From Clouds to Communities: A Spotlight on Rainwater Harvesting in Syria

Save_**Tigris**

About Save the Tigris Foundation

Save The Tigris is a civil society advocacy platform aiming to promote water justice in the Mesopotamian basin. Save the Tigris seeks to link groups and movements from Iraq, Türkiye, Syria and Iran concerned with the protection of the Tigris and Euphrates Rivers.

Our platform provides international solidarity and supports the exchange of knowledge. We advocate for policies that secure ecological justice including the equitable and democratic use of water for all who live in the Mesopotamian region, promoting water as a tool for peace.

savethetigris.org

All images and maps acknowledged in the notes of this report. Cover image by Toon Bijnens, Save the Tigris.

For comments and clarifications please contact: coordinator@savethetigris.org

Produced by: Hiba Mohammad.

Executive summary

Syria has been suffering from a severe drought since the later months of 2020.

This current drought is unfolding in a nation whose agricultural capacity has already been devastated by decades of agricultural and water mismanagement, as well as an 11-year conflict, leaving it less prepared to deal with a drought than at any other moment in its modern history.

Syria's crop land may have reached a tipping point because of prolonged agricultural failure, to the point that it is incapable, or at least straining, to recover from times of deficit rainfall.

In the context of this dire agricultural disaster that this drought is causing and intensifying, we discuss the importance of Rainwater Harvesting to tackle drought and water scarcity conditions.

With an objective to highlight the research on Rainwater Harvesting done in Syria, we review the literature written solely in Arabic to get glimpse of the interest on rainwater harvesting in Syria.

The research shows an increasing interest on rainwater harvesting in different regions of Syria, where 60% of the land receives less than 250 mm of rainfall annually, and 55% of the land is considered a rangeland (badia) that is of a dire need to efficiently harvest every drop of rain.

Only 23.25% of Syria's planted land is irrigated; the rest is rain-fed. Although the country is definitely in the grip of a drought, threatening rain-fed crops, may Syria's irrigated fields offer a type of agricultural lifeline? This seems to be out of the question.

Our message is to promote the utilization of rainwater harvesting in Syria for the sake of tackling societal issues (migration and displacement) associated with drought spells by empowering local communities, fostering connections, and unifying knowledge to assure that no one is left behind as foreseen by SDGs.

Hiba Mohammad
Ph.D Candidate, UniBS, Brescia, Italy.
Sustainable Water Resources Management in Large River Basins
hibamohammad388@yahoo.de

Table of contens

Water and Agriculture in Syria: A Crisis On The Horizon?

Syria: 7th on a global risk index of 191 countries most vulnerable to a humanitarian or natural catastrophic event that might exhaust response capability, owing in part to the continuing war, which impedes appropriate preparatory measures.

3rd most likely among the nine countries at "very high risk" of drought[1].

Precipitation rates over 2020 decreased by 50-70% depending on the province.

80% of Syria's rain-fed wheat fields in 2021, usually half of the country's total wheat fields, were not planted due to the lack of rainfall in 2020.

This left 40% of Syria's total wheat fields lying fallow in 2021.

> *"Syria has not seen such a drought in years. In previous years, drought was witnessed in one or two provinces only, while this year, all provinces have been affected, which severely impacted agriculture. Winter crops, namely wheat and barley, whose production is strategic, were very much affected, especially in rain-fed areas."*

Mohammed Hassan Qatana, 2021[2]
Syrian Agriculture and Agrarian Reform Minister

The UN Food and Agriculture Organization's (FAO) Historic Drought Frequency over 1984-2021 as defined by the Agricultural Stress Index (ASI), illustrates the frequency of severe drought in places where 30% of cultivated land has been hampered, provides a more precise data measurement (Figure 1).

The vast majority of the northeast region of Syria was characterized by regular drought occurrences with a severity more than 10%, as illustrated in the map below.

Obviously, this suggests that the wheat and barley harvests have been and will continue to be severely impacted by dry periods.

Moreover, the FAO's Annual Agricultural Stress Index (ASI) depicts the percentage of arable land, within an administrative area, that has been affected by drought conditions over the entire cropping season. As shown below by the annual summary of ASI maps (2010-2021), even though the 2021 drought was one of the worst droughts ever, it was also at least the fourth worse year for rainfall in the last 10

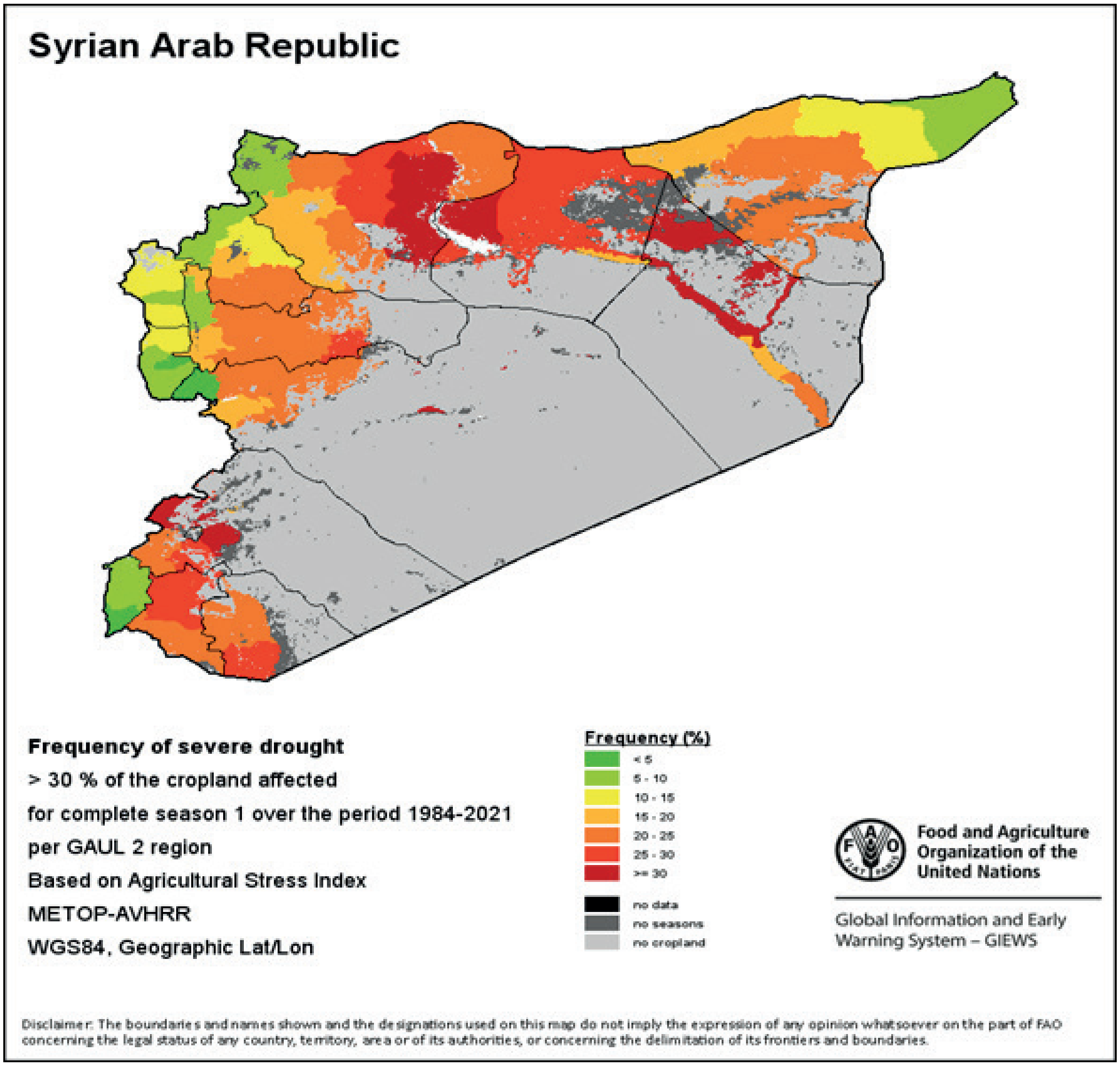


Figure 1. Historic Drought Frequency, 1984-2021, FAO. Source: FAO.

years. This has left farmers with a lot of unrealized input costs and not much ability to handle another harvest lost.

These events were claimed to have a significant effect on internal migration, water availability, and crop failure[3] (Figure 2).

Syria is one of the world's most water-stressed countries, with an estimated renewable water resource of 16.8 km³ per year and 72.36% dependency ratio[4] in 2003[5]. Water scarcity is driven primarily by the climatic conditions and socioeconomic factors related to the increased population growth.

More than **60%** of the country receives less than 250 mm/year. The annual rainfall declines from 900 mm in the coast to 60 mm in the eastern regions[6].

Syria can be divided into seven main water basins (Figure 3): Barada and Awaj, Al-Yarmouk, Orontes, Tigris and Khabour, Euphrates and Aleppo, Desert, and the Coastal Basin[7]. The Al-Assad Lake is the largest (674 km²), while Masada is the smallest (1 km²). Syria has one big dam (Euphrates), seven medium dams (Al-

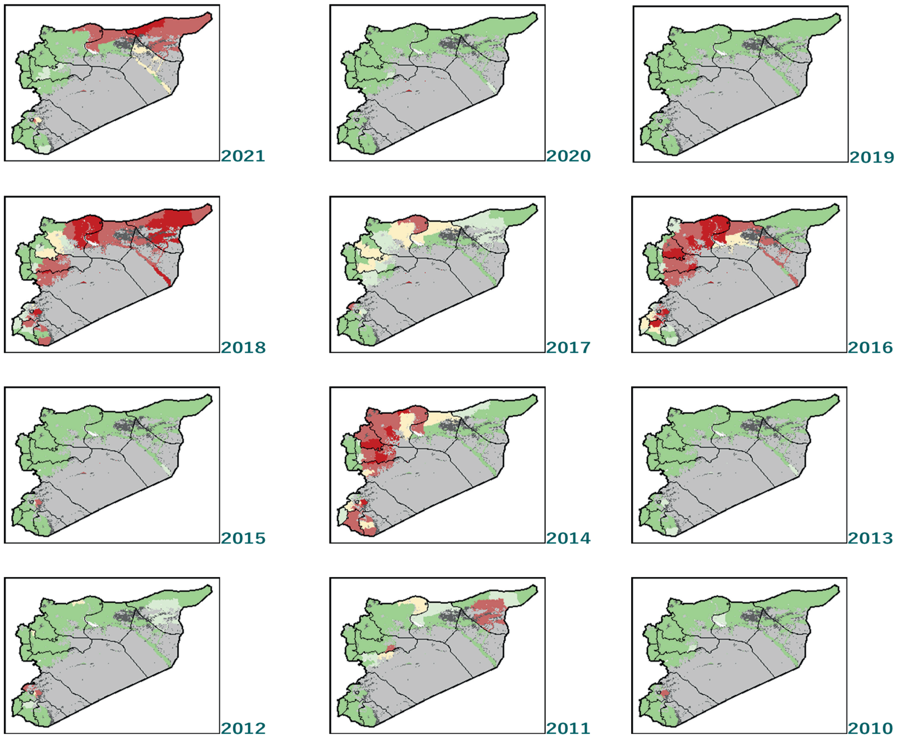


Figure 1. Drought Intensity in Syria during 2010-2021, FAO

Agricultural droughts are classified by their intensity and are categorized into four classes: Extreme, Severe, Moderate or Mild. The intensity of drought is calculated through the Weighted Mean Vegetation Health Index, indicating that the poorer the vegetation health the more severe the drought.

Figure 2. Annual Agricultural Stress Index (2010-2021).

