An Assessment of the Suitability of Wadi Sarkhar Watershed for the Implementation of Water Harvesting Projects, Wasit-Iraq

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Abstract

Extreme climate conditions represent one of the main challenges in arid and semi-arid regions. Water harvesting applications in various regions of the world have shown a tangible effect in reducing the impact of these climatic changes. The study area is exposed to such circumstances over the years. Wadi Sarkhar watershed-Wasit Governorate / Iraq, represents a transboundary watershed between Iraq and Iran, with an area estimated at 1134 square kilometers, and an elevation ranging between 1501 meters within the mountainous region in Iran and 14 meter in areas of drainage in the Hor Ash Shwaicha. The Soil and Water Assessment Tool (SWAT) model was used for watershed delineation and assessing the water balance elements. The initial assessment of the suitability of the area for the establishment of water harvesting projects indicated its suitability to implement several forms of water harvesting systems, especially in the Iraqi part in terms of the slope that ranged between 0-2% in most of this part, as well as the quantity and the amount of rain reached 174.1 mm annually. Floodwater and macro- catchments water harvesting Systems showed greater compatibility with the area conditions compared to Rainwater and Micro-catchment water harvesting systems. Some Rainwater harvesting systems may be more preferable for implementation due to their low cost, ease of application at the individual level, with the advantage of combining the catchment area and the application area in the same place.

Keywords: Wadi Sarkhar, Wasit, Water Harvesting and SWAT

تقييم مدى ملاءمة مستجمع مياه وادي سرخر لتنفيذ مشاريع حصاد المياه، واسط / العراق

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الخلاصة

تمثل الظروف المناخية القاسية أحد التحديات الرئيسية في المناطق القاحلة وشبه القاحلة. أظهرت تطبيقات حصاد المياه في مناطق مختلفة من العالم تأثيرًا ملموسًا في الحد من تأثير هذه التغيرات المناخية. تتعرض منطقة الدراسة لمثل هذه الظروف على مر السنين. حوض وادي سرخر محافظة واسط / العراق، يمثل حوضاً مائياً عابرا للحدود بين العراق وإيران، تبلغ مساحته 1134 كم^2، ويتراوح ارتفاعه بين 1501 مترا داخل المنطقة الجبلية في إيران و14 مترا في مناطق التصريف في هور الشويجة. تم استخدام نموذج سوات (أداة تقييم الترب والمياه) لترسيم حدود حوض وادي سرخر وتقييم عناصر الموازنة المائية. أوضح التقييم الأولي ملاءمة المنطقة لإقامة مشاريع حصاد المياه وتنفيذ عدة أشكال من أنظمة حصاد المياه، خاصة في الجزء العراقي حيث الانحدار الذي تراوح بين 0-2٪ في معظم هذا الجزء، وكذلك الأمطار التي بلغت 174.1 ملم سنويا. أظهرت أنظمة حصاد مياه الفيضانات والاحواض المائية الكبيرة توافقًا أكبر مع ظروف المنطقة مقارنةً بأنظمة تجميع مياه الأمطار وأحواض المياه الصغيرة. قد تكون بعض أنظمة حصاد مياه الأمطار أكثر تفضيلًا للتنفيذ نظرًا لتكلفتها المنخفضة وسهولة التطبيق على المستوى الفردي، مع ميزة الجمع بين منطقة تجميع المياه ومنطقة التطبيق في نفس المكان.

الكلمات المفتاحية: وادي سرخر، واسط، حصاد المياه وسوات.

Introduction

Water harvesting (WH) involves the collection, concentration and storage of rainwater that runs off a natural or man-made catchment surface. (Lee and Visscher, 1990). The applications of different water harvesting systems around the world have shown tangible changes in terms of providing part of the water demands in areas of high scarcity or those suffering from waves of climate extremes. The implementation of any of the water harvesting systems in a given area is subject to the availability of several conditions related to societal, climatic, and natural aspects. The literature that deals with the issue of water harvesting as a description, analysis or implementation, laid down many requirements that must be met in a place to be suitable for the establishment of successful water harvest projects. All these requirements may be available in a specific place or some of them may be available at times, and they may also exist in varying degrees. Consequently, this affects the level of results sought from the implementation of any of these projects. Critchley and Siegert (1991) mentioned people's priorities (The Prevailing Social and Cultural Aspects), in addition to the criteria for basic technology that included (Slope, Soil, And Cost) as the most important requirements that must be achieved when selecting the water harvesting's technique and site.

