation due to limited vegetative cover. The dam is built within a seasonal streambed (wadi), a setting that aligns with subsurface dam design principles: intercepting and storing subsurface water flow within the channel sediments.

By storing water underground, the structure helps reduce evaporation losses and maintain water availability beyond the rainy season. Water is accessed via shallow wells located upstream of the dam.

Recharge basin

Recharge basins is the use of infiltration basins or injection/infiltration wells to recharge groundwater resources. The concept is to collect rainwater typically from roofs, rock surfaces or established catchment areas and lead it towards the preferable well via a filtering arrangement. The filtering arrangement or the storage time in the aquifer normally is sufficient to assure water of drinking quality at the point of abstraction (borehole or open well). Widely used now in urban settings but also used in rural areas throughout the world as a traditional approach as well as institutionally well accepted additional water supply structures.

Artificial recharge may be defined as the process of replenishing groundwater by augmenting the natural infiltration of rainwater or surface water into underground formations through various methods designed depending on the topographic, geologic and soil conditions.

Adoption

Hydrological consideration

Recharge basins function best in locations with:

- **Permeable sandy or loamy soils** to allow rapid infiltration,
- **Shallow aquifers**, typically within 5–10 meters of the surface,
- **Flat terrain** to retain floodwater without requiring large embankments.

Potential constraints include clogging due to fine sediment deposition and waterlogging in areas with shallow impermeable layers. Therefore, site selection must involve careful assessment of geological structure, soil texture, and existing groundwater conditions

Structure Design

A recharge basin generally includes the following components:

- **Main infiltration basin:** excavated or delineated area where water is retained for slow percolation.
- **Inlet channel:** directs water from catchments, such as irrigation drains or stormwater systems.
- **Sediment settling basin:** reduces siltation and prolongs infiltration capacity.
- **Embankments:** may be required for water retention depending on the topography.

Recharge structures can be sized based on expected inflow, local infiltration rates, and groundwater storage goals. Maintenance of the basin bottom and desilting are essential for sustained performance

Water quality

As water infiltrates through unsaturated soil layers, sediment and contaminants are naturally filtered. This biological and physical filtration process significantly improves water quality, particularly for drinking and irrigation. However, caution is needed when recharge sources include urban runoff or agricultural effluents. High turbidity or pollutants may clog soil pores or degrade aquifer quality. Protective measures such as settling tanks, exclusion of first flush runoff, or buffer zones can enhance safety and efficiency

Challenges

- **Sedimentation and Clogging:** Fine particles settle in the basin and reduce infiltration. Regular desilting or upstream settling structures are necessary.

- Land Requirements: Recharge basins require large, flat areas not in productive use.
- Maintenance Burden: Without regular upkeep, infiltration rates drop rapidly.
- Contamination Risks: Infiltration of untreated runoff can introduce pollutants to the aquifer.
- Institutional Oversight: Success requires coordination between users, local governments, and water resource managers

Uniqueness and Comparison

Recharge basins are unique for their large infiltration surfaces that receive diverted water from irrigation drains, stormwater, or floods. Unlike percolation dams or check dams, they do not block flows but instead capture and spread them for infiltration. Their suitability is high in irrigation tail ends, urban runoff zones, or dry riverbeds, where controlled recharge and sediment management are feasible. Compared to structures like subsurface dams, they require more space but offer visual monitoring and scalable recharge.

Climate change

Recharge basins are most effective in semi-arid zones with permeable soils and declining shallow aquifers, conditions found in North Kordofan and parts of eastern Sudan. By capturing and infiltrating stormwater, these basins transform episodic rainfall into a steady groundwater resource. Their contribution to resilience is indirect but significant: they help maintain dry-season well yields and reduce dependency on unpredictable surface water. As outlined in the NAPA, recharge-based strategies are essential for bridging the gap between increasingly intense rainy seasons and extended dry periods. Recharge basins are especially promising when linked to water user associations and protected from sedimentation by upstream filters.

Feature infrastructure

Matatieb Recharge Basin

Locality: North Delta

State: Kassala

Coordinates: in 18.59541, 36.757224

The structure lies in the end of Matatieb block of Algash Spate Irrigation scheme, and it receives drainage of the upstream irrigation plots. The residual flow is diverted into the open basin and infiltrate gradually into the water bearing coarse sand layer with 7-meter depth.

The structure was repurposed in the 1965 and has been supporting nearby shallow wells with groundwater recharge for most of the year. To help reduce the sediment load, hence, increase the recharge rate, a cascading settling basin were constructed in 2020. The pilot have helped reducing almost 86% of the sediment load encouraging replication in similar structures across Algash Scheme.