Rastan, Katineh, Tishreen, Al-Baath, Al-Kabeer Al-Shemali, Basel Al-Assad, and Mouhardeh), and about 60 surface check dams scattered over the basins of a minimum storage capacity 400000 m³ in Qara Dam, which harvest rainwater to be used for domestic and agricultural purposes[8]. Dams are constructed in rivers and streams to expand their capacity for storing water, which is used for other purposes at a later time. Dams are constructed in areas where water is already flowing, whereas small impoundments are used primarily to collect and store runoff from nearby rainfall. These impoundments may dry up during droughts, unlike dam reservoirs. With water demand rising and easily mobilizable resources depleted, relying solely on small impoundments for water collection and storage is no longer a viable option.

Consequently, if water demand at current market prices continues to rise, Syria may soon face a serious resource gap[9]. Moreover, over 10 years of conflict in Syria has destroyed water facilities throughout the country.

Millions of Syrians lack safe drinking water, with 40% less than a decade earlier[10].

Figure 3. Syrian water basins.

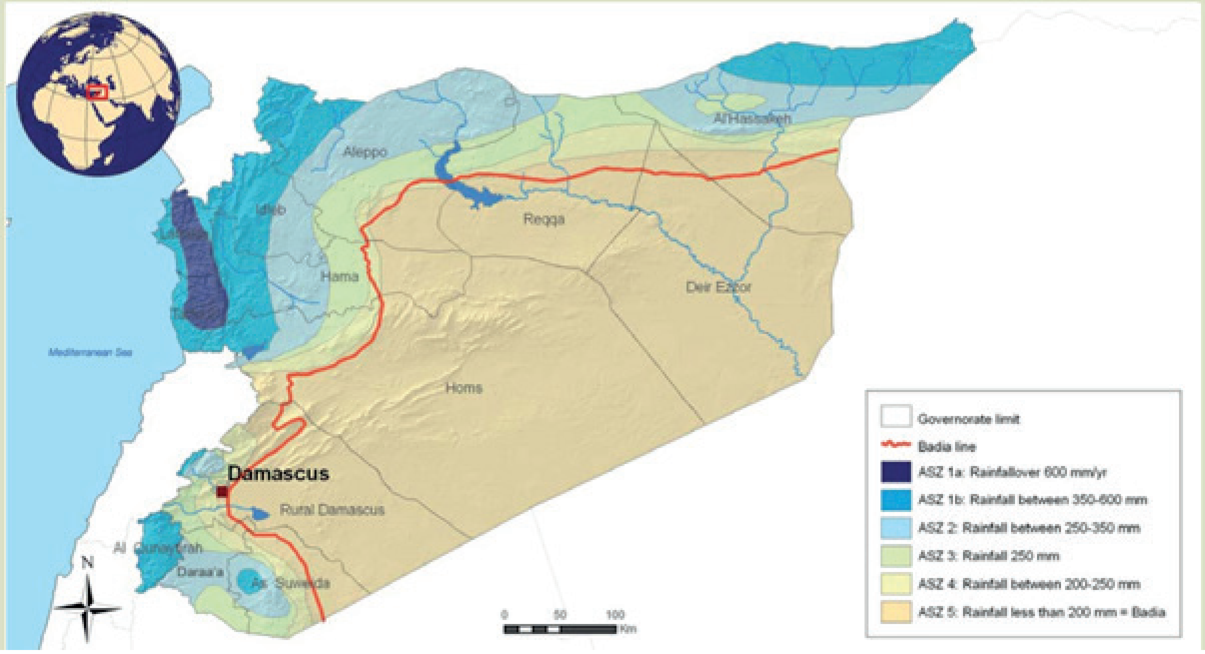


Figure 4. Agro-ecological zones in Syria.

Syria has been divided into five agro-ecological zones (AEZs) according to the level of annual precipitation received (Figure 4)[11].

Agriculture is a vital economic sector and a primary source of income for the families in Syria, particularly in rural areas

The agriculture sector accounted for 60% of water use in Syria in 2018, compared with 17% in 2010.

The UN's International Labour Organization (ILO) claimed that 23% of the country's population worked in agriculture in 2017[12]. While an estimated 30% of Syria's total cultivated land (or around 1.4 million hectares) was irrigated before the crisis, the majority of Syria's grain agriculture is rainfed and hence vulnerable to weather shocks and climatic instability.

Note that at least 90% of the area used for growing barley is rainfed, and that 60% of the land used for growing wheat is rainfed[13].

A total of 18 sub-districts in Northern Eastern Syria (NES) reported losses in harvested crop area of 75% or more due to failed rainfed crops; 13 of these were in Al-Hasakeh Governorate, including 7 with losses of 90% or more. This affected an estimated 60,087 people whose livelihoods depend on agriculture, including an estimated 50,474 farm owners; and an estimated 228,496 people who are dependent on agriculture for food[14]. In Al-Hasakeh, irrigated soft wheat yields were cut by 50%, whereas they were cut by 37% in Ar-Raqqa. While farmers who planted their rainfed crops reported minimal yield.

In spite of the decrease in irrigated land, the country is completely in water stress due to climate change-related weather patterns, inefficient irrigation practices, and inequitable water sharing from transboundary rivers, notably the Euphrates[15].

Climate models predict that the water scarcity will be more than 3500 hm^3 in 2050. By 2050, climate change might potentially decrease the amount of water that flows from the Euphrates, Tigris, and Orontes by 695, 132, and 34 hm^3, respectively. Other water resources will also be affected due to a declining trend of rainfall and increasing evaporation. This highlights the necessity to create new technologies, new forms of collaboration, or improved management strategies for water to alleviate this shortfall.

It is anticipated that there will be a decline of around 700 hm^3 by 2050[16].

The main objective of this report is to review recent literature written in Arabic on RWH techniques and their potential application for crop production with a special focus on Syria. This paper reviews the methods, design of RWH systems, and its impacts adopted in Syria.

Rationale for HRW in Syria

Due to prolonged droughts, the consequences of climate change have also clearly affected crop yields[17]. The reduction in harvestable grain area was due to several factors e.g., insufficient and uneven rainfall in the agricultural season, along with many heat waves, high input costs, restricted irrigation water availability, and high pumping fuel costs. The high cost of inputs and harvesting, as well as dwindling seed quality, seem to be more pressing issues for NES producers than irrigation (particularly of concern in Ar-Raqqa) (Figure 5).

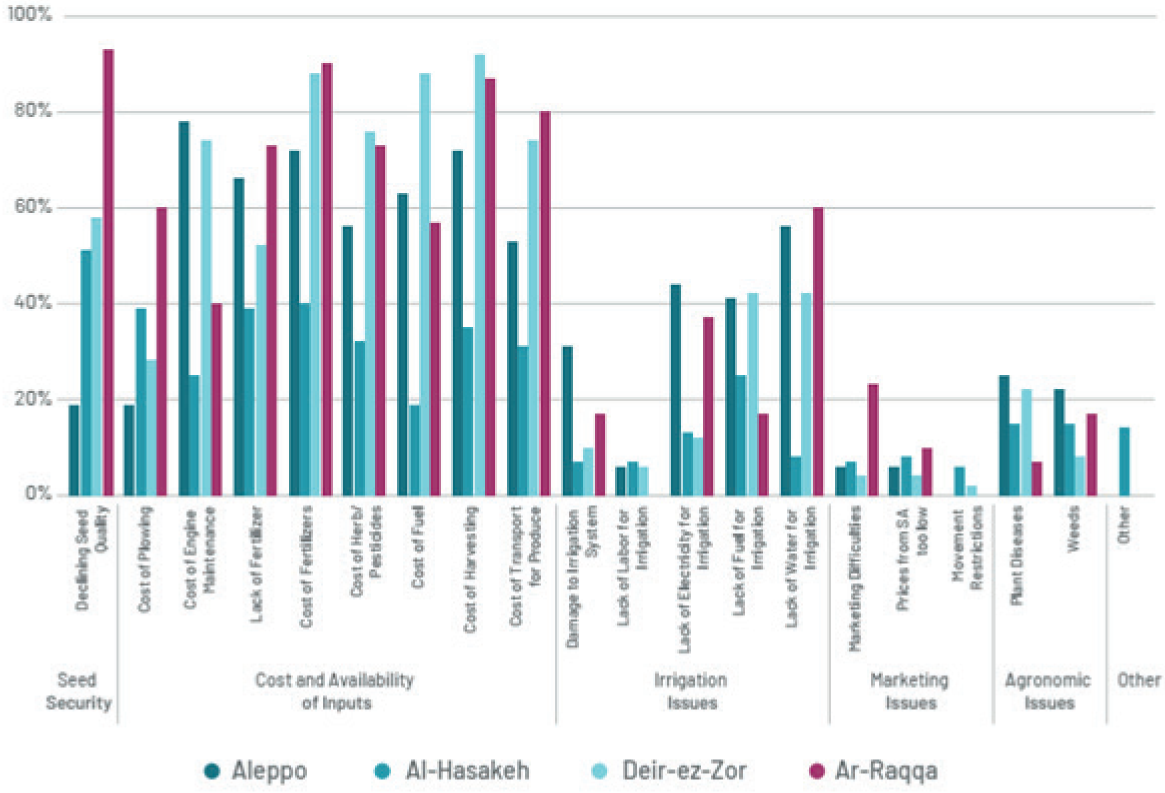


Figure 5. Difficulties farmers confronted in 2021 (as measured by the percentage of farmers who agree that the difficulty exists). Source. FAO, 2021

In 2021, barley production was estimated at 268000 tons, 10% of the cultivation in 2019 and 2020.

Wheat production was expected to be about 1.05 million tons in 2021, down from the 2.8 million tons in 2020 and is just one fourth of the average of 4.1 million tons produced over the years 2002-2011[18].

The irrigation system is a state-managed scheme, moreover, farmers pump water from lakes, reservoirs, rivers, or wells individually or in groups. The Euphrates valley accounts for about 45% of the public irrigation network, with the remaining 55% concentrated in the Orontes valley, Dara'a Governorate, and the coastal region[19].

Most private irrigation relies on groundwater from wells (Figure 6), half of which were unapproved in the past. After the destruction of irrigation network, the digging of illegal wells increased in the crisis. Overexploitation of groundwater from more wells is assumed to be lowering the water table in various governorates, although no direct systematic monitoring of the groundwater table has been done lately owing to a lack of measuring equipment[20].