Oweis, *et al*., (2012) listed the parameters for identifying suitable areas for water harvesting as, rainfall characteristics, hydrology and water resources, vegetation and land use, topography, soil type and soil depth, socioeconomics and infrastructure. Mekdaschi and Liniger (2013) prepared a table for the suitability and limitations of applying water harvesting systems based on many kinds of literature and databases in the field of applicability, a large number of criteria were listed, the most important of which were rainfall, terrain, slope, water use, land use, human or mechanical effort required, cost, and many others. (Ali, 2018) developed number of criteria to determine the suitability of Badra area for water harvesting, and these criteria were (Slope, Riverine Level, NDVI, Precipitation, and Distance from Roads). Certainly, rain is the mainstay of all water harvesting activities, and its availability in any quantity may make a big difference in some cases. Most of the other criteria vary in importance, but it is noted that the slope of the land is of special importance to its direct relationship to the generation of surface runoff, its flow velocity, the degree of soil erosion in the catchment area or application area, and thus select the proper water harvesting system. The other requirements are, mechanization that may only be required in large areas, also the human effort required can be high depending on the type of system applied. In general, experience is required in implementation and maintenance. It needs financial support for implementation and according to the type of applied system. It is worth mention that an application in some countries around the world showed an increase in production, ranging between 30-400%.

In this paper, the rain and slope factors were used to determine the suitable places for constructing different water harvesting systems.

Materials and Methods

Location of the Study Area

The area is located between longitudes 45° 55' 00" – 46° 30' 00” and latitudes 32° 45' 00”- 33° 12' 00" in the Wasit Governorate, specifically on its eastern borderline, confined between the watersheds of Galal Badra River in the north and the Al-Chabbab River in the south.

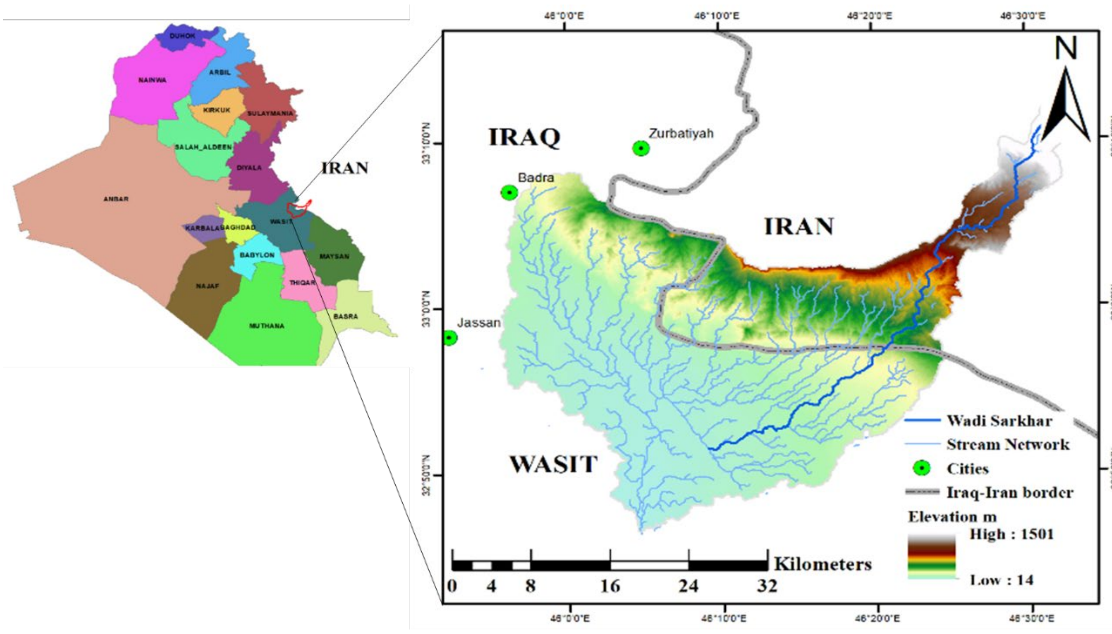

Figure (1) Location of the Study Area.

The headwaters of Wadi Sarkhar are in the Pashtakuh mountain ranges, and it represents a seasonal valley in which water flows during periods of severe rainstorms, and in other seasons the weather is dry. Wadi Sarkhar is the main watercourse in this watershed, in terms of the amount of water and the volume of sediments that drain through it. In addition to a network of small tributaries, Wadi Sarkhar drains its water toward the southwest in Hor Ash-Shwaicha, Fig. (1). There are few studies that specifically dealt with this area, the last of which was a study of (Matuq and Oreibi, 2019) which focused on morphometric processes in Wadi Sarkhar and ground forms resulting from them.

Geologically, the region contains the Tertiary and Quaternary formations. The Tertiary Age formations expose in the highland regions, which are mostly located in Iran, with a small part of them exposes inside Iraq, southeast of Badra, represented by the Bai Hasan and Muqdadiyah formations. The Quaternary deposits cover the greater part of the area and are represented by sheet runoff deposits, flood plains deposits, alluvial fans, some Aeolian deposits in the form of dispersed sand dunes, and depression fill deposits. (Barwary, *et al*., 1992), Fig. (2).

According to (Al-Kubaisi, 2004), the area is classified within an arid to semi-arid climate, with a total annual rainfall of 171 mm, and 3,273 mm evaporation.