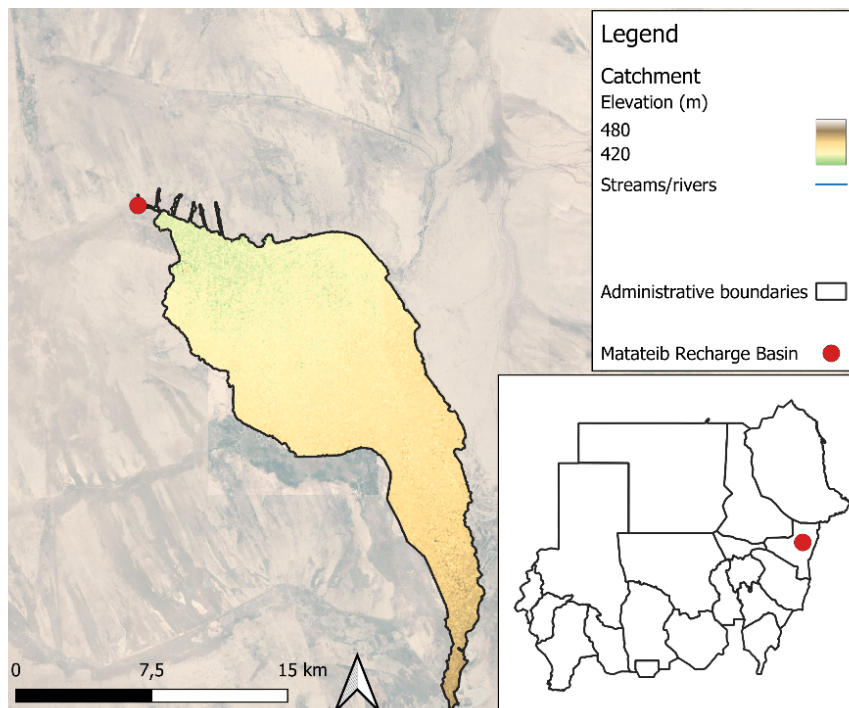


Figure 39, Map showing the catchment of the Matateib recharge basin

Catchment size: 188.5 km²

Land use: 77% rangeland, 12.5% trees, 9% crops, 1% bare ground/built up area.



Figure 38 Matateib during wet season. Source: Plan International



Figure 37 Matateib recharge basin during dry season. Source: field work 2024

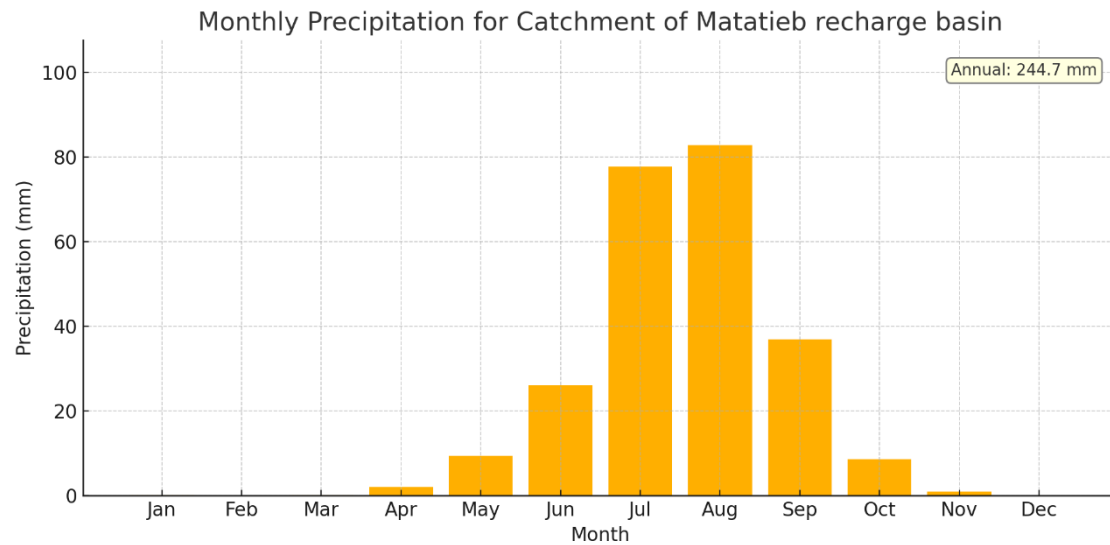


Figure 40, Monthly precipitation in the catchment of the Matateib recharge basin. Data from cru cl2

Environmental suitability

The catchment area is 188.5 km², and land use is a mix of 77% rangeland, 12.5% trees, and 9% crops, with only 1% built-up or bare land. This diversity supports both natural recharge and the potential for surrounding agricultural benefit. The site overlays a coarse sand aquifer at a depth of 7 meters, which is highly permeable and suitable for infiltration-based recharge.

The basin's suitability is enhanced by the 2020 addition of a cascading settling basin, which successfully reduced sediment load by 86%, maintaining infiltration performance and enabling year-round water availability in nearby shallow wells. This controlled sedimentation setup significantly distinguishes the site from more erosion-prone recharge structures.

Check dams

Introduction

Check dams are transverse engineering structures of different size and height, made of various materials such as concrete blocks, loose rocks, rocks in gabion baskets or wood. They are built across torrents, gullies and streams that may be ephemeral or not. Check dams control soil erosion, moderate water and sediment flows, and can improve land (McGraw-Hill, 2003). These engineering structures have a long history of use in general watershed restoration, erosion mitigation, and soil conservation. Check dams are small barriers placed in gulleys and are designed to capture sediment and limit erosion. They are smaller than sand dams and unlike sand dams; they allow water to trickle through them.

Adoption

Hydrological consideration

Check dams are most effective in:

- Ephemeral riverbeds or gullies with coarse alluvial material.
- Shallow aquifers where increased recharge can be observed within a few meters of the riverbed.
- Moderate slopes, ideally between 2% and 10%, to allow sediment trapping without excessive backwater pooling.

Hydrogeological assessments are essential to ensure that the site has adequate infiltration potential and won't cause waterlogging or backflooding.

Structure Design

The design of check dams is highly site-specific but generally follows these principles:

- Height: Typically ranges from 1 to 3 meters, depending on gully depth and gradient.
- Width: Matches gully width; crest width is commonly 2 meters.
- Materials: May include loose stone, gabions, or concrete, often reinforced with steel rods in semi-permanent installations.
- Side Slopes: Commonly designed at 1V:3H downstream and 1V:1H upstream for stability and accessibility.
- Foundation: Keyed into the streambed to a depth of 0.5–1 meter, depending on substrate.
- Spacing: Determined such that the base of the upstream dam is at the crest level of the downstream dam, ensuring sequential flow and sediment trapping.