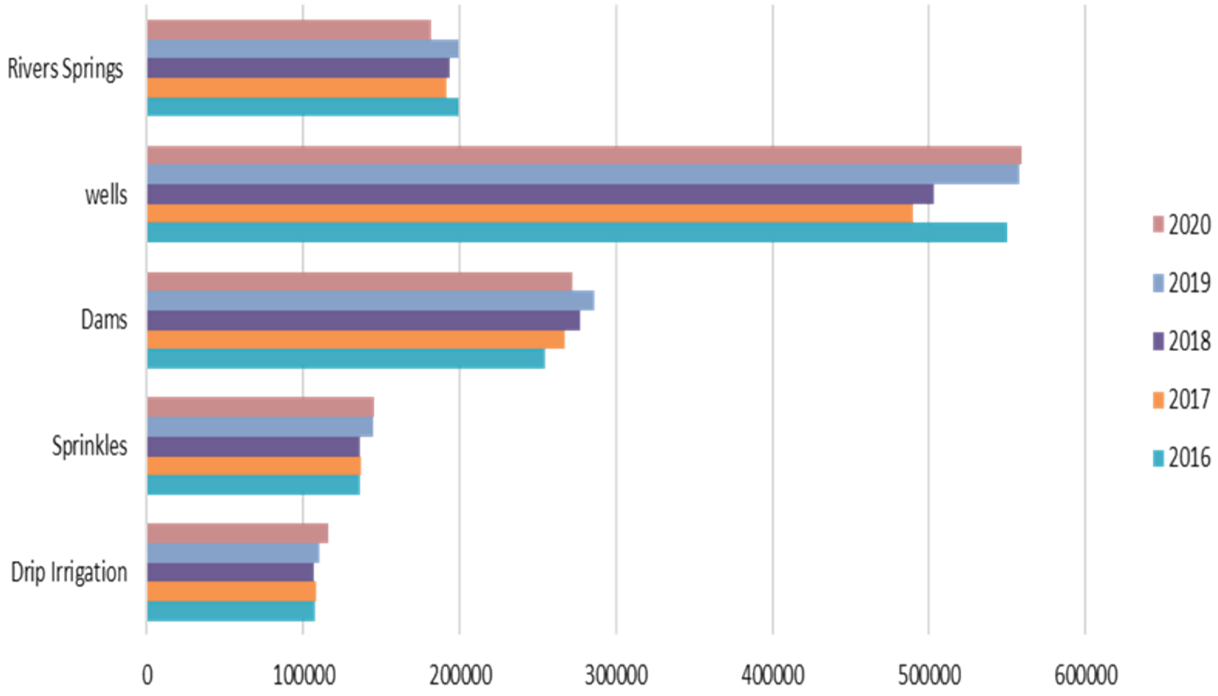


Figure 6. Irrigated land by irrigation method, 2016-2020. http://www.cbssyr.sy/index-EN.htm

In 2021, the majority of farmers interviewed in the governorates of Aleppo, Deir ez Zor, and Ar-Raqqa had irrigated crops, whereas in the governorate of Al-Hasakeh, the majority of farmers planted rainfed crops at a rate of 57%. The governorate was responsible for determining where the irrigation water came from (Figure 7).

Diversifying the sources of agricultural water supply requires the development of alternative methods that are less expensive.

As stated previously, the bulk of Syrian grain agriculture is rainfed, with 60% of the land planted with wheat and 90% planted with barley, making it vulnerable to weather shocks and climatic instability, the erratic rainfall and water availability. The new decreased rainfall regime and high temperatures will alter the cropping season in the following years. Farmers and herders in Syria are used to dry spells, but not ones that occur more often and with more severity as a result of global warming. The interlinkages between climate change (rainfall shortage) and war in rural areas in northeast Syria demonstrates how increased pressure on natural resources is harming lives, which may exacerbate social and political tensions in a society weary of war and poverty[21].

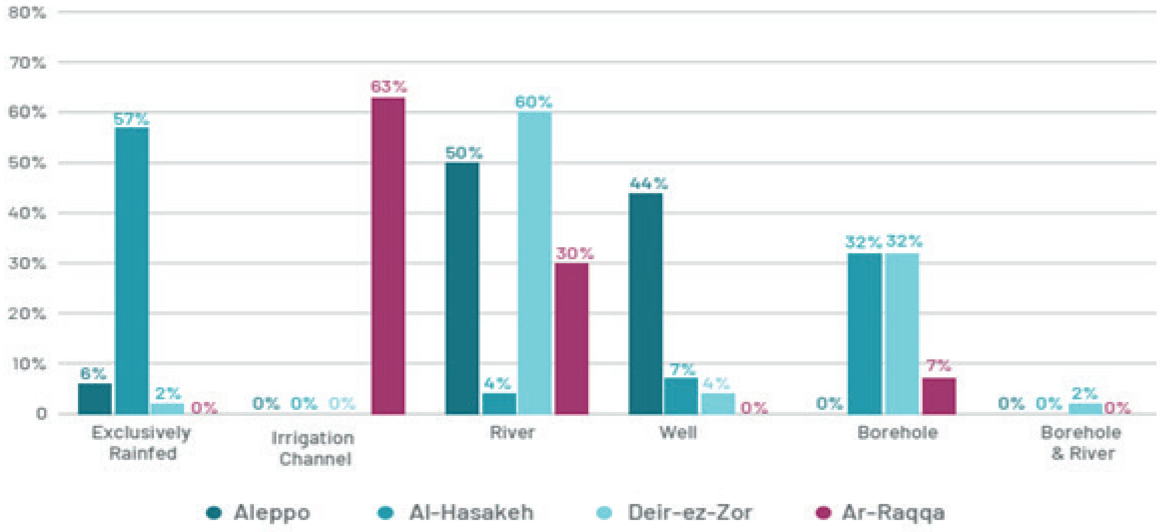


Figure 7. Percent of Farmers Using Various Irrigation Sources.

In this setting, actions and policies such as improving water resource management, irrigation conveyance systems, and agricultural watering practices might be used to increase water availability and access in the short and medium term. It is extremely important to favor water-saving agriculture[22].

Rainwater harvesting is one of these alternatives.

Rainwater harvesting (RWH) is defined as "The collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance"[23]. Another definition describes RWH as "the process of concentrating precipitation through runoff and storage, for beneficial use"[24].

The following constitute the main components that make up RWH systems:

Catchment area: The portion of terrain that provides some or all of its rainfall to a region outside of its borders. The catchment area might range from a few square meters to several square kilometers in size. It might be agricultural, rocky, or marginal terrain, a rooftop, or even a paved road.

Storage facility: The location where runoff is stored from the moment it is collected until it is used. Surface reservoirs and subterranean reservoirs such as cisterns, soil profile as soil moisture, and groundwater aquifers are all viable locations for water storage.

Target Area: It is where the collected water is utilized. In agricultural production, the plant or animal is the aim, but in domestic usage, the people or business and their demands are the focus.

There are a few different ways to categorize water-harvesting techniques, the most popular of which is based on the catchment size rather than the kind of usage or storage (Figures 8, 9) and Table 1.

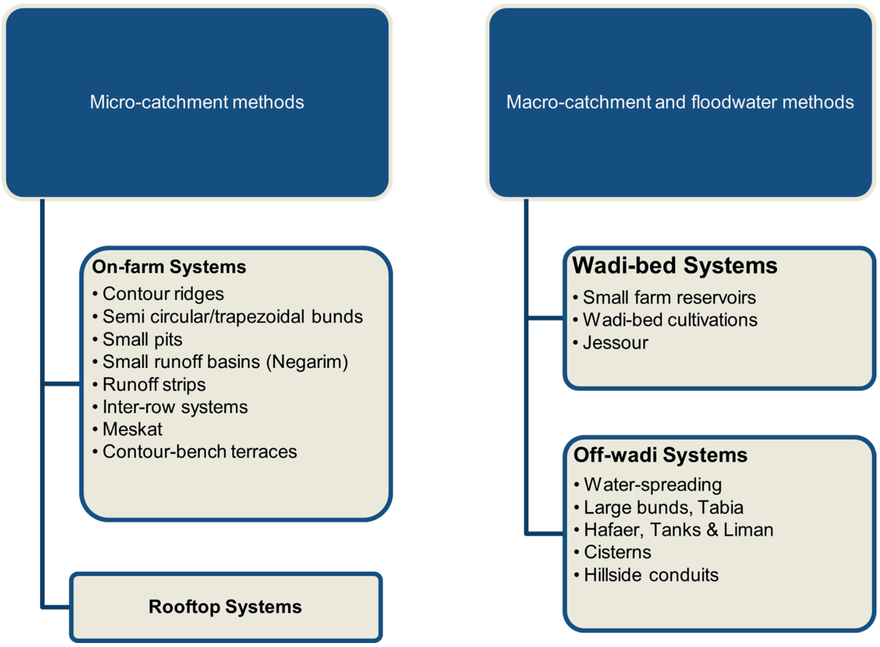


Figure 8. Classification of water-harvesting systems.

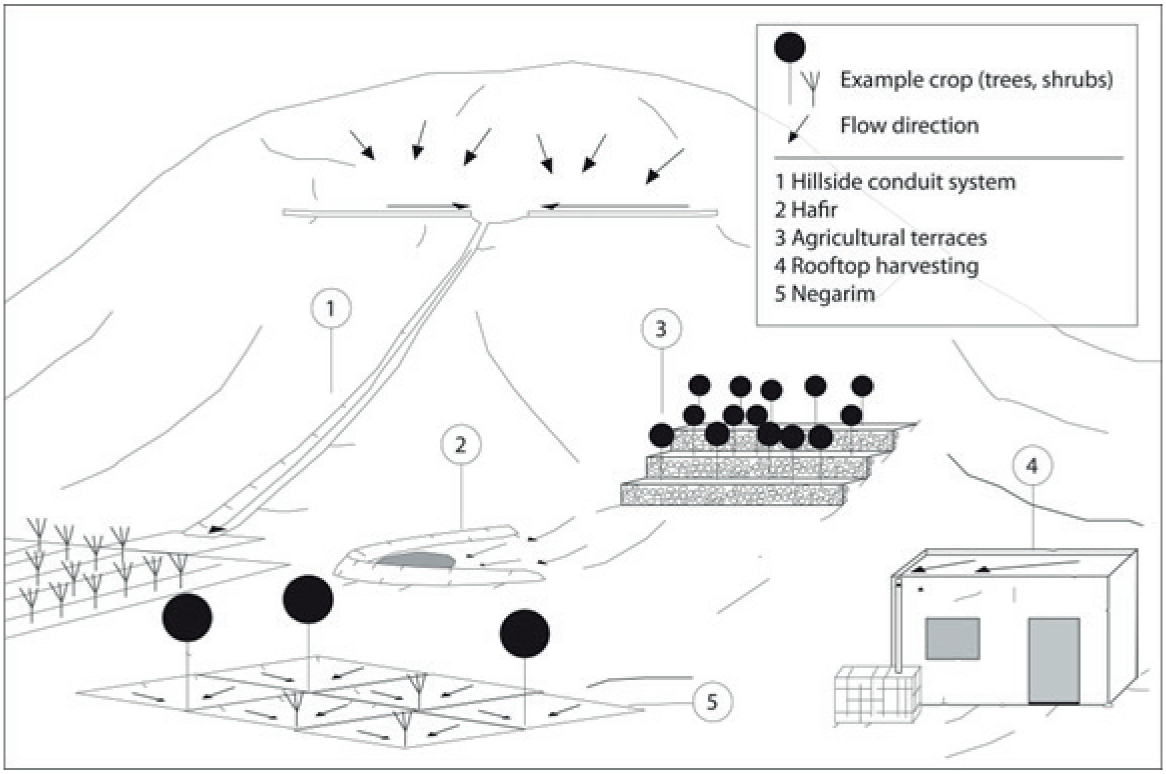
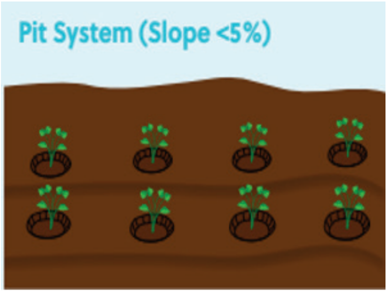


Figure 9. Examples of micro- and macro runoff harvesting techniques[25]*.*

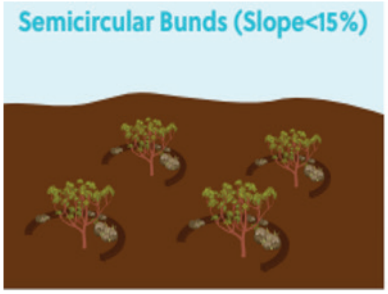
Table 1. The main types of rainwater harvesting systems based on the type of catchment[26] [27]

Micro-Catchment Systems

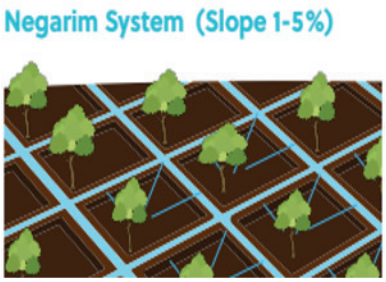
On-farm agricultural techniques such as creating holes, pits, basins, strips, bunds, terraces, and other similar features in the soil are examples of micro-catchment systems. These features allow for the collection of surface runoff water from small catchment areas that are adjacent to the crops or plants.