Methodology

SWAT model was used for watershed delineation of Wadi Sarkhar, in addition to calculating the elements of the water balance within this watershed, including the volume of the resulting sediments. SWAT is a basin-scale, continuous-time model that works on a daily time step and estimates the effect of management acts on water, sediment, and agricultural chemical yields in ungauged basins (Arnold, *et al*., 1998). Thus, SWAT has emerged as one of the most popular models for basin studies and has been widely used in dealing with many hydrological and/or environmental problems (Gassman, *et al*., 2014).

SWAT Model Requirements are:

- Digital Elevation Model (DEM): the SRTM DEM with a 30-meter resolution was used. Fig. (3a).

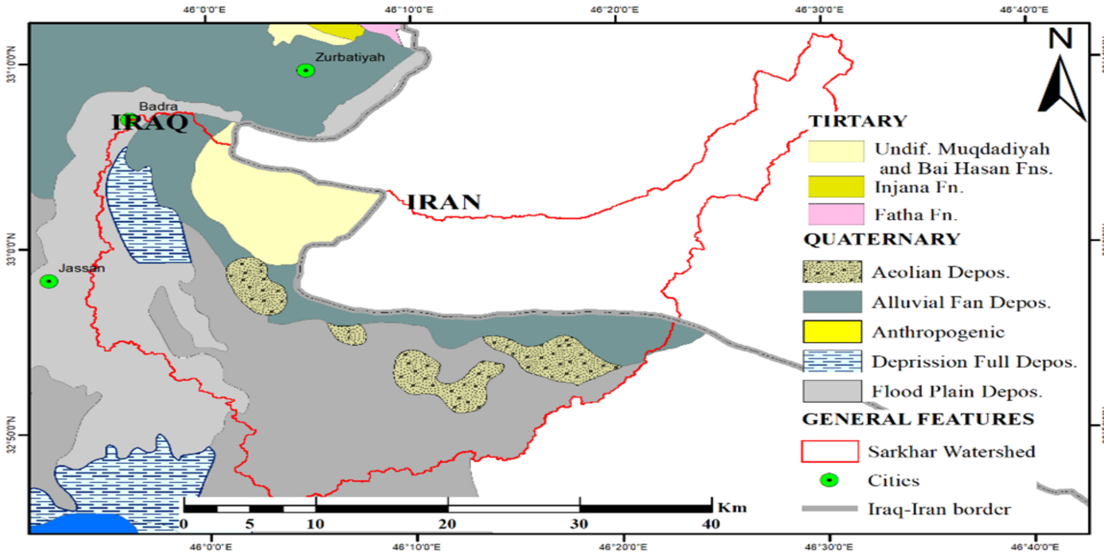

Figure (2) Geological Map of the Study Area.