Cascading design is preferred in longer valleys, as the first dam acts as a reference for calculating spacing and managing flow. Sediment-laden flows are intercepted upstream while cleaner water infiltrates downstream.

Sample design

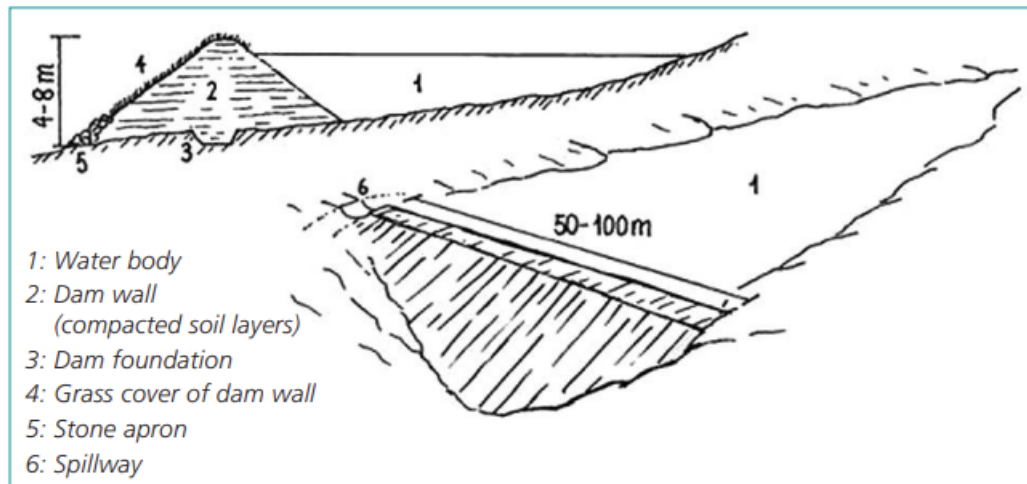


Figure 41, Small earth dam. source: Liniger et al., (2011)

Challenges

- **Sedimentation**: While check dams trap sediment intentionally, over-accumulation can reduce capacity and redirect flows unless regularly desilted.
- **Structural Integrity**: Poor construction (e.g., lack of proper foundations or energy dissipators) can lead to dam failure.
- **Backwater Effects**: Improper design can cause localized flooding, waterlogging, or erosion upstream.
- **Maintenance**: Community ownership is often needed, but long-term maintenance plans and funding are frequently lacking.

Uniqueness and comparison

Check dams are multipurpose: they reduce erosion, trap sediment, and recharge groundwater. What makes them distinct is their flexibility in size, material, and use across landscapes. Compared to sand dams, they are less reliant on sediment transport, and unlike percolation dams, they may have visible storage. They're best used in gully systems or degraded uplands, often as precursors to vegetative restoration or as part of cascaded recharge systems in upland watersheds.

Climate change

Check dams serve as an important tool for controlling gully erosion and rehabilitating degraded land, key issues in Sudan's NAPA. Their role in climate resilience is especially strong in agro-pastoral zones where soil degradation undermines rainfed agriculture and grazing capacity. By reducing runoff speed and promoting sediment deposition, check dams not only stabilize landscapes but also improve infiltration, boosting soil moisture retention and groundwater recharge. In regions like the Butana plateau and South Darfur, where rainfall extremes are intensifying, check dams help buffer communities against both floods and droughts. Their effectiveness depends on maintenance and correct placement but is high when used strategically.

Feature infrastructure

Umsenibra Check Dams

Locality: Algabalt Alshargiya

State: Al Gadarif

The structure was implemented in 2018 by a participatory effort from the community and technical support from local contractor and funding from Rural Water For Sudan. The check dams were constructed in cascading approach targeting six small streams in the Umsenibra hills which all form small upper sub-catchment to the village 3 open dug wells. The dug wells have suffered from continuous drawdown over the past 30 years. Prior to this, the wells were forming natural spring during the rainy season, when baseflow contribution raised groundwater level above the natural ground level.

The structures were built using gabion check dams with an elevation of 2 meters and width not exceeding 10 meters. Despite the small size of the temporary reservoir created by the check dams, the check dams have a significant impact on groundwater recharge. During the first season of implementation, the water table increased by 4 meters to 7 meters in each of the downstream dug wells. The community reported an overall satisfaction as the wells continued to supply water as late as June of the following year at a significantly high-water level. This has reduced the financial pressure on community, as they used to purchase water from surrounding areas relying on expensive water vendors.