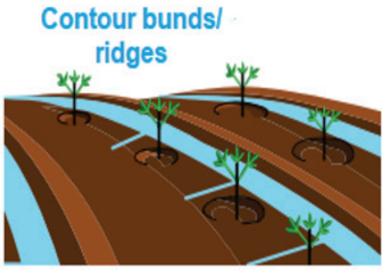
Pits are usually holes of 20 -30 cm width and 20-30 cm depth & spacing 60 cm-1 m apart.



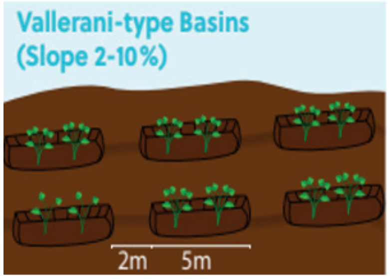
Earth or rock bunds in the shape of a semicircle arranged in alternation, with the tips set on the contour facing upslope.



Have a diamond shape and are limited by low earth bunds.

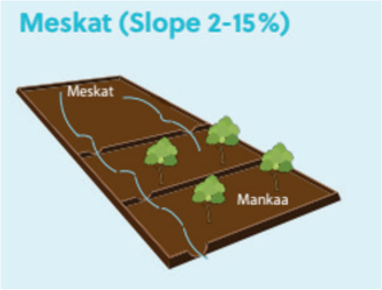


Parallel earth bunds subdivided to micro-catchment by small earth strips perpendicular to the bund.



Mechanized semicircles using a specially designed tractor plough.

Farm is divided into strips along the contour with upstream strip used as water catchment & downstream strip planted with crops.



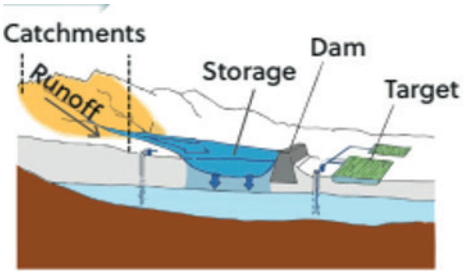
Rectangular shaped basin with water runoff flowing from one Mankaa to the other through spillways.

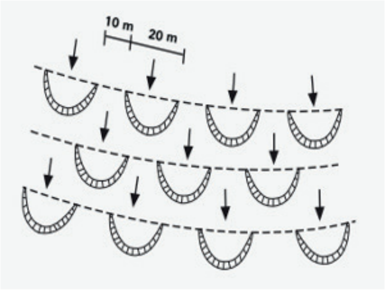
Bench terraces are a flat or slightly sloping beds.

Micro-basins in the shape of an eyebrow, often made from soil & stones.

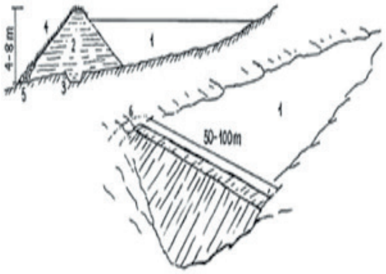
Macro-Catchment Systems

In macro-catchment systems, water is redirected from natural catchment areas like slopes of mountains or hillsides to cultivated fields or storage facilities like ponds, small dams, or reservoirs. These natural catchment areas include hillsides, woods, and mountain slopes.



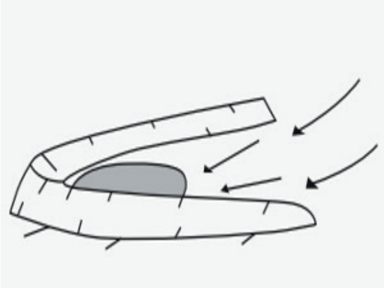


Large bunds: Large earthen embankments (semicircular, trapezoidal, or V-shaped) distributed in zigzag lines

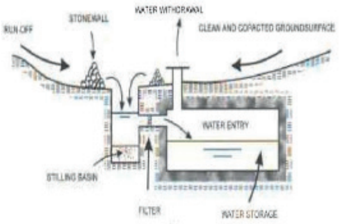


Surface dams: small earth and stone dams, check dams, rock catchment masonry dams.

Capacity: 1000-500000 m³



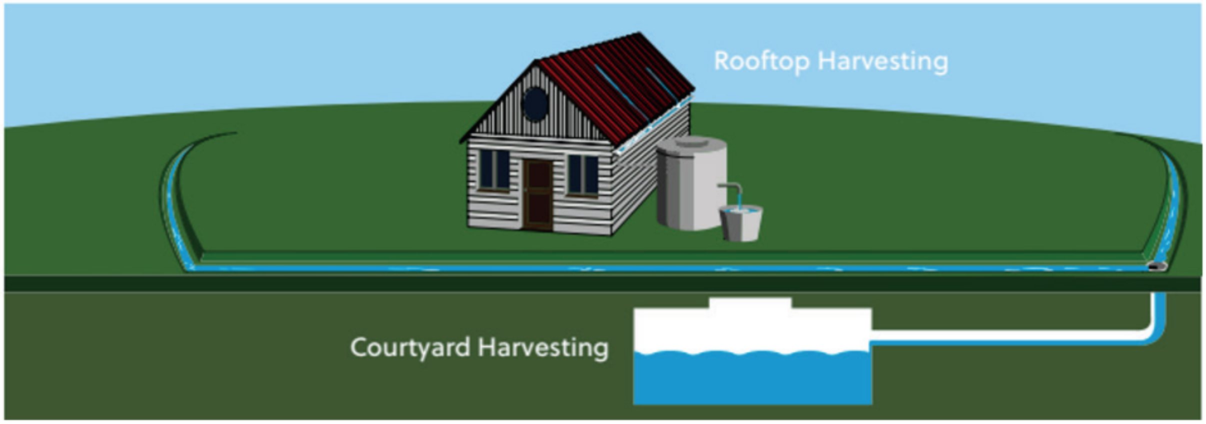
Hafir:
Excavated ponds:
individual capacity of
(200-500 m^3).



Cistern:
Subsurface reservoirs
(10-1000m^3).

Rooftop Water Harvesting

In Rooftop water harvesting, water is collected from the roof of an establishment and stored in a storage tank for future usage. Other diversion of this method is the courtyard water harvesting, water is collected from surfaces that could be of rock, compacted soil, paved or covered with sheeting.



Long-term reduced rainfall in Syria will further disrupt rain-fed agriculture in huge regions, and prolonged dry seasons will diminish rangeland grazing time[28]. Even this water is mostly lost via evaporation and runoff, resulting in repeated dry spells throughout the growing season. Most of the rain here accumulates as puddles before running into streams and eventually into swamps or "salt sinks", where it loses quality and evaporates; just a tiny fraction enters groundwater. It may generate significant gully erosion along the route[29]. In such a context, rainwater harvesting is a viable choice for supplementing the available water supply to enable supplementary irrigation (when rainfall fails to deliver adequate moisture for regular plant development)[30].

Rainwater harvesting plays an important role in the planned activities under the 2006 National Strategy and Action Plan to Combat Desertification. By harvesting water to enable greater infiltration before it is utilized or evaporated, water harvesting may alleviate strain on Syria's aquifers and enhance groundwater recharge rates.

Rainwater is recognized as a clean renewable water resource; its quality in rural locations with little air pollution is dependent on receiving roofs and collecting tanks. Rainwater harvesting in the field may also be accomplished by diverting surface runoff into a rainwater reservoir or agricultural regions. Some rainwater gathering systems may also aid in soil erosion reduction[31].

Human communities in arid regions including Syria have evolved strategies for dealing with water shortages, with the development of those societies and their ways of life frequently going hand in hand. This traditional knowledge promotes behaviors that are generally accepted by society, fosters a sense of community among its adherents, and the use and management of natural resources in a sustainable manner. This latter point is especially important in drylands, where water shortage, seasonal and annual variability, and the possibility of conflict and rivalry among users all pose serious threats to human life.

The sustainable management of water resources, which is at the heart of traditional approaches to water collection and management, allows them to triumph over this difficulty.

It is important to develop fresh solutions as well as to refine technologies that have been around for a long time. Traditional knowledge, though it is rooted in the past; rather, it is dynamic and evolving. It is hoped that implementing RWH can undoubtedly benefit from scientific knowledge mixed with a historic flow of traditional methods, while connecting it to local communities and including options for sustainable livelihoods.

The Potential of RWH in Syria

60% of Syria might benefit from water harvesting infraestructure.

Syria could save more than **600hm³ / year**[32] by water harvesting and water shortage will be around 1500 hm³ in 2050.[33]

35MCM[34] in rural areas additional roof harvesting in Syria could increase water availability.

Roof rainwater harvesting could add up to **3%** to available national water resources (Figure 10)[35].

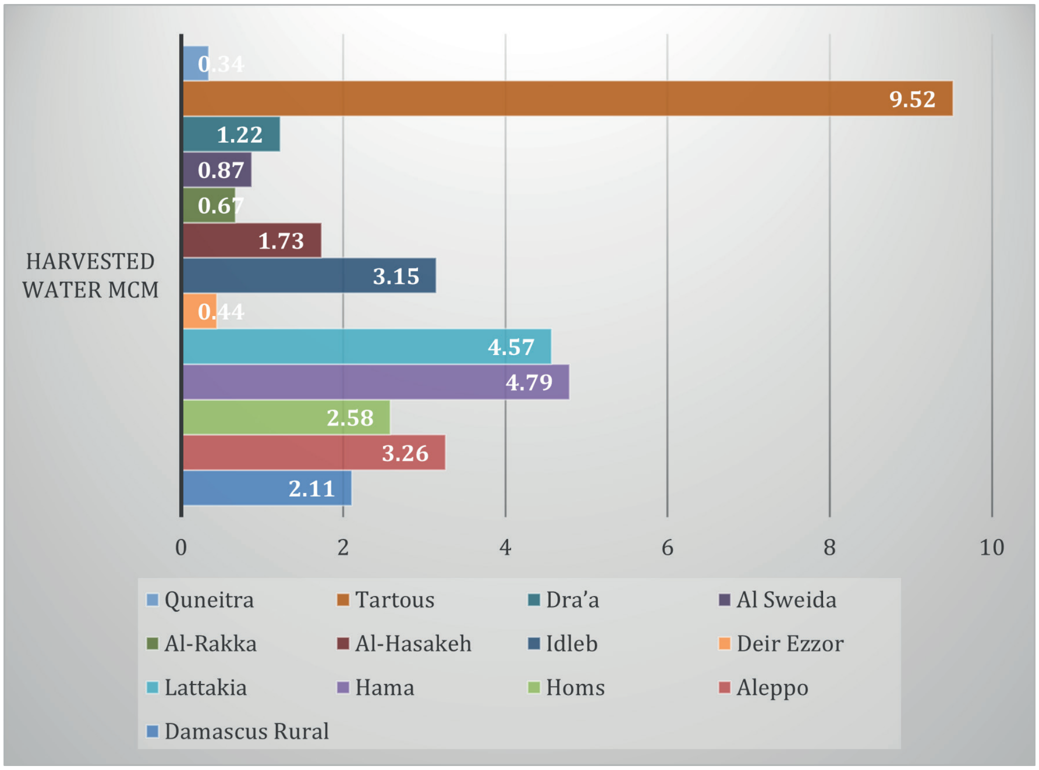


Figure 10. Roof runoff in different rural areas of Syria.