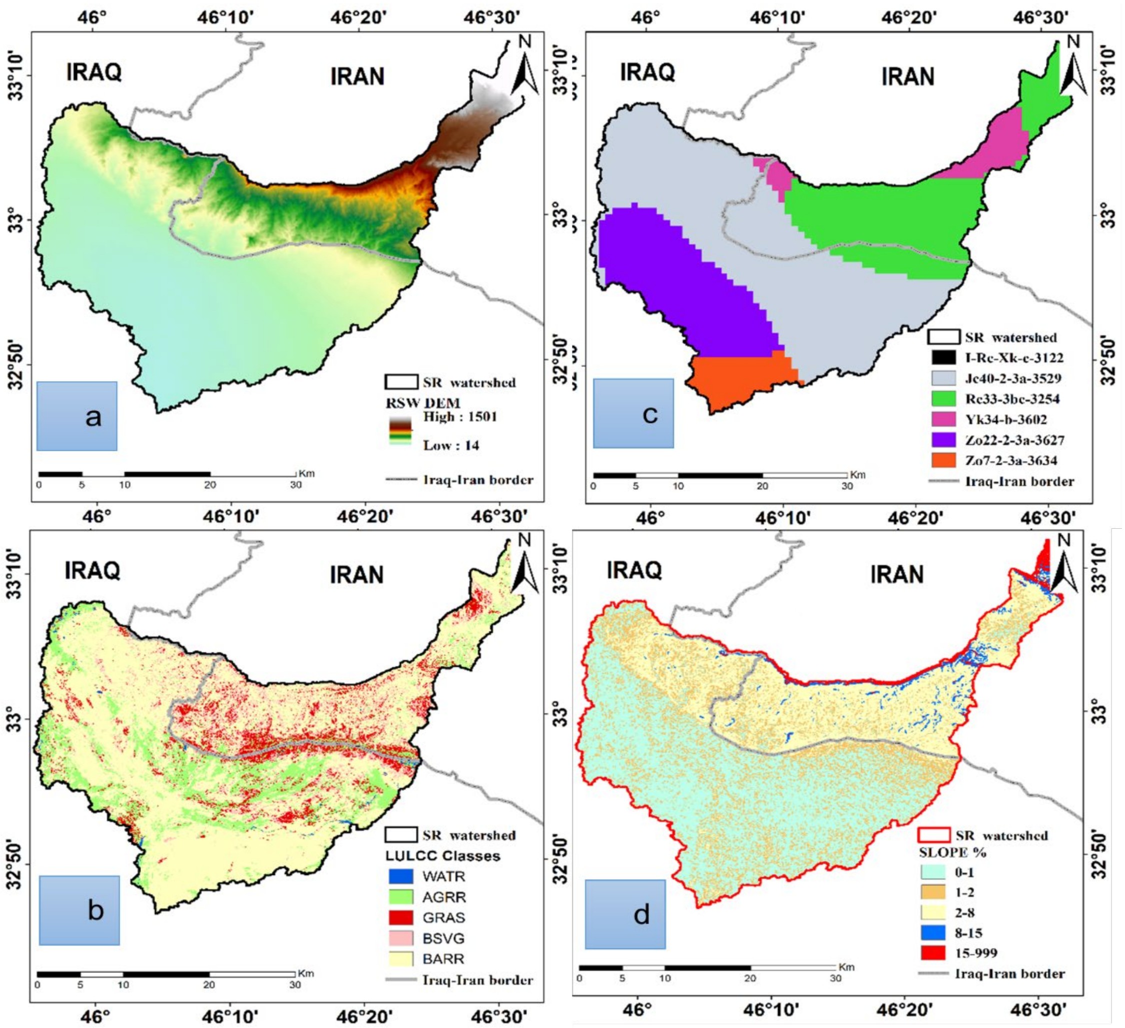

Figure (3) (a) DEM, (b) LULC Map, (c) Soil Map and (d) Slope Map.

- Land Use Land Cover map (LULC): Landsat 8 satellite images with a spatial resolution of 30 meters which was processed within the ERDAS software. For creating LULC map, unsupervised classification was applied. Fig. (3b).
- Soil map: extracted from Digital Soil Map of the World (DSMW) version 3.6 provided by Food and Agriculture Organization (FAO) (FAO, 2007). Fig. (3c).
- Slope map: derived from DEM. Fig. (3d).
- Climate data: The National Centers for Environmental Prediction (NCEP) produced the Climate Prediction System Reanalysis (CFSR). SWAT requires precipitation, relative humidity, wind speed, solar radiation, and min/max air temperature.

The study area suitability for establishing WH projects was examined in accordance with common requirements that listed in (Mekdaschi and Liniger, 2013) where they Summarize these requirements in terms of numbers and description. As for rain, it ranged between 100-1500 mm annually according to the applied system, while the slope ranged between 0-50%.

Results and Discussion

According to watershed delineation resulted from SWAT model, the total area of Sarkhar watershed (SRW) is 1134 km^2. About 777 km^2 (68.5 %) of which is located within the Iraqi borders, and it is a semi-flat area with a slight slope (0-2%), with the exception of the northwestern part of the watershed, which represents an extension of the mountainous region of high slope. The rest 357 km^2 is located within Iran, which is mostly represented in mountainous areas with steep slopes, therefore, the erosion rates are greater, and the runoff water has a high sediment load. Regarding to LULC, the region is dominated by barren land with about 62%, Fig. (3b). According to the (FAO) World Soil Map, the region contains seven classes of soils, Fig. (3c). All these classes are of the D type concerning the hydrologic group. Most of the Iraqi part of SRW has a slope ranged between 0-2%. Other part inside and outside Iraq has steep slope, Fig. (3d).

Along the foothill part of the study area, many valleys developed by the waters coming from the nearby highland areas. These valleys gradually flow within the flat area, releasing their loads of water and sediments in the form of sheet runoff or sometimes develops to torrents. The water of this area flow towards Hor Ash Shwaicha, Fig. (4).

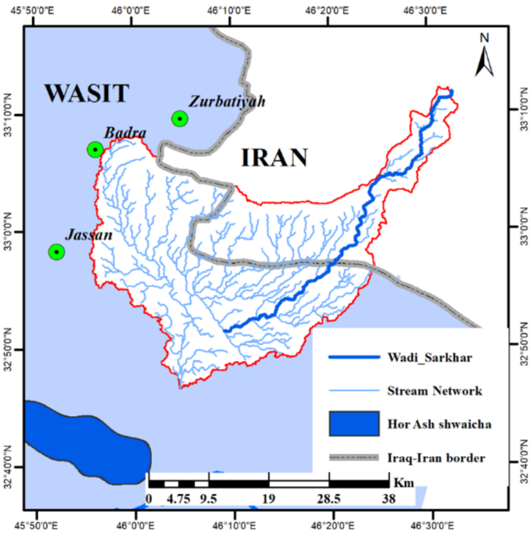

Figure (4) Stream Network.

The Water balance elements SRW resulted from the hydrological simulation of the SWAT model are shown in Fig. (5). Also, SWAT model simulation results showed that the area produces an average of 383,292 tons of sediments annually. This quantity is carried by the running water towards the discharge are-as within the Iraqi part of the watershed.

Regarding the rainfall, WH systems require a minimum annual rainfall of 100 mm for Flood Water Harvesting (FWH) systems and 200 mm for Macro and Micro catchment systems.