Figure 42 Umsenibra check dam

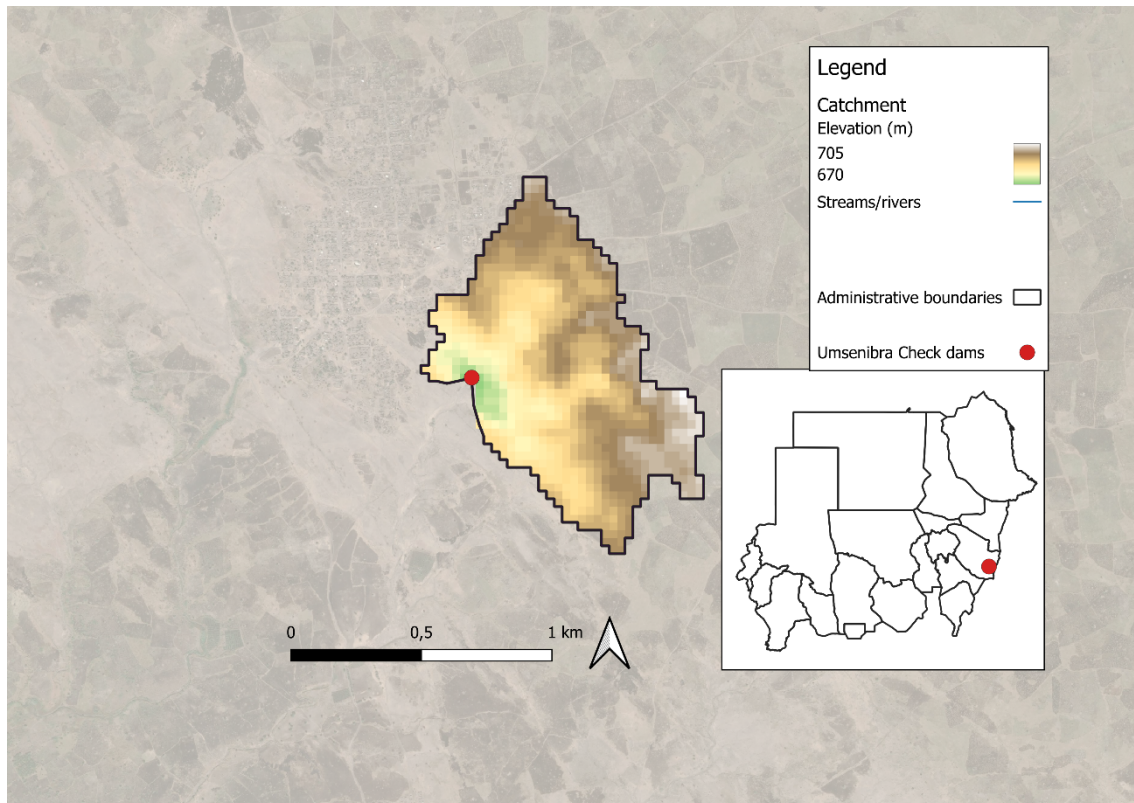


Figure 43, Map showing the catchment of the Umsenibra check dams

Catchment size: around 1km²

Land-use: 90% rangeland, 5% crops, 4% bare ground.

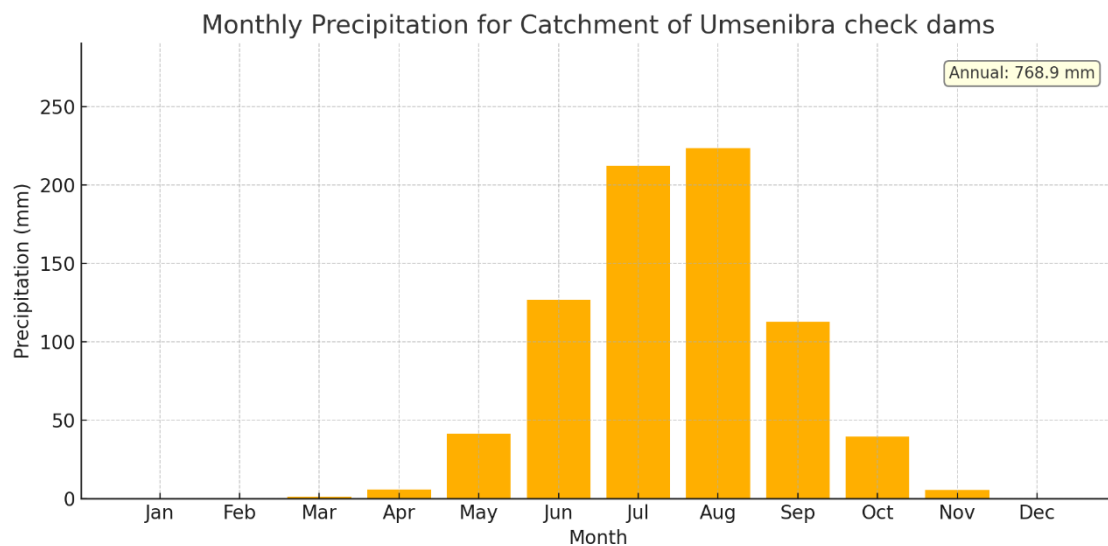


Figure 44, Monthly precipitation in the catchment of the Umsenibra check dams. Data from cru cl2

Environmental suitability

The Umsenibra Check Dams, located in South Darfur, are situated in a relatively wet part of Sudan's semi-arid belt. The site receives 768.3 mm of annual rainfall, with peak precipitation during July and August. The surrounding land is primarily rangeland, with seasonal flows occurring in incised gullies. These characteristics make the site well suited to check dam installation, which is designed to reduce flow velocity, trap

sediment, and improve soil moisture retention. The steep terrain and episodic high-energy runoff events necessitate physical stabilization measures like these to prevent further degradation.

This context differs significantly from that of drier regions where other interventions like sand or subsurface dams are used. In Umsenibra:

- The higher rainfall ensures more regular flow events for the dams to intercept.
- The gully system offers a natural setting for staged or cascading check dams.
- The intervention supports both soil stabilization and shallow infiltration, rather than large-scale water storage or aquifer recharge

Rocky (Mountainous) Catchment

Introduction:

Rock catchments are simple systems for the collection of rainwater. The placement of these structures should take into account ease of access of the users and the geological structure of the site. The best sites are found on the lower reaches of bare rock (without fractures or cracks), where runoff losses to the soil, vegetation and structures is minimized. The retention of runoff is made in natural hollows or a valley which is made into reservoirs by constructing a simple masonry wall. The reservoir should have a relative high depth to surface ratio to minimize evaporation.