The total potential of harvested water from roofs in Syrian rural areas could reach 35 MCM. Knowing that the Syrian population in the rural areas is about 9.4 million, this harvested water would be 3.7 m³ per capita per year.

The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) carried out and is running many RWH projects in Syria, including the Al-Tanf, Deir Attia, and Mhasseh projects, in addition to the project to combat desertification and harness rainwater in Jabal Al-Bishri in Deir Ezzor[36].

The International Center for Agricultural Research in the Dry Areas (ICARDA) has been interested in water research and RWH techniques planning, selection and appropriate implementation. They are also involving farmers in this work. Incorporating micro-catchment rainwater harvesting (MIRWH) into an integrated solution with appropriate plant species and competent grazing management has the potential to promote significant vegetation development and aid in ecosystem restoration by capturing and storing a large percentage of this otherwise lost precipitation in the soil. ICARDA's research program for the rehabilitation of the badia in Syria has shown that it has the potential for widespread implementation in dry environments[37].

Moreover, ICARDA's researchers conducted experiments in the "Mhasseh" region close to Palmyra where the annual precipitation yield is less than 150 mm. The water that was harvested was adequate to provide for more than 90% of the newly planted plants.

In Mhasseh, three years of drought had wiped out all vegetation except for Salsola and Atriplex shrubs planted in semicircular micro-catchment bunds (Figure 11)[38].

The General Commission for the Administration, Development and Protection of the Badia made the decision to spread this technique to additional arid regions, and the results showed that supplementary irrigation works to enhance output that only uses relatively modest quantities of water[39]. This was done by developing rainwater harvesting projects for drinking, livestock, and irrigation purposes, by establishing 37 small earth dams of varying sizes, 50 mini reservoirs as well, 7 water dikes in the flat valleys and terraces to collect runoff in winter; in addition to planting suitable plants in some areas.

A MIRWH system, shrub plants, and good grazing management may revegetate this highly degraded pastoral habitat in four to five years.

Figure 11. Manually constructed semicircular bunds planted with salt bush and receiving runoff water after a rainstorm in 2003 in Mhasseh, Syria.

The General Commission of Water Resources in Syria conducted several surveys and construction projects of ponds, reservoirs and small dams (Macro-Catchment RWH System)[40].

Farmers in Syria do not use RWH very often. One of the causes is a lack of detailed and systematic information on prospective regions and acceptable places for water collection in Syria's agricultural research and extension assistance services. To bridge this gap, the suitability of potential sites was assessed for various water harvesting systems (e.g. contour ridges, semi-circular bunds, small pits, runoff strips, and contour bench terraces) in Syria through a GIS-based analysis (Figure 12)[41].

Prior to deciding on a particular technique, careful consideration needs to be given to the social and cultural aspects that are prevalent in the area of concern. These factors are of the utmost importance and will have a direct impact on the success or failure of the technique, regardless of which one is chosen[42].

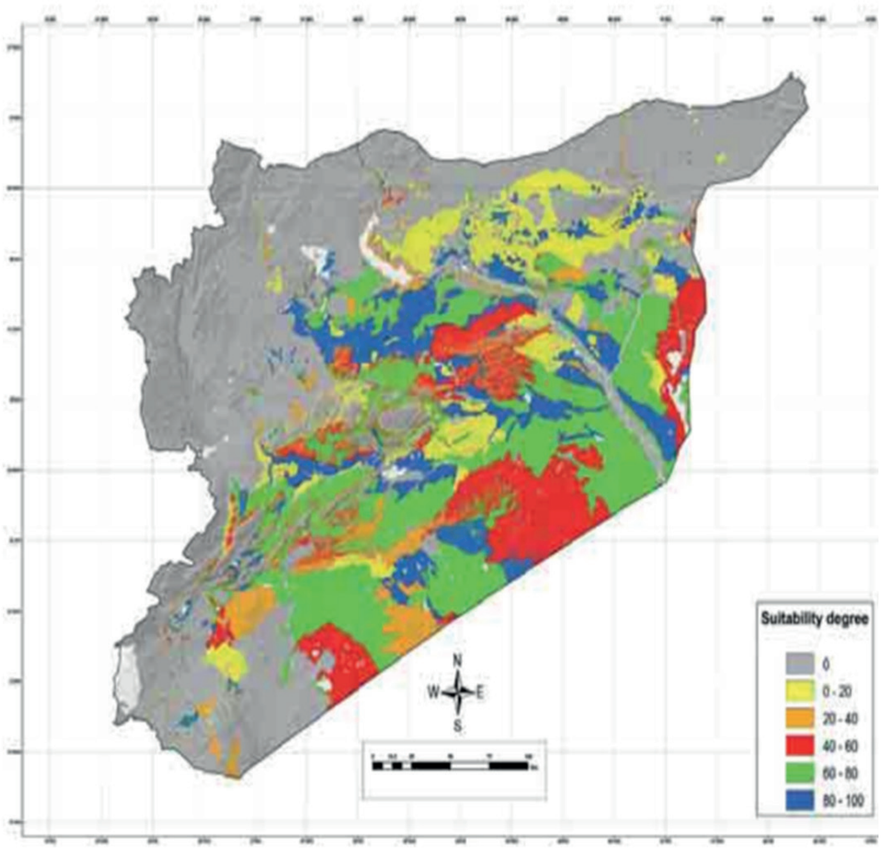


Figure 12. Suitability of Macro-catchment RWH in Syria.

The total number of small dams and ponds is **61**

Macro catchment water harvesting systems:

- **13** implemented
- **10** under implementation
- **4** under contracting
- **10** ready for contracting
- **2** under study

These macro-catchment rainwater harvesting techniques fulfill irrigation purposes, thus increasing the irrigated area, which reflects positively on the agricultural production and livelihood conditions in the catchment areas of these techniques, as well as extinguishing fires when needed.

Al-Safriqiyah Small Dam (left). Kafr Small Dams (right).

Arabic Studies related to RWH in Syria

To fulfill the objective of this study, the journals of the Syrian Universities and institutes were used to obtain the sample of studies to be analyzed. The search parameters used were all of the frequently used terms related to rainwater, agriculture, and irrigation. Their selection was based on previous studies on the same subject in Syria. These parameters were used in the search fields of title, keyword, and abstract. The study period selected was 1990 to 2022. All the results of a study as conference papers, book chapters, and articles were included in the sample.

Traditional water harvesting techniques in Syria date back to 3000 BC and include the harvesting of the surface water in reservoirs in ābār (sing. b'ir) rūmānī and birak[43], and cisterns (e.g. Resafa (Figure 13)[44]) and later the transportation of water through waterwheels. There are many examples such as those found near Khan al-Arous in the area of Al-Thannaya in Jabal al-Qalamoun; as well as in the Qulaya area in Jabal Shebeth southeast of Aleppo; and in al-Sihiyat north of Palmyra. Runoff was directed through inclined surface furrows to drain into water channels roughly parallel to the slope lines, after which rainwater is driven into terraces with edges ranging in height from (30-50 cm). In medium and low-slope areas, rainwater was channeled through low stone walls into underground cisterns, to utilize the collected water for domestic and livestock proposes during drought spells, and an example of this method is found in Wadi Al-Atheeb in Hama[45].

It is worth mentioning that ancient "qanats" are examples of systems that are classified as RWH systems although they don't treat runoff. Qanats only get groundwater to the surface for usage, no runoff included[46].

Figure 13. The "large cistern" in Resafa, Syria. It was filled by channeling periodical floods from a wadi west of the city into the cisterns and had a capacity of ~18,000m³.

Nofal (2009) investigated the combination of RWH and supplementary irrigation to increase the water use efficiency of terraces in Fahel and Rapah in Homs. The study revealed the vital role that terraces played in preventing soil erosion and land degradation in the agricultural fields of the area (Figure 14). However, these terraces need continuous maintenance and proper management. The study suggested utilizing constructed cisterns and hafair for supplementary irrigation to apply limited amounts of water during scarce episodes of rain in order to increase crop production (apples and wheat).

MIRWH techniques to reduce soil erosion, and improve vegetation cover on terraces, and support supplemental irrigation.

Figure 14. Terraces implemented in Rapah, Homs, Syria (Nofal, etal, 2009).

MunlaHasan et. al, (2009) described mechanized micro-catchments rainwater harvesting and its economic profitability. This study was conducted in two pilot sites in the Syrian rangeland near Qaryatain and Sheikh Hilal communities between fall 2004 and spring 2007. Different RWH techniques were implemented such as semicircular bunds and contour ridges in addition to planting drought tolerant shrubs (Artiplex Halimus, Artiplex Leucolada and Solosola Vermiculata). The study revealed that that Vallerani technique was more profitable compared to other techniques such as Pakistani/ regular tractor (Pakestani-12m), and (Pakestani-6m) or manual approach in terms of the net present value of vallerani compared to other techniques.

Alasta (2013) conducted an experimental trial in Latakia to study the following parameters of rooftop rainwater harvesting: its classifications, contents, components, benefits and few water quality parameters (conductivity, pH, fecal coliform, total coliform). According to the findings of this research, using rainwater plays a significant part in cutting down on the amount of water that is lost while also meeting the freshwater demands of the home. The potential volume of rainwater harvested relies on the surface area of the roof and the quantity of local rainfall, with estimates reaching a range between 11.4% to 38.17%. The savings may reach 40% when using this collected water for non-potable purposes such as flushing the toilet, stairs washing, cars washing and watering the garden.

Yaghi et.al. (2015) applied a Water Accounting System (WAS) to calculate and predict water balance in the upper and mid Orontes Basin until 2050. They found that the water flow at the inlet of the basin near Rastan Dam was about 55.20 Mm³ in 2010 at Ghajar al-Amir Gauge Station compared to 220.03 Mm³ in 2004. The applicability of RWH to tackle this deficit is foreseen to be limited to the eastern and southern parts of the basin and can be used to cover irrigation purposes (Figure 15).

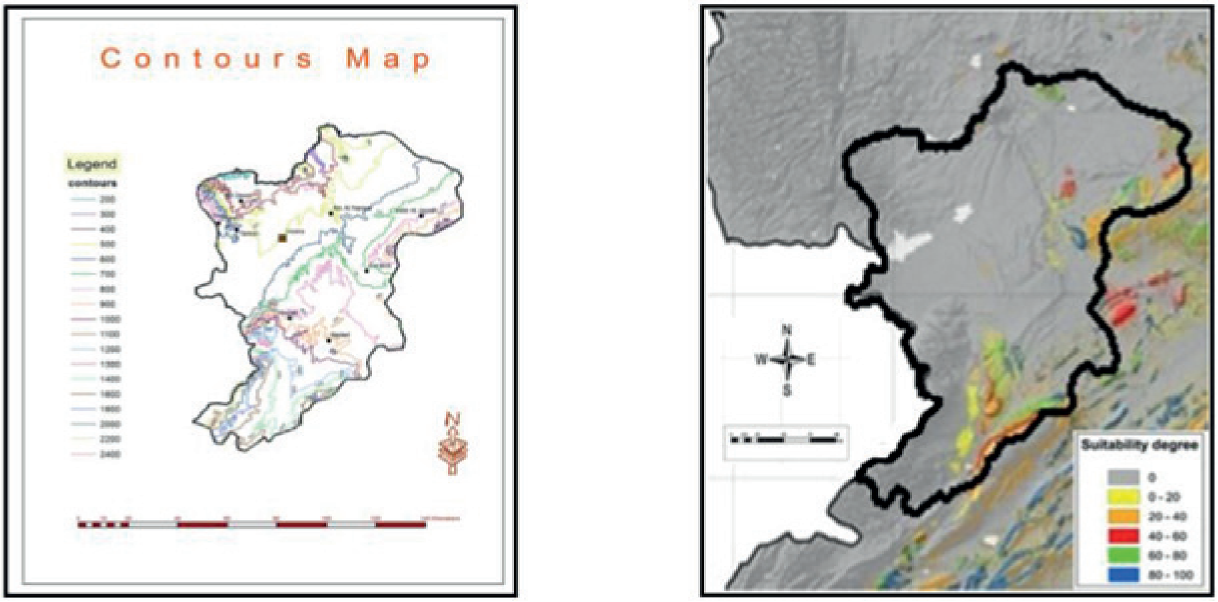


Figure 15. Water harvesting site planners and contour lines using GIS.