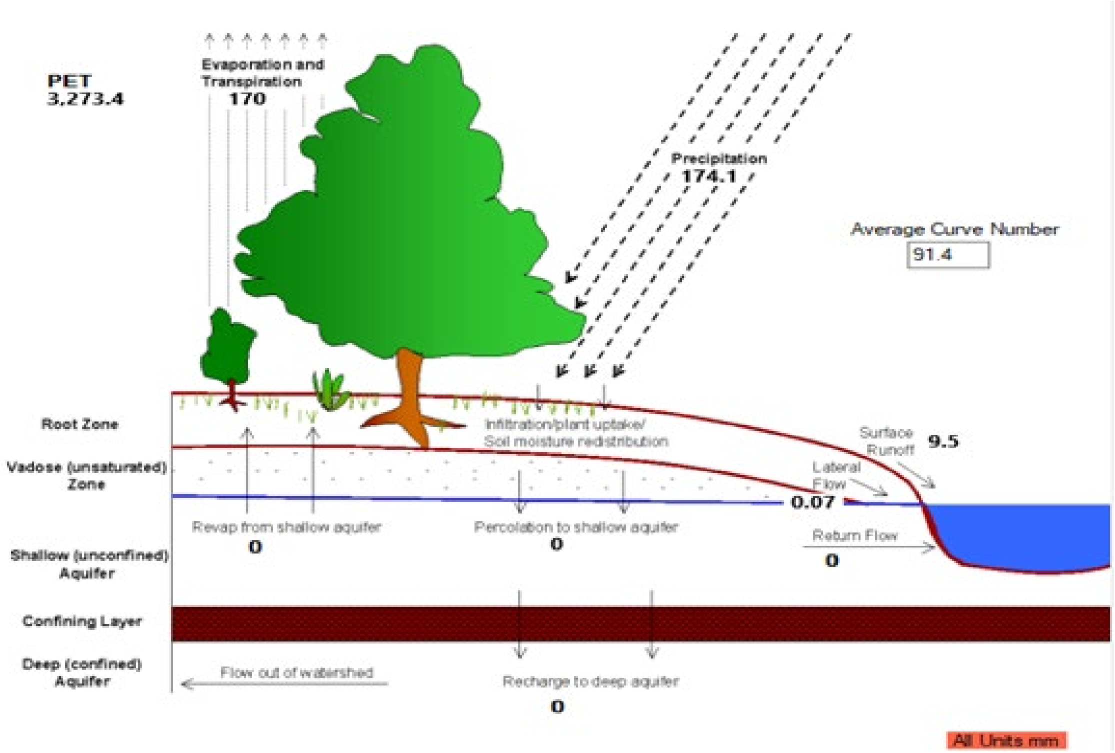

Figure (5) Water Balance Elements. All Units are in mm. CN without Unit.

The average annual precipitation in SRW is 174.1 mm which fulfills the requirement of FWH and can be considered acceptable for both Macro and Micro catchment systems as the difference between it and the minimum required is around 12.6%. Al-so, the climatic data of the study area showed that precipitation in some years reaches more than 200 mm, and this pro-vides a better opportunity to collect larger quantities of water and more achievement of the requirements for implementing these systems. The annual surface runoff in this area was 9.5 mm that corresponds to 5.4 % of the total precipitation. This value is considered very little when speaking in terms of water harvesting, as the remaining amount goes as evaporation losses. What must be taken into account is that this part is lost in the summer months, and since water is harvested during and shortly after the rains, so the harvested water will not be subjected to evaporate at the same degree if it is not harvested. Storing water as soil moisture, for re-charging groundwater, or using it directly as irrigation water (When Using Certain Systems) will greatly contribute to reducing the levels of losing water, and this of course is one of the benefits of water harvesting. It was found that both RWH and FWH, or in another word, both Micro and Macro WH systems could be applied in the region, each according to its conditions. Both categories contain many systems, and the potentiality of applying any of these systems will be evaluated in each part of the region.

FWH Systems Applicability

FWH is most often implemented within the seasonal watercourse. Figure (6) represents the suggested location for such a system in terms of the presence of the watercourse, the required slope and the isolation of the collection area from the application area. The catchment area is located in the Iranian part of SRW, which is characterized by a high slope. The mainstream is represented by Wadi Sarkhar.