Stone and mortar gutters may be built across the rock face to channel the runoff into the dam. Storage may be provided in dams or open tanks. Other surfaces can also be used as catchment – e.g. concrete, plastic sheets, treated soils etc.

Rock catchments are the most economical and reliable water source in ASAL and desert regions with saline groundwater, low rainfall, no rivers and large rock outcrops, because small rain showers falling on large rocks can provide huge volumes of run-off water.

Usually, rock catchments are built and used by self-help communities. It is a labor-intensive work to construct rock catchments sufficient large to supply water for many households throughout dry seasons. Most rock catchments have been constructed during droughts when the demand for water is highest and work in field at is lowest, which is the best combination for communal labor-intensive activities. Food-for-Work programs are also very suitable for construction of rock catchments.

Adoption

Hydrological consideration

Ideal locations for rocky catchment systems include:

- Bare, impermeable rock outcrops with minimal fracturing, allowing maximum surface runoff and minimal infiltration losses.
- Natural depressions or small valleys to reduce the need for engineered storage.
- Moderate to steep slopes to promote overland flow.
- Absence of vegetation and soil cover, which would otherwise intercept rainfall.

The main advantage is the high runoff coefficient of clean rock surfaces, therefore over 80% of rainfall can be harvested. However, careful siting is required to avoid fractured rocks that could allow seepage losses or structural instability

Structure Design

The design of rocky catchment systems generally includes:

- Runoff collection surface: A bare rock face with a well-defined drainage path.
- Stone or masonry gutters: Built across the rock face to intercept and channel runoff toward a storage structure.
- Storage reservoir: Constructed in a natural hollow or valley, retained with a masonry or concrete wall. The reservoir should have a high depth-to-surface-area ratio to minimize evaporation losses.
- Optional surface treatments: In the absence of rock, other impervious surfaces like compacted clay, concrete, or plastic sheeting may be used to replicate the runoff effect.

Where natural slope is insufficient, artificial bunds may be constructed to redirect flow. In some designs, multiple rock surfaces feed a shared tank through a network of lined channels

Sample design

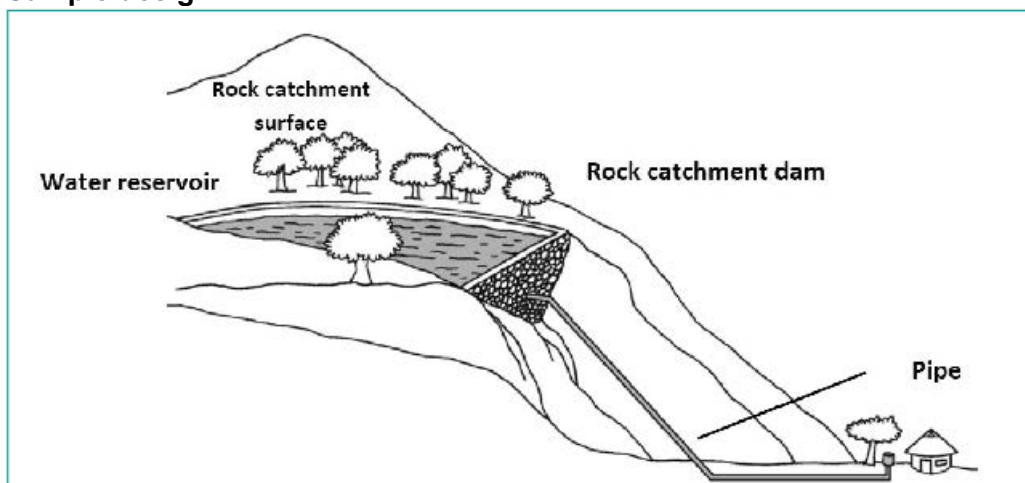


Figure 45, Rock catchment dam. Source: Clements et al., 2011.

Water quality

Water from rock catchments is typically of good physical quality due to minimal sediment and turbidity, especially if stored in covered tanks. However, initial runoff may contain debris or contaminants from bird droppings and dust accumulation. As such, installing a first-flush diversion system is recommended to discharge the initial contaminated runoff. Covering reservoirs or using underground cisterns can reduce contamination and limit mosquito breeding.

Challenges

- Evaporation Losses: Open reservoirs in hot, windy areas lose water rapidly; hence, deep tanks or covers are preferred.
- Sediment Build-up: Although minimal on rock surfaces, occasional cleaning of gutters and reservoirs is required.
- High Labor Input: Construction is labor-intensive, particularly for large catchments or high-capacity tanks.
- Fragility in Fractured Zones: Cracks in rock can reduce water yield through percolation losses.
- Limited Storage Volume: These systems are not suitable for large-scale irrigation or livestock; they are best used for household-level water security.

Uniqueness and comparison

Rock catchments are unique in harvesting runoff from impermeable rock outcrops without requiring constructed catchments. Unlike bunds, terraces, or dams, they use natural topography as a collection surface. Water is typically stored in lined cisterns or masonry tanks, and evaporation is minimized by storage method, not site design. They are ideal in mountainous or granitic areas with no shallow aquifer, where rainfall is sparse but rock exposure is high, and community needs are domestic and seasonal.