Douba (2013) assessed the performance of water harvesting techniques and maximizing efficiency at ICARDA (Figure 16). In the Tal Hadya research facility, run by ICARDA, a demonstration field has been developed specifically for the purpose of displaying and testing various water harvesting systems. Olive and almond trees were planted within the 121 micro-catchment semi-circular bunds that were created across a hill that was 0.5 hectares in size and had a slope of 9-11%. The bunds were spaced at 5, 7, and 9 meters apart. The second site has an old underground cistern of 29 m³ with a 0.33 ha macro-catchment. After compacting the soil, they were able to increase the collection efficiency by twenty percent, and to maximize the storage efficiency by fifty percent by providing supplementary irrigation depending on the average rainfall. Studying soil moisture curves of the soil profile in semi-circular bunds, soil moisture was found to be higher during the rainy season until the end of March, and by applying supplemental irrigation from the cistern, the same value was maintained even after March until the end of the summer.

Preparing the contour lines in the site #1.

Semicircular bunds.

Building the underground cistern.

Preparing the site #2.

Figure 16. Experiments water harvesting techniques established in Tal Hadya research center, ICARDA.

The Directorate of Water Resources in Hama identified the locations of hafairs in the Hama Badia (Salamiyah) region based on the Russian study of the Syrian Badia, that was published in 1987 and completed its investigations between 1983 and 1986. However, it did not utilize any of the modern techniques currently employed in determining such locations. Therefore **Alibraheem (2014)** conducted a research aimed to shed light on the significance of modern techniques in hydrological studies through reliance on decision support systems. This included predicting suitable locations for implementing RWH, verifying the suitability of executed hafairs' locations in the Salamiyah area for RWH, and attempting to identify alternative sites based on a set of criteria and conditions per the intended objectives.

The General Organization for Remote Sensing (GORS) in Syria has carried out several rainwater harvesting projects using remote sensing (RS) techniques. These projects included the preparation of catchment maps in the development project of rural areas in Idlib Governorate; a study of rainwater harvesting in the Syrian Badia; and a rainwater harvesting study of the rural development project in the northeastern region; and defining the suitable sites for rainwater harvesting projects in Al-Qalamoun region[47].

Alkhaleel (2015) investigated the role of RWH techniques in improving grazing cover vegetation In Hama Steppe (Debah Site). In the location, several methods of micro-catchments RWH were evaluated (manually prepared semi-circular, contour ridges, small pits). A comparison between three different fodder species, Atriplex halimus, Atriplex leucoclada, and Salsola vermiculata, as well as three different spacings (6,8, and 12m) along contour ridges was conducted. The effectiveness of the water harvesting techniques was assessed based on the percentage of shrubs that survived, the development of the shrubs, the moisture content of the soil, and the quantity of silt that was collected after each discharge. As compared to the case without RWH, statistical analysis revealed that micro-catchment RWH methods improved land production by boosting soil moisture content, shrub growth, and shrub survival rates. The results also demonstrated the importance of these techniques in reducing erosion and sedimentation downstream. Compared to Salsola vermiculata, Atriplex sp. had the best survival rates and biomass. Manually created semi-circular bunds, contour ridges, tiny pits are more efficient than contour ridges.

Ammar (2015) utilized remote sensing technologies to identify potential locations of RWH sites in the southern part of the coastal mountain chain in Syria. The coastal basin is considered one of the basins with a surplus of water, where the annual volume of rainfall is about 4880 Mm³, of which only 1038 Mm³ is currently used[48], yet it suffers from a chronic inability to meet the demand for water in the summer[49]. They identified 68 locations to apply RWH systems (Figure 17). Priority was given to 27 of them geographically distributed over the entire study area. These sites fulfill the purpose of securing the water demands necessary for agricultural and pastoral activities and domestic service.

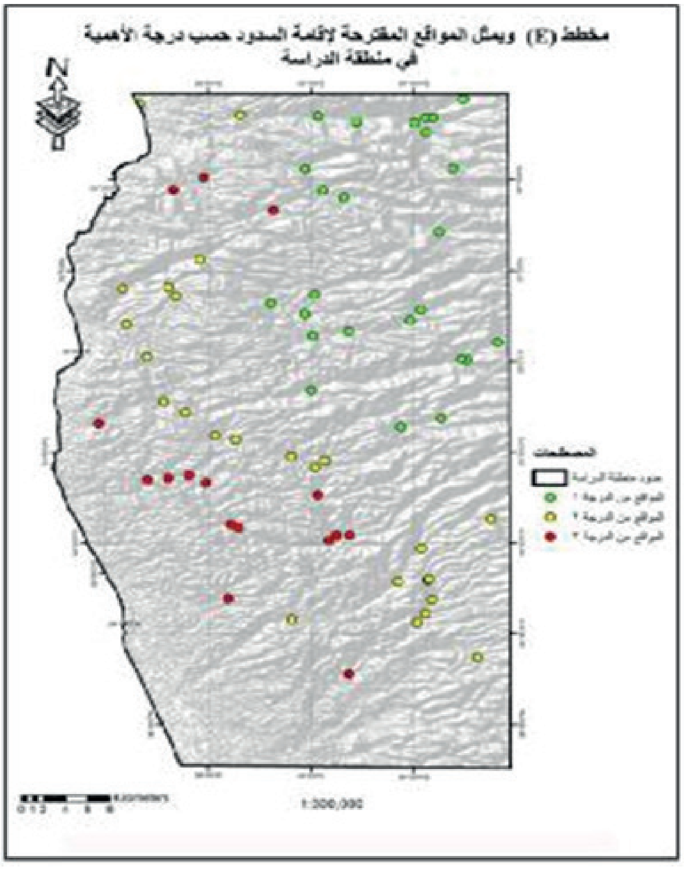


Figure 17. The proposed site map is arranged according to the degree of importance.

Al Omar (2016) used remote sensing (RS) and geographic information systems (GIS) to identify potential areas for RWH projects in Hessia and the neighboring areas, within a total area of 1300 km². The study suggested the use of small dams and bunds to help meet the water demands required for agricultural and pastoral activities (Figure 18).

AL-Saram (2018) utilized GIS and remote sensing techniques to determine the appropriate potential sites for RWH in Masyaf catchment in Hama (598.15 km²). The annual precipitation ranges between 342 mm to 1500 mm, with abnormal distribution due to high variation in precipitation. The analysis shows that the best sites were distributed in the western part and cover 8% of the catchment; while the second best were in the east part with 24% of the catchment; and in third best in middle part with 68% of the catchment.

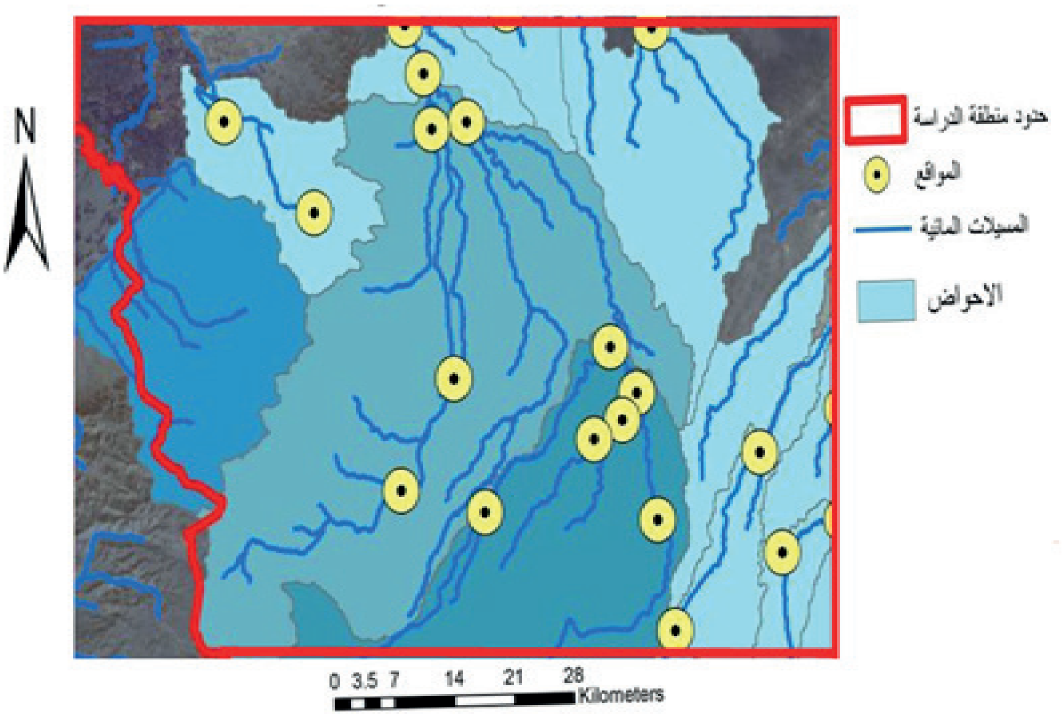


Figure 18. Sites of high potential to be used for RWH projects (yellow circles with a black dot inside).

Droubi (2018) conducted research in Mehasseh Research Center during the period 2006-2012. To evaluate the efficiency of mechanized Vallerani techniques to improve the production of pastoral plants and re-vegetate the Syrian steppe. The main results of the research included an increase in soil moisture twice the the annual average; the prevention of soil erosion by 70%; and increasing plant growth by 80%. This technique is of great importance in terms of utilization in large areas such as Homs desert (7000 ha), Al Hess Mountain (150 ha) and the Jordanian desert (700 ha).

Khoury (2021) utilized GeoMedia Professional 6.1 software to determine the best location for a small dam in Selqin Basin which is a part of the Northern Orontes Basin, to improve the management of water resources and to achieve sustainable development in the basin. The volume of the dam reservoir was established at 1.7 million cubic meters, a capacity attained within a single year with specific dimensions. Upon execution of the dam, the economic yield will be considerably substantial, as the economic coefficient is 26, which is greater than 8. The classification of this site within the environmental and economic objectives aims at fostering local community development, alongside promoting the diffusion of RWH techniques due to their economic and societal benefits.

Said And Yasin (2022) studied the effect of water harvesting projects using mountain bunds on production cost and economic efficiency for each studied crop for a sample of beneficiaries in mountainous areas in Latakia (Syria). Citrus production increased 1686.6kg /donums and vegetable production by 433.3kg/ donums due to mountain bunds. While apples have risen 4.6 donums, olives reduced 4.6 donums, and tobacco saw a rise of 1.7 donums[50].

Ziadat (2011) documented a project in Afrin, and Betya village in Idlib in Syria to utilize Semicircle stone bunds (Figure 19) as soil conservation and water harvesting structures to reduce soil erosion and improve productivity of olive trees. The main strength gained by implementing this system of RWH include reducing soil erosion; increasing soil moisture; and increasing yield[51].