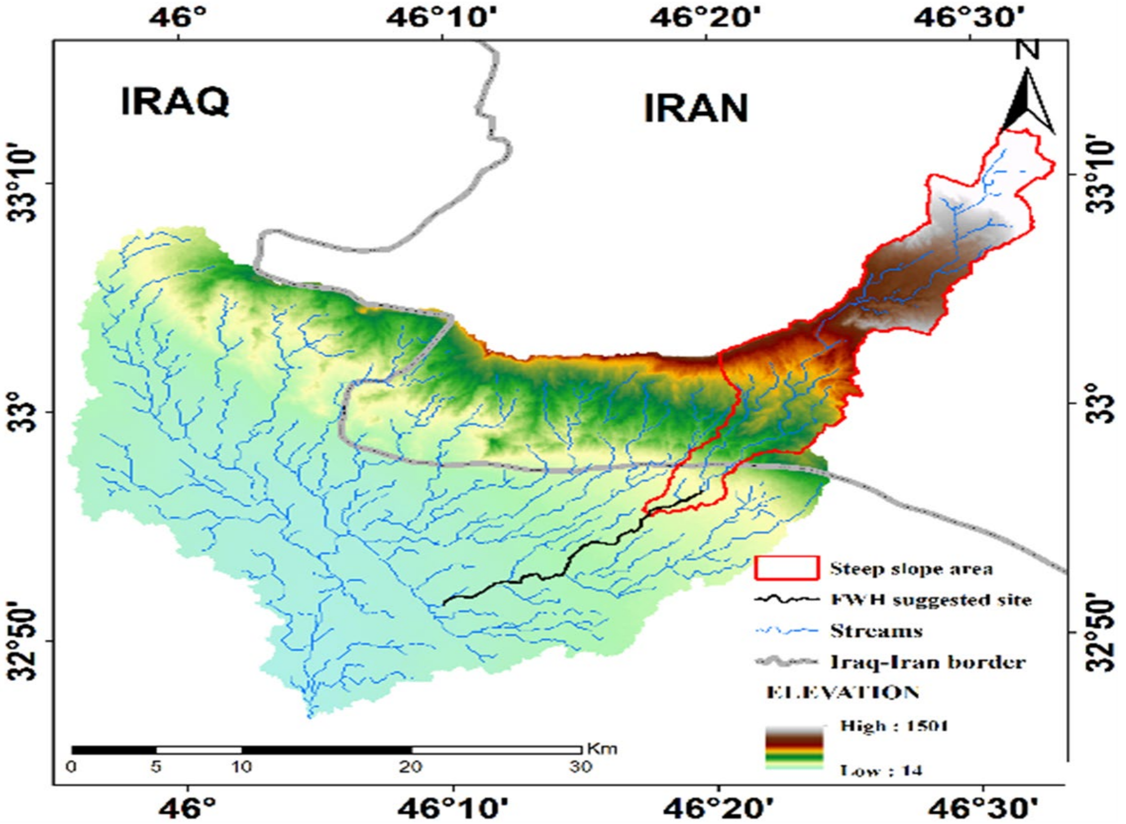

Figure (6) Steep Slope Area in SRW and Suggested Sites for Implementing FWH Systems.

Figure (7) Left: Small Farm Reservoirs (http//www.agric.wa.gov.au), and Right: Wadi-bed Cultivations (Oweis, *et al*., 2001).

About the terrain requirement, the area fulfills the FWH conditions, which stipulate "spate irrigation: where high-lands meet alluvial land, and downstream areas receive water from upstream catchments in form of floods during heavy rainfall". This corresponds to the situation of the region, especially the southeastern part (The Steep Slope Area), Fig. (6). Many systems fall under this category of water harvesting forms, which in turn were classified into two parts, systems that are established within the valley channel (Wadi Bed Systems), and the systems are established outside the valley channel (Off-wadi Systems).

Wadi bed WH, includes three systems, small farm reservoir, wadi bed cultivation, and Jessour. Fig. (7). In a small farm reservoir system, a small barrier is established to confine all or part of the valley's flow and is ponded within the streambed. This method pro-vides quantities of water that can be used later for planting or watering animals, as well as providing the opportunity to water infiltration and recharging the groundwater. Also, the nutrients rich sediment that will accumulate can be used for agricultural purposes. This system can be constructed along the course of Wadi Sarkhar (Within the Iraqi Part of it, of Course), and local materials can be used in the construction of the reservoir barrier. Wadi bed cultivation and jessour, both are relatively the same, except that jessour is constructed in valleys with a high slope, while wadi bed cultivation is established in valleys with a slight slope, and thus it's more applicable to this case. This system is also similar to the first system (Small Farm Reservoir) and it can be said that over time, it could become as a wadi bed cultivation.

This system can be achieved by the construction of a small dam or dike (not more than 1-meter height) across the wadi to reduce the flow speed and allow soil-sediments to settle. The accumulation of sediments behind the walls will create a flat ground, rich in natural elements, and suitable for cultivation after the end of runoff season. Like the first system, it can be established along the course of the valley and at specific distances from one site to another, depending on the degree of slope. The length of the proposed wadi path is approximately 22 km (Bold black line in figure (6), with a slope rating of 0.002. This system can be constructed in several places depending on the easiest to implement in terms of valley width and availability of wall construction materials. If 1 km is the distance from one application site to another, 22 water harvesting sites can be implemented. This method can achieve many benefits, including, providing the suitable land for cultivation and guaranteed production to a large extent for its rich soil and providing suitable moisture for planting and this will achieve tangible stability for the inhabitants. Also, the trapping of sediments behind will reduce its accumulation in Hor Ash Shwaicha and allow a greater volume of water storage in it. The second part of water harvesting systems comes under the name (Off- wadi Systems), where the harvested water is applied outside the wadi bed. Most of these systems require structures used to force the water to leave its natural course and flow to nearby areas prepared for cultivation. Off-wadi includes several systems, namely: Water-spreading, large bunds, Hafaer, Tanks, Cisterns, Liman, and Hillside conduits. Fig. (8).