Climate change

Rock catchments, natural or engineered systems that harvest rainwater runoff from exposed rock surfaces, offer localized, low-maintenance water supply solutions, especially in hilly or rocky terrain. In Sudan, these systems are most applicable in highland areas of the Red Sea State and parts of South Kordofan, where impermeable rock outcrops are common and communities often face acute dry-season water

shortages. Their contribution to climate resilience is generally modest and highly site-specific: while they provide important relief in isolated settlements lacking surface or groundwater access, their storage capacity is limited and heavily dependent on rainfall frequency. Under the more erratic and intense rainfall conditions projected for Sudan, rock catchments can play a complementary role, buffering short-term water scarcity for domestic use, but they are not sufficient to support agriculture or livestock at scale. As noted in the NAPA, integrating such micro-scale solutions into broader catchment-level water strategies is key for their sustainable contribution to resilience.

Feature infrastructure

Al fao Mountainous pond

Locality: Al-Fao

State: Al Gadarif

The mountainous storage pond of Alfao is one of the city's landmarks, with its noticeable location on the Alfao mountain and along Algadairf Madani National Road. The pond stores more than 40,000 m³ annually and is famous for its ability to last long through summer season (sometimes for the whole year). The mountainous area in Alfao forms steep slope catchments which generate considerable flow seasonally. A small low-level area was reshaped and proposed to form a storage pond at the mountain foot harvesting water and protecting from floods. Other small borrow pits were constructed along the hilly area and yielded promising storage characteristic.

The storage pond is mainly utilized for livestock drinking and for commercial purposes. There are no proper inlet or outlet system, and the water is typically pumped via temporary low-head pumps.



Figure 46 Alfao mountainous pond

The Al Fao Mountainous pond has no clear catchment that can be delineated remotely. Therefore the remote analysis was skipped.

Half-moon terraces

Introduction

Half-moon terracing is a technique to rearrange the soil in a way that water is better preserved. They are usually dug on gentle slopes and in areas that have less than 600 mm of rainfall per year. It is a semi-open mechanical structure with the shape of a half-circle that collects and holds runoff water and improves soil infiltration. Thus, it contributes to recovering and restoring the fertility of the encrusted soil for agronomic and agroforestry purposes.

Adoption

Hydrological consideration

Half-moon terraces are best suited to areas with gentle to moderate slopes (2–5%) where rainfall is low (200–600 mm/year) but often intense, leading to high runoff. The soils should have at least moderate infiltration capacity and sufficient depth to support root growth. In shallow, rocky, or very sandy soils, terrace performance can decline. The technique enhances local infiltration, raises soil moisture levels, and can contribute to shallow aquifer recharge by reducing rapid surface runoff and allowing more time for water infiltration .

Structure Design

Half-moon terraces are carefully designed semi-circular earth bunds constructed to open against the direction of water flow, facing upslope. Each terrace typically has a diameter ranging from 2 to 8 meters, although larger structures, reaching up to 12 meters in diameter, are sometimes used for the rehabilitation of extensive grazing areas. The bunds are built with compacted soil and have a base width between 40 and 80 centimetres and a height of approximately 30 to 50 centimetres, dimensions that provide enough strength to withstand runoff forces while enabling easy infiltration. The half-moons are laid out along a contour line, ensuring that their tips meet precisely at the same elevation to promote even water distribution. Terraces are organized in staggered rows down the slope so that any overflow from the upper row is captured by the terraces immediately downslope. The density and spacing of half-moons are adapted according to climatic conditions: in drier regions, larger terraces are constructed with greater spacing, while in zones with higher rainfall, smaller terraces are placed closer together. This design adaptation allows an optimized catchment-to-application area ratio (C:A ratio), typically between 1:1 and 3:1, ensuring that enough runoff is collected without causing waterlogging.

Soil excavation is carried out manually or with light machinery, and the excavated material is used to form the bunds. Good compaction during bund formation is critical to prevent breaching during high-intensity rain events. In some cases, a small planting pit is prepared in the centre of each half-moon to further concentrate water and facilitate the establishment of trees, shrubs, or grasses. Proper layout, bund compaction, and periodic maintenance are essential to the long-term success of half-moon terraces in restoring degraded land and enhancing vegetation cover.

Sample design

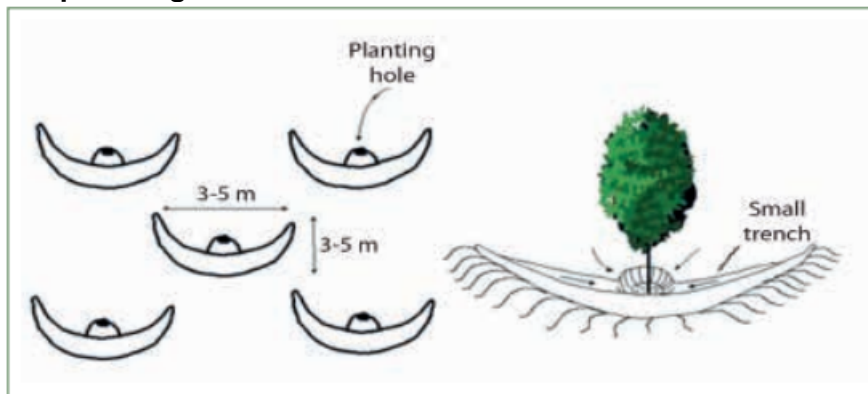


Figure 47, Sample design of a half moon bund (Mati, 2005)

Water quality

Half-moon terraces indirectly improve water quality by promoting infiltration rather than surface runoff, reducing erosion, and minimizing sediment transport. They reduce contaminants entering streams and can promote localized recharge of shallow aquifers with filtered water through the soil matrix.