Ghassali (2021) documented another project in Obisan, Obisan, Dalbouh, Aleppo on Range Pitting and Reseeding[52]. They were implemented by an ordinary 2-wheel-drive pickup. Small shallow 'pits' are scooped out by the action of inclined metal disks (similar to the disks of a disk plough). A seed hopper mounted on the top of the implement releases small quantities of range-plant seeds into the pits and an attached light harrow covers the seeds with a thin layer of loose topsoil. The implement can also be used without the seeding device. Artemisia and Salsola species have been used successfully for rangeland reseeding.

Figure 19. Semicircle Stone Bund within Olive Tree Field.

Community-based Approaches to Adopting RWH

Several conservation and development studies have begun to favor the use of social participatory action as a tool for analyzing the resource base conditions. Soil erosion risk assessments that include farmers input into monitoring and evaluation may improve resource management. The most motivating aspect of these initiatives, beyond their water-saving advantages, was the local awareness, trust-building, and continual support.

The integrated watershed development project in Mehasseh, Syria, was one of the most important research projects on proper management of water resources, soil, and vegetation cover for the development of scarce resources in the Syrian Badia to preserve the natural pasture and ensure the sustainability of impoverished sheep herders. The socio-economic analysis of the Mehasseh project (1999) included land beneficiaries. The shepherds and pastoralists were aware of the importance of this project components (securing drinking water for livestock, utilizing RWH techniques, and planting pastoral shrubs to restore vegetation pastures). However, most of them were unhappy due to the exclusion of shepherds from its development or execution.

Ziadat (2013) highlighted that natural and anthropogenic causes of land degradation have resulted in steadily declining revenue from agricultural crops in certain places in Syria. Most of these changes are reversible if prudent conservation measures are applied at the appropriate time and location. In addition to profitability, the farmer's perception of RWH, and soil conservation initiatives are crucial adoption factors that should be carefully evaluated. From a farmer's perspective, investments to avoid land degradation are expensive and only provide long-term returns. Yet, diversification of agricultural operations, which leads to the sustainable use of resources, affords the possibility to get short-term advantages and lessen the farmer's susceptibility while preserving resources[53].

Before broadening any case study, validity should be determined. For instance, a project targeted two communities in the mountains of Afrin and Idlib including isolated, disadvantaged, and monocultural groups. Hence, it may not fit all Syrian villages or arid regions[54] (Figure 20). The broad and long-term improvement of these regions depends on community micro-credit schemes. Farmers in these areas have been asking for interest-free loans to implement diversification strategies (e.g., water harvesting, soil conservation, and water-use efficiency) on their farms. The distribution of loans was accomplished by merging a GIS-based land degradation priority map with the communities' judgements and land tenure maps. This was helpful in the formulation of a community-based strategy to prioritize the execution of different interventions of soil water conservation (SWC) to optimize the effect on the environment, boost land productivity, and maximize the use of available water resources. Throughout the capacity-building activities, the farmers demonstrated a keen interest in understanding RWH and its effective application in agriculture.

Figure 20. Technology fair (upper right) and training of the communities on implementing SWC interventions.

Another important conclusion drawn from this project is the farmer-to-farmer concept of these participatory approaches. This project was piloted in Maghara and Khaltan in Afrin, and after its completion, it was expanded to Bitiya in Idlib. There was a tight solid relationship between the communities in Maghara and Bitiya; the communities shared their experiences with one another, and the Bitiya community benefited from the experiences of the Maghara group.

Another project in Northwest Syria in Khanasser Valley (Figure 21) sought farmers' cooperation to expand water harvesting, soil conservation, and water-use efficient diversification methods to increase land productivity and farmers' revenue in hilly northwest Syria villages. The project developed a participatory approach that worked toward the goal of benefiting from the synergy that may be achieved when indigenous knowledge and scientific competence are combined. With a focus on developing and testing various techniques for water and land management in order to sustainably improve olive production in a semi-arid region, while ensuring that the techniques were adequately adapted to the agricultural practices that are common in that area.

The environmental impact was positive; semicircular bunds decreased rill erosion by 40% when compared to areas without such interventions and reduced the number of rills created. There were no rills found in a field with continuous stone bunds, but rill erosion from a nearby area was as high as 13.6 ton/ha. Out scaling this project and successful pilot projects like it to other areas requires prudence.

The aforementioned projects emphasized the involvement of local communities in the different phases of the projects (initiation and motivation. Planning, implementation, monitoring and evaluation, and dissemination). The role of farmers

An exercise of priority ranking of problems for growing olives in Harbakiyah, Khanasser Valley, and involves Khanasser farmers, a community facilitator, researchers.

Joint field visit including farmers and ICARDA researchers to a local innovator's field to implement MIRWH bunds- Harbakiyah, Khanasser Valley, NW Syria.

Figure 21. Participatory technology development (Syrian Arab Republic)[55].

is to identify priority problems and potential solutions, to test new technologies on their farms, and to evaluate their suitability.

Through a socioeconomic survey, **Alkhaleel (2015)** explored the local perception on the role of rainwater harvesting techniques in improving grazing cover vegetation In Hama Steppe (Debah Site). RWH techniques were not widely applied in the study area for many reasons indicated by the respondents to the survey.

These factors include lack of sufficient knowledge (30% of respondents) and training (14%), absent financial support to implement RWH techniques (26%), high implementation costs (12%), and the misperception on such techniques (useless (6%); and not suitable for agricultural purposes (2%). 2% of the respondents were not interested in the techniques and 6% said the lack of sufficient rainfall is the reason behind them not adapting RWH techniques.

These findings are important, because implementing RWH techniques can only be sustained if it is mainstreamed properly to the farmers through an enhanced farmer-researcher collaboration that enables farmers to learn about RWH from researchers, while researchers can identify prospective advancements from local people.

It is not enough to build new systems; local people need the knowledge and skills to run these systems sustainably and effectively.

To ensure the wider dissemination of RWH among rural farmers, it is crucial to provide training for people responsible for the system's correct designation, utilization and maintenance to maintain maximum efficiency. These people in charge include local people who are the final users of RWH systems in addition to personnel (engineers, foremen, workers...etc.). For example, in figures 22 and 23, training activities on RWH organized by the General Commission for Scientific Agricultural Research in Syria on the design and implementation of RWH techniques in various forms concluded by a field demonstration.

Figure 22. Training Day on RWH, GCSAR, Syria, 2016.

Figure 23. Training Day on RWH, GCSAR, Syria, 2017.

In February 2023, the NEXTEP Organization organized a focus group discussion with experts and farmers in northeastern Syria (Figures 24, 25). They highlighted several water harvesting techniques such as sandy dams and large bunds/ hafirs. All these techniques fall under the Macro-catchment WH (MaWH). The room for improvement is seen in the implementation of Micro-catchment WH (MiWH) as small planting pits, micro-basins (negarims, meskats, small semicircular bunds, eyebrow terraces, mechanized Vallerani basins), Cross-slope barriers (vegetative strips, contour bunds and ridges, tied ridges, stone lines and bunds, contour bench terraces, in addition to Rooftop WH which was of an interest. This will require training and awareness raising about all different types.

Experts and farmers highlighted a significant point which is the groundwater depletion. We can also use the water harvesting methods for groundwater recharge.

Experts encouraged to use modern irrigation techniques. Here a training course to introduce the use of rainwater harvesting to support supplementary irrigation would be crucial.

Due to the nature of the buildings in rural regions, collecting rainwater from roofs will become an important strategy for ensuring a reliable water supply.

Even though sand dams are cutting-edge technologies, more education for professionals and farmers is required to ensure that they are built and maintained properly.

Experts and farmers emphasized the effects of mimicry on adopting the projects. This point is critical because it means that few people will articulate the decision on WH projects in the future.

Figure 24. Group discussion with farmers.

Figure 25. Group discussion with experts.

Takeaway Messages

Syria would be entrapped into a country where water is scarce. RWH method provides a potential answer for meeting the increasing demand. Rooftop RWH will increase water availability by 3%, and RWH systems can withstand demands of up to 600 hm^3.

Rainwater harvesting has been the subject of research from a variety of fields in recent years due to its potential as an attractive option in agricultural settings characterized by limited availability of water resources. According to the findings, this subfield of study is taking on an increasingly significant role within the field of irrigation research.

With more focused research and experimental analysis, the techniques of RWH can be established, and with the correct oriental proposal, water volumes may be stored, and a crisis-free community might be built in the near future. Even though significant advancements have been made in this field, there is still a pressing need to conduct additional research on the following topics: the ability of rainwater harvesting systems to fulfill the irrigation requirements of a variety of agricultural climates; the factors that influence the adoption of these systems by farmers; the economic and financial viability of their implementation; and their contribution to the reduction of the effects of global climate change.

It is difficult to identify potential locations for RWH due to the presence of competing factors such as hydrological (rainfall–runoff relation), climatic (temperature), geographical (land slope), soil parameter (texture, structure, and depth), and socio-economic (population size, people's priorities and preferences with RWH and water regulations). As a result of this, significant utilization of GIS can enable the tools that are necessary to facilitate data integration.

Knowing that when implemented regularly, RWH may also serve as a reliable source of income. However, studies on the economic benefits of having more RWH on hand means are still lacking.

Spreading the practice of rainwater harvesting will assist raise water security and resilience, and enough public awareness, along with local knowledge and skills on water storage systems and management, will be a significant contributor.

Farmers' attitude towards the environmental and socio-economic benefits gained after implementing RWH will improve through an investment in community training and a commitment to post-installation support which in turn will result in strong community management systems.

Furthermore, an iterative learning cycle facilitated by past and ongoing projects' monitoring is crucial to learn about the strengths and weaknesses and grasp the potential opportunities of RWH while pursuing future projects.

We recommend the following:

There is an urgent need to conduct further research on the following topics within the context of rainwater harvesting (RWH):

1. The potential of RWH techniques to contribute to the development of social cohesion and crisis-free communities in Syria. This requires focused research, experimental analysis, and the formulation of appropriate proposals that emphasize increased stored water volumes and job opportunities.

2. The identification and analysis of assets and challenges associated with current and past RWH projects.

3. The adoption of a participatory approach that places the opinions and perceptions of communities residing in targeted areas at the forefront of decision-making processes. This approach aims to overcome obstacles hindering the adoption of RWH practices, meet local needs, select suitable project sites, and ensure project success.

4. The evaluation of rainwater harvesting systems' ability to meet the irrigation requirements of various agricultural climates.

5. The investigation of factors influencing farmers' adoption of RWH systems.

6. The examination of the economic and financial viability of implementing RWH practices, as well as their contribution to mitigating the effects of global climate change.

7. The utilization of Geographic Information Systems (GIS) to identify potential locations for RWH implementation, facilitating data integration.

8. The undertaking of field surveys at potential RWH sites to prioritize implementation based on environmental conditions and social aspects.

To raise awareness and promote the practice of rainwater harvesting, the following actions are recommended:

1. Conducting public sessions to share information, document local knowledge, and highlight the impact of RWH experiences.

2. Organizing training sessions for farmers, cooperatives, and local authorities to educate them about RWH principles and practices.

3. Arranging field visits and knowledge-sharing opportunities to showcase successful macro and micro RWH initiatives.

4. Utilizing accumulated knowledge, it is crucial to develop plans for both micro and macro RWH projects. These plans should involve local communities, local authorities, civil society organizations, and farmers, and be based on comprehensive social and environmental evaluations.