-Water spreading system: this sys-tem can be established on both sides of the Wadi Sarkhar, Fig. (6) in locations where the bottom of the valley is suitable for the establishment of the water diversion barriers that rising the water level and directing it toward transporting channels in order to reaching it to the application areas.

- Large bunds: One of the effective measures is to control surface runoff by holding large quantities of its water be-hind these bunds. These earth bunds are established with a height of 1-2 meters and a length ranging between 10-100 m along the contour lines and perpendicular to the direction of surface runoff, and they are either semi-circular, trapezoidal, or V-shaped. The wide extension of large bund (10-100m) is because they deal with sheet flow, which is by nature not concentrated in a specific flow channel, so the extension of these bunds for a large distance provides an opportunity to capture a large part of these sheet water flow.

The SRW area is dominated by sheet runoff coming from highland areas. The water is trapped behind the bunds until they are full and the excess water flows from both ends towards the next bund, and so on. Most of the area are suitable for implementing this system as shown in Fig. (9).

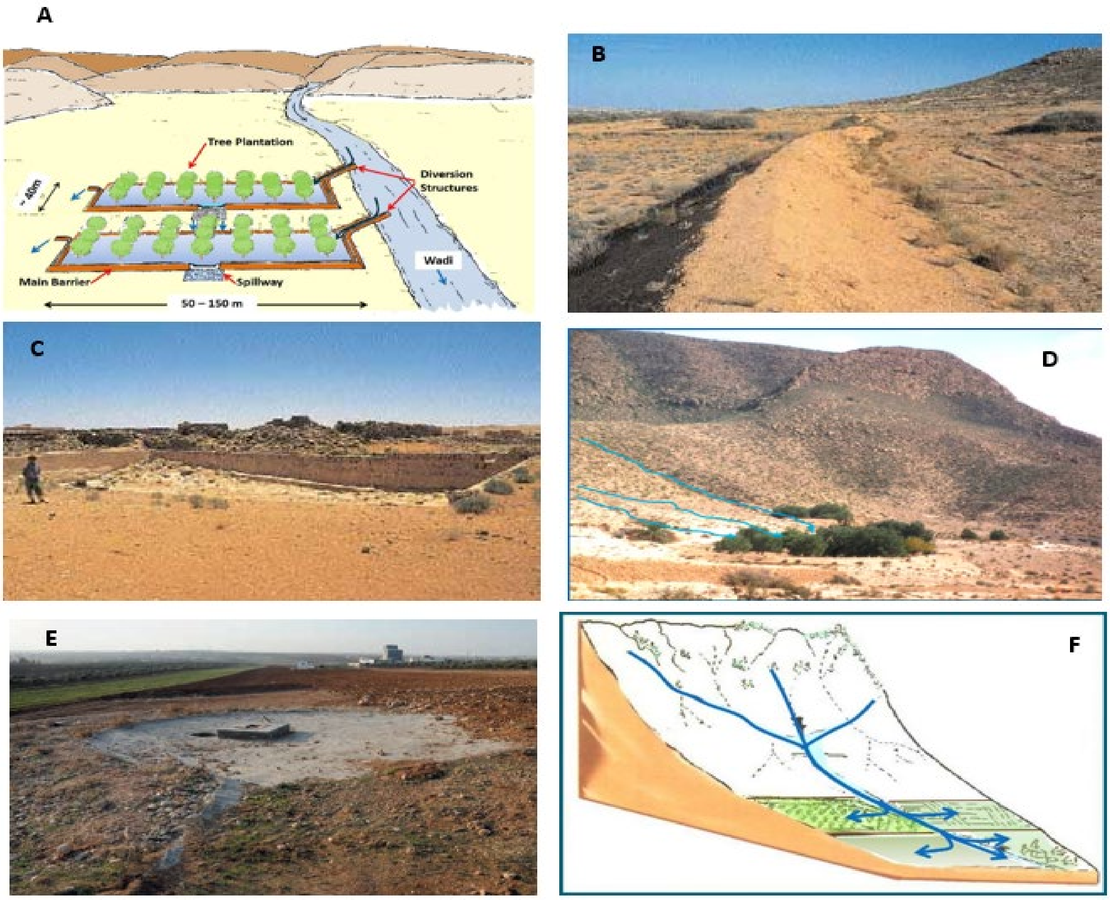

Figure (8) Macro-Catchment off-wadi FWH Systems, (A) Water-spreading (Prinz, 2013), (B) Large Bunds (Oweis, *et al*., 2001), (C) Tanks and Hafaer (Oweis, *et al*., 2001), (D) Limans (Prinz, 2014), (E) Cisterns (Mekdaschi and Liniger, 2013), and (F), Hillside Conduits (Oweis, *et al*., 2012).