However, water collected in the basins is primarily intended for plant growth, not direct human consumption. There is no significant risk of water quality deterioration from the terraces themselves, but stagnant water in poorly maintained basins could breed mosquitoes if not designed with proper infiltration capacity.

Challenges

- **Labor Intensive**: Large-scale construction requires significant manual labor, often only feasible through community mobilization or external support.
- **Maintenance**: Bunds can degrade over time due to livestock trampling, erosion, or collapse during intense rainfall events.
- **Soil Suitability**: Poorly structured soils (e.g., very sandy or heavy clay) may reduce terrace effectiveness.
- **Grazing Pressure**: If livestock access the site too early after establishment, they can damage bunds and inhibit vegetation recovery.

Uniqueness and comparison

Half-moon terraces are distinctive due to their individual plant-focused design, combining water harvesting with micro-rehabilitation. Unlike large-scale bunds or terraces that shape entire fields, half-moons collect runoff around individual plants, making them suitable for low-rainfall areas and degraded rangeland. Compared to eyebrow or crescent terraces, half-moons are easier to construct by hand and better adapted for pastoral landscapes or community restoration efforts where concentrated impact is needed on a small scale.

Climate change

Half-moon terraces are among the most effective soil and water conservation techniques for restoring degraded rangelands and supporting tree or fodder crop establishment in semi-arid zones. Their semicircular design captures rainfall and runoff, enhances infiltration, and retains soil moisture for extended periods, critical under Sudan's increasingly erratic rainfall and prolonged dry spells. In regions such as North Kordofan, Darfur, and the Butana plateau, where rainfall has become both less predictable and more intense, these structures help mitigate drought impacts and reduce surface runoff that would otherwise cause erosion. The NAPA prioritizes

rangeland rehabilitation and water conservation as central to climate adaptation in Sudan's drylands. Half-moon terraces align well with these goals, offering a low-cost, labor-intensive method suitable for community-based implementation. They support regeneration of vegetation, reduce livestock pressure on vulnerable areas, and contribute to long-term ecological and livelihood resilience, particularly when scaled up in conjunction with reseeding or agroforestry efforts.

Feature infrastructure

Mahala Half Moon Terraces

Locality: Algalbat Alshargiya

State: Al Gadarif

Coordinates:

The structure was implemented by Islamic Relief Worldwide (IRW) in 2019 in collaboration with the Mahala community in Gadarif State with the aim to capture rainwater and improve pastureland for livestock. Mahala, a hill surrounding five villages, had become unproductive due to erosion.

Half-moon terraces were implemented in relatively small sizes of curved clay and rock soil structures dug along the gentle slopes of Mahala hills where annual rainfall is around <400 mm/year). In total, the community implemented 12,000 micro terraces across 200 feddans, restoring the hill's greenery. The terraces captured rainwater, reduced soil erosion, and created viable pastureland. This project, the first of its kind in Gedaref State, also provided temporary jobs for over 400 locals.

The Mahala half moon terraces have such small microcatchments, that they cannot be delineated and analyzed remotely. Therefore the remote analysis was skipped.

(Crescent) Terraces

Introduction

One of the most effective actions that can take to mitigate the problem of an eroding slope is to break up the rate of water descent by constructing terraces. The terraces for water erosion control consist of some mechanism to protect land surface as well as to reduce the erosive velocity of runoff water. It involves some land surface modification for retention and safe disposal of rainfall.

A Terrace is an earth-embankment, constructed across the slope, to control runoff and minimize soil erosion. A terrace acts as an intercept to land slope and divides the sloping land surface into strips. In limited widths of strips, the slope length naturally available for runoff is reduced.

Adoption

Hydrogeological considerations

Terraces are effective in environments with:

- Slopes between 2% and 60%, depending on the type.
- Rainfall between 200–600 mm per year, especially in areas prone to intense, erosive rain.
- Medium to deep soils that can support excavation and retain moisture.
- Good drainage to avoid waterlogging behind bunds.

By shortening slope length and intercepting overland flow, terraces reduce erosion and enhance infiltration into the root zone. In semi-arid zones, they also slow water loss and extend the moisture availability period after rain events.

Structure design

Terrace types and construction depend on slope, rainfall, and land use goals. Common terrace forms include:

- Fanya juu (Kenya): Soil is dug from a downslope ditch and thrown upslope to form a bund. Ditches are typically 0.6 m deep and 0.6–0.75 m wide, while bunds are 0.4–0.5 m high. Spacing varies from 5–30 meters depending on slope.
- Forward-sloping bench terraces: Designed on 5–30% slopes, these collect runoff from adjacent upslope strips. Used mainly for tree crops.
- Eyebrow terraces: Small microcatchments (5–50 m²) designed to capture water for individual trees or bushes on slopes up to 50%. (see half-moon terraces)
- Crescent terraces: Semi-circular embankments used for revegetation or tree planting in degraded rangelands.

Bunds are typically stabilized with grass species (e.g., Napier or makarikari grass, but dependent on local indigenous species), and trees are often planted immediately above or below the bund depending on slope and runoff patterns

Sample design

Water quality

Terraces primarily improve soil water quality by reducing runoff and sediment transport, which in turn prevents downstream water body contamination. By enhancing infiltration and reducing erosion, terraces promote groundwater recharge with filtered, cleaner water. However, water retained behind terraces is not stored for direct use and thus does not typically pose quality risks.

Challenges

- High labor requirements: Terracing is one of the most labor-intensive techniques, particularly on steep slopes or degraded land.
- Maintenance: Annual bund rebuilding and vegetation trimming are needed to retain structure and function.
- Cost-benefit trade-offs: Benefits accrue over time and may not be immediate, discouraging investment without incentives.
- Limited mechanization: Most terrace systems are manually constructed and unsuitable for large-scale mechanized farming.
- Design errors: Incorrect spacing or alignment can result in back-cutting, bund collapse, or gully formation.