In terms of partnerships, we recommend active involvement and collaboration with civil society organizations to implement research, awareness campaigns, and practical experiences related to micro RWH projects. Local authorities play a pivotal role in facilitating research, awareness, planning, and implementation of RWH initiatives. Local communities and farmers should not only be recipients but also active participants and stakeholders in all of these activities. It is essential to foster collaboration with academia and field researchers when undertaking research and planning initiatives. Finally, international donors have a valuable opportunity to contribute to RWH initiatives as a means to enhance long-term resilience and sustainable peace in Syria.

References

Alasta, D. (2013). Reusing Rooftop Rainwater Harvesting In Households. Tishreen University Journal for Research and Scientific Studies - Engineering Sciences Series, 35(0), 115-127.

Alibraheem, A. (2014). Contributing to management and enrich of water resources using water harvesting techniques with the help of modern technologies in Salmia (master's thesis, Department of Water Engineering and Irrigation, the Faculty of Civil Engineering, Tishreen University).

Alkhaleel, S. (2015). The Role of Water Harvesting Techniques In Improving Grazing Cover Vegetation In Hama Steppe (Debah Site) (Doctoral dissertation, Department of Natural Resources and Ecology, Faculty of Agriculture, Aleppo University, Syria).

Al Omar, A. (2016). Identifying the Potential Areas for Water Harvesting Projects by Using Remote Sensing and Geographic Information System. Al Baath University Journal, 38(6), 51-80.

Ammar, R., Jabr, R., & Al-Kofari, A. (2015). Using the remote sensing technologies and the support systems in managing the rainwater and locating the ideal locations to apply the harvest systems in the southern part of the coastal mountains chain. Damascus University Journal of Basic Sciences, 31(2), 201.

Douba, A. (2013). Assessing the Performance of Water Harvesting Techniques and Maximizing Efficiency at ICARDA (Master's thesis, Rural Engineering Department, Aleppo University).

Droubi, A. (2018). Evaluation of Mechanized bunds (Vallerani water harvesting system) for improving range production in the Syrian steppe. Proceedings of the 12th Scientific Conference of the General Commission for Scientific Agricultural Research.

Khoury, W. (2021). Locating and designing a dam in Salqin Basin (Orontes Basin) using GeoMedia professional 6.1. Syrian Journal of Agricultural Research – SJAR, 8(2), 116-131.

MunlaHasan, A., Ismail, I., & Shideed, K. (2009). Financial Feasibility of Rainwater Harvesting (Vallerani Technique) in Syrian Rangelands. Damascus University, Journal of Agricultural Science, 25(2), 391-405.

Nofal, I. (2009). The Integration Between Water Harvesting and supplemental Irrigation for improved Water use efficiency In the Terraces of Fahel and Rapah areas (Master's thesis, The Department of Renewable Natural resources and Ecology, Faculty of Agricultural Engineering at Aleppo University).

AL-Saram, A. (2018). Determination of Suitable Sites for Rainwater Harvesting (RWH) in Masyaf catchment Using GIS/RS Technique. Proceedings of the 12th scientific conference General Commission for Scientific Agricultural Research.

Yaghi, T. (2015). WEAP modeling-based study of Water Accounting System and levels of water productivity in the Upper and Middle Orontes River Basin. Al-Baath University Journal.

Yasin, M., & Said, A. (2022). The Effect of the Water Harvesting Projects on some of the Economic Indicators Population in some Mountain Villages in Latakia (Syria). Arab Journal of Arid Environments, 13(1), Article 14.

Notes

1 OCHA, 2021
2 "Minister of Agriculture, Mohamed Hassan Qatana, for Sham FM" (in Arabic), Sham FM Facebook Page, May 21, 2021.
3 Kelley, C. P., Mohtadi, S., Cane, M. A., Seager, R., & Kushnir, Y. (2015). Climate change in the Fertile Crescent and implications of the recent Syrian drought. Proceedings of the National Academy of Sciences, 112(11), 3241–3246.
4 https://www.unescwa.org/sd-glossary/dependency-ratio-water
5 FAO 2019, AquaStat: Syria Country Fact Sheet, FAO: Rome.
6 CBS-SYR. Central Bureau of Statistics of Syria, population and demographic indicators. 2011.
7 MoI-SYR. Ministry of Irrigation in Syria. Agreements with neighboring countries.
8 Mourad, K. A., & Berndtsson, R. (2011). Syrian Water Resources between the present and the Future. Air, Soil and Water Research, 4, ASWR.S8076.
9 Salman, M., & Mualla, W. (2008). Water demand management in Syria: Centralized and decentralized views. Water Policy, 10(6), 549–562.
10 https://www.icrc.org/en/document/syria-water-crisis-after-10-years-war
11 IFAD (2010). Syrian Arab Republic: Thematic study on land reclamation through defrocking. International Fund for Agricultural Development. Rome, Italy.
12 FAO. 2019. Special Report - FAO/WFP Crop and Food Security Assessment Mission to the Syrian Arab Republic. Rome
13 FAO. 2021. Syrian Arab Republic: Precipitation analysis, 1980–2021. Rome. https://doi.org/10.4060/cb7151en
14 FAO,2021. Crop Monitoring and Food Security, Situation Update. North East Syria (NES), 2020/2021 Winter Season Post-Harvest Overview, North East Syria Agriculture Working Group (AWG), IMMAP, Food Security and Livelihood Unit (FSLU) & Geoinformatics Unit.
15 FAO. 2021. Special report: 2021 FAO Crop and Food Supply Assessment Mission to the Syrian Arab Republic – December 2021. Rome. https://doi.org/10.4060/cb8039en
16 Mourad, K. A., & Alshihabi, O. (2016). Assessment of future Syrian water resources supply and demand by the WEAP model. Hydrological Sciences Journal, 61(2), 393–401.
17 Kelley et.al., 2015
18 FAO. 2021. Special report: 2021 FAO Crop and Food Supply Assessment Mission to the Syrian Arab Republic – December 2021. Rome. https://doi.org/10.4060/cb8039en
19 Food and Agriculture Organization of the United Nations, "Special Report: FAO/WFP Crop and Food Security Assessment Mission to the Syrian Arab Republic," 5 September 2019, https://bit.ly/3LFOd4N
20 Increased salinity has been reported in Deir al-Zor, al-Hasaka and parts of the coastal governorates. FAO, Special Report. FAO Crop and Food Supply Assessment Mission.
21 Schwartzstein, P, Zwijnenburg, W. 2022. "We fear more war, we fear more drought": How climate and conflict are fragmenting rural Syria. PAX.
22 Daher, J., European University Institute, Water scarcity, mismanagement and pollution in Syria, European University Institute, 2022, https://data.europa.eu/doi/10.2870/99423
23 Mekdaschi Studer, R. and Liniger, H. 2013. Water Harvesting: Guidelines to Good Practice. Centre for Development and Environment (CDE), Bern; Rainwater Harvesting Implementation Network (RAIN), Amsterdam; Meta Meta, Wageningen; The International Fund for Agricultural Development (IFAD), Rome.
24 Oweis, T., D. Prinz and A. Hachum. 2001. Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments. ICARDA, Aleppo, Syria. 40 pages.
25 Beckers, B., Berking, J., & Schütt, B. (2013). Ancient Water Harvesting Methods in the Drylands of the Mediterranean and Western Asia. eTopoi. Journal for Ancient Studies.
26 Mekdaschi Studer, R. and Liniger, H. 2013. Water Harvesting: Guidelines to Good Practice. Centre for Development and Environment (CDE), Bern; Rainwater Harvesting Implementation Network (RAIN), Amsterdam; MetaMeta, Wageningen; The International Fund for Agricultural Development (IFAD), Rome.

27 https://depar.unescwa.org/book-page/rainwater-harvesting

28 Evans JP (2009): 21st century climate change in the Middle East. Climatic Change (2009) 92:417–432

29 Oweis, T., Prinz, D. and Hachum, A. 2001. Water Harvesting: Indigenous Knowledge for the Future of the Drier Environments, ICARDA: Aleppo, Syria.

30 FAO. 2016. Assessment of the water harvesting sector in Jordan.

31 Oweis T.Y. Rainwater harvesting for restoring degraded dry agro-pastoral ecosystems: a conceptual review of opportunities and constraints in a changing climate. Environmental Reviews. 25(2): 135-149. https://doi.org/10.1139/er-2016-0069

32 https://acsad.org/

33 million m^3

34 Mourad, K.A. & Alshihabi, O. (2016) Assessment of future Syrian water resources supply and demand by the WEAP model, Hydrological Sciences Journal, 61:2, 393-401, DOI: 10.1080/02626667.2014.999779

35 million m^3

36 https://acsad.org/

37 Oweis T. Y. (2017). Rainwater harvesting for restoring degraded dry agro-pastoral ecosystems: a conceptual review of opportunities and constraints in a changing climate. Environmental Reviews. 25(2): 135-149. https://doi.org/10.1139/er-2016-0069

38 Somme, G., Oweis, T., Abdulal, A., Bruggeman, A., and Al, A. 2004. Micro-catchment water harvesting for improved vegetative cover in the Syrian Badia. On-farm water husbandry research reports series No 3. ICARDA, Aleppo, Syria.

39 Oweis, Theib & Hachum, A.. (2012). Supplemental Irrigation, A Highly Efficient Water-use Practice.

40 http://gcwr.gov.sy/?page=show_det&category_id=24&id=369&keyword=%D8%AD%D8%B5%D8%A7%D8%AF&lang=ar

41 E. De Pauw, T. Oweis, and J. Youssef. 2008. Integrating Expert Knowledge in GIS to Locate Biophysical Potential for Water Harvesting: Methodology and a Case Study for Syria. ICARDA, Aleppo, Syria. iv + 59 pp.

42 Bakir, M and Liang, R.L. 2004. Rainwater Harvesting Techniques in Syrian Desert (Badia Basin). Journal Of Lake Sciences. Vol. 17.

43 de Miranda, A.. Water-harvesting Tradition in Syrian Steppe, Procedia Engineering, Volume 89,2014, Pages 1522-1528,ISSN 1877-7058

44 Berking, J., Beckers, B. and Schütt, B. "Runoff in Two Semi-Arid Watersheds in a Geoarcheological Context: A Case Study of Naga, Sudan, and Resafa, Syria". Geoarchaeology 25 (2010), 815–836.

45 Sankari, Muhammad Nazir (1988). Applied Botanical Ecology. Publications of the Directorate of University Books and Publications, University of Aleppo. Syrian. 321 pages.

46 Oweis, T. and Taimeh, A. 2001. Farm water-harvesting reservoirs: issues of planning and management in dry areas. In Proceedings of a joint UNU-CAS international workshop: Integrated Land Management in Dry Areas, Beijing, China, 8–13 September 2001. Edited by Z. Adeel. United Nations University, Tokyo, Japan. pp. 165-182.

47 General Organization for Remote Sensing. Syria, projects.

48 http://gogreensyria.blogspot.com/2011/02/blog-post.html

49 Sumy, G. 2003. Water Resources Uses in 2003 in The Syrian Arab Republic for agricultural purposes until 2030. GCSAR. Water Resources Science and Technology Conference, the 43rd science week. Damascus University, p.180.

50 1 donum=0.1 hectares=1000 m2

51 https://qcat.wocat.net/en/wocat/technologies/view/technologies_1549/

52 https://qcat.wocat.net/en/wocat/technologies/view/technologies_1410/

53 Ziadat F. Challenges And Opportunities Of Soil Conservation And Land Management In The Dry Areas. (2013).

54 Ziadat, Feras M. et al. "Soil conservation and water harvesting to improve community livelihoods and fight land degradation in the mountains of Syria." (2013).

55 https://qcat.wocat.net/en/wocat/approaches/view/approaches_2631/