Uniqueness and comparison

Terraces are distinct for their dual function of water harvesting and soil erosion control. Unlike other technologies that store water, terraces retain water in the soil profile by reducing slope length and runoff speed. They're ideal for sloped agricultural lands, particularly where crops need more root-zone moisture. Compared to bunds or half-moons, terraces are more intensive and suited for permanent land cultivation rather than extensive grazing or tree planting.

Feature infrastructure

Hilaliyah Crescent Terraces

Locality: Rifi Kassala

State: Kassala

Coordinates:

Located in 15.3975845, 36.4785797

Hilaliyah crescent terraces is located in Selkay area near khor Abu-Alga. It was constructed in year 2019 through recent land user's innovation with a total area of 21 square kilometers covered with in-situ water harvesting and a catchment area of 10 HA.

It was constructed on top of silty soil foundation with dimensions of 70x70 wings, height of 1 meter and weight of 2 meter.

The construction of the dam has led to an increased sorghum sales which contributes in food security, and provides significant value to the local economy.

The main purpose of constructing the terraces was to improve agricultural production.

The on-site impacts of the wind and rain affects the technology by causing removal of terraces wings, which reduces its efficiency.



*Figure 49 Alhilalya crescent terraces during dry season.
Source: field work 2024*



*Figure 48 satellite imagery for Alhilalya crescent
terraces during wet season*

Conclusions

Water harvesting is an essential adaptation strategy for Sudan's increasingly variable and challenging climate. As this assessment illustrates, Sudan possesses a diverse and rich portfolio of traditional and modern water harvesting technologies—from ancient Hafirs and half-moon terraces to sand dams and recharge basins—each with distinct ecological, hydrological, and socio-economic roles.

This document demonstrates that no single solution is universally appropriate; rather, the effectiveness of a water harvesting technology depends on a complex interplay of factors, including local rainfall regimes, soil and geological conditions, land use, and community capacity. For example, sand and subsurface dams are highly effective in enhancing groundwater recharge in arid regions with seasonal streams, while water spreading weirs and percolation dams offer landscape-level benefits in semi-arid and agro-pastoral zones. Meanwhile, road water harvesting and rocky catchments exemplify the potential of repurposing infrastructure and leveraging natural topography to increase water availability at minimal additional cost.

Across technologies, a number of cross-cutting challenges persist: sedimentation, evaporation, insufficient maintenance, and lack of climate-informed designs undermine long-term performance. Climate projections suggest more intense and erratic rainfall patterns, higher temperatures, and prolonged dry spells—all trends that will exacerbate these existing vulnerabilities if left unaddressed.

At the same time, these challenges highlight the growing importance of investing in resilient water harvesting systems. Strategic upgrades to design standards, increased technical oversight, and integrated catchment-level planning can greatly enhance the sustainability and equity of water access. Furthermore, strengthening community ownership and improving institutional capacity—particularly for operation and maintenance—are critical to ensure that benefits endure over time.

Recommendations

Based on the assessment of representative water harvesting technologies and their performance across diverse Sudanese landscapes, the following recommendations are proposed to enhance the efficiency, sustainability, and climate resilience of water harvesting in Sudan:

1. Develop Climate-Informed Design Standards

- Update the design criteria of water harvesting structures to incorporate local climate projections, particularly regarding rainfall intensity, duration, and frequency and temperature/evaporation.
- Integrate design safeguards such as spillways, sediment traps, and evaporation control measures across all technologies.

2. Develop Tailored Technology Selection

- Develop and disseminate a decision-support tool or catalog that guides practitioners and planners in selecting suitable water harvesting technologies based on local conditions (e.g., rainfall, topography, land use, soil type).
- Promote hybrid systems that combine multiple technologies (e.g., sand dams with shallow wells, or terraces with vegetative barriers) for improved resilience.

3. Strengthen Maintenance and Operation Capacity

- Formalize operation and maintenance (O&M) responsibilities at local and state levels, ensuring that roles are clearly defined and supported by adequate funding.
- Provide targeted training to local technicians, community members, and government staff in routine maintenance, desilting, repair, and water quality monitoring.

4. Enhance Community Engagement and Ownership

- Ensure community involvement from project planning to post-construction phases to foster ownership, sustainability, and conflict mitigation.
- Support women's participation and leadership in water harvesting initiatives, especially in user associations and local water governance structures.

5. Improve Institutional Coordination

- Facilitate coordination between federal and state-level institutions to ensure consistency in design reviews, monitoring protocols, and data sharing.
- Promote intersectoral collaboration among agriculture, water resources, environment, and rural development ministries.

6. Invest in Monitoring and Impact Evaluation

- Establish standardized monitoring systems for evaluating water harvesting impacts on water availability, groundwater recharge, vegetation recovery, and livelihoods.
- Encourage the use of remote sensing, field-based hydrological assessments, and participatory evaluation tools to ensure data-driven decision-making.

7. Scale Up Proven Models

- Prioritize replication and scaling of successful pilot sites such as the Matatieb recharge basin, Girgir water spreading weir, and Baba sand dam, with adjustments based on lessons learned.

8. Support Research and Innovation

- Promote applied research on emerging technologies (e.g., geomembrane-lined Hafirs, smart sediment management) and context-specific innovations.
- Strengthen partnerships between research institutes, universities, and practitioners for adaptive learning and co-development of solutions.

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