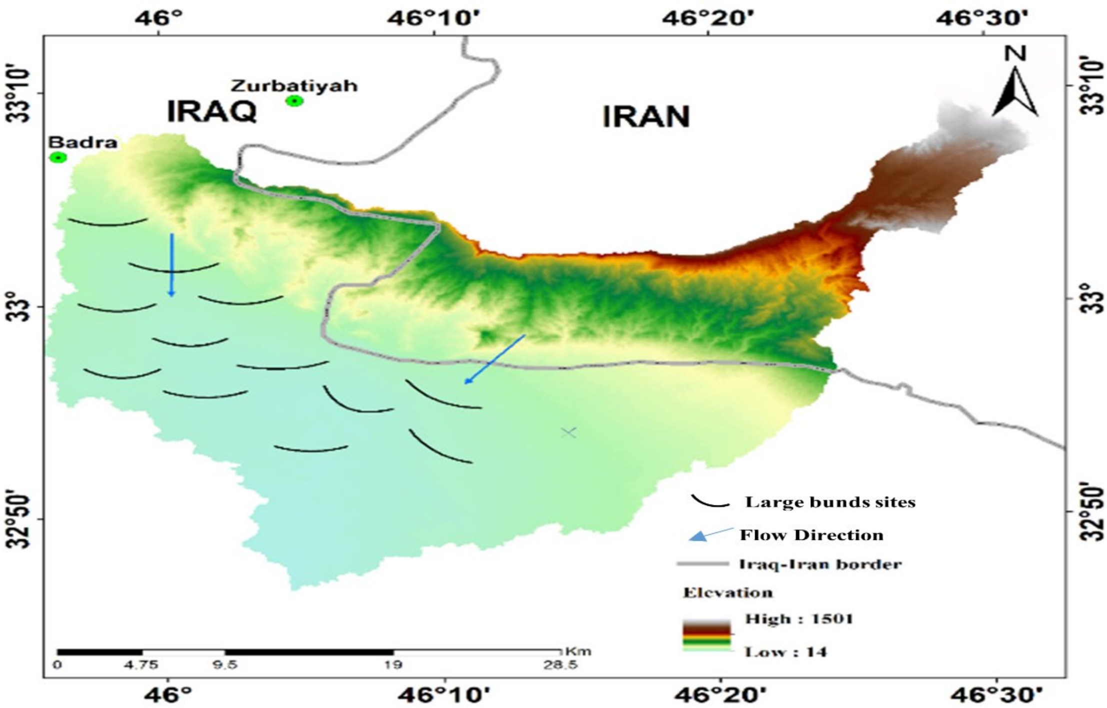

Figure (9) Proposed Sites of Implementing Large Bounds Systems.

In most cases, the completion of this system requires a mechanical effort due to the size of the constructor. This measure contributes to increasing soil moisture, enhancing groundwater recharge, reducing surface runoff velocity and thus reducing soil erosion rates. Also, this system is effective in reducing the flood risks that threaten the region from one period to another. Tanks, Hafaer, and Cisterns: These systems represent structures for storing water within the ground, to be used later in domestic and livestock consumption, or for supplemental irrigation during very dry seasons, as they can bridge the gap in water scarcity and complete the agricultural season. They daffier from each other by their storage capacity. There are not many requirements for building these systems, but in general, they are built on lands with a slight slope, and water is collected either from surface runoff or water resulting from the application of water spreading system.

Most of the region has demonstrated the ability to implement these systems, because, as mentioned above, their few requirements, as they can be applied at an individual level for various purposes, taking into account the reduction of losses resulting from evaporation and percolation, in addition to preparing the path for water flow towards the system, removing obstacles, and decreasing the water load that may accumulate and reduce storage capacity over time. These systems, depending on the size of the constructed system, may provide quantities of water ranging from several to tens of thousands of cubic meters, which will make a significant difference during severe dry seasons.

- limans and hillside conduits: These systems are established in areas with slight slopes located at the hillsides, and this makes the areas close to the borders are best suited for their application, specifically those in the north, where the highland areas are within the borders of Iraq, while in the southeastern parts the highland chains are directed to the inside of Iran It makes it unsuitable to implement these systems. With these systems, arable areas are created by investing harvested water in growing fruit trees, forest trees, or crops that can withstand water shortages in dry months. Fig. (10) represents the locations proposed for implementing these systems.

RWH Systems Applicability

The second main category of water harvesting measures to be assessed for their viability within SRW are rainwater harvesting (RWH) systems, which sometimes come under the name of micro-catchment water harvesting. The area fulfills the rainwater harvesting (RWH) requirements, whereby in terms of slope, the conditions of high or slight slope in both collecting and application areas correspond to large parts of the area. Many systems fall within this category, which are largely the same in their implementation requirements. Among the most important of these systems are Pitting or Small pits (Zai), Meskat, Small semicircular/trapezoidal bunds or half-moons, contour ridges, living (Vegetative) barriers, runoff strips, small runoff basins (Negarim), and Roaded catchment (Inter-row Systems), Fig. (11).

All these methods demonstrate their applicability within the region, as its implementation is often within limited are-as, and its broad application is deter-mined by the availability of financial and human capabilities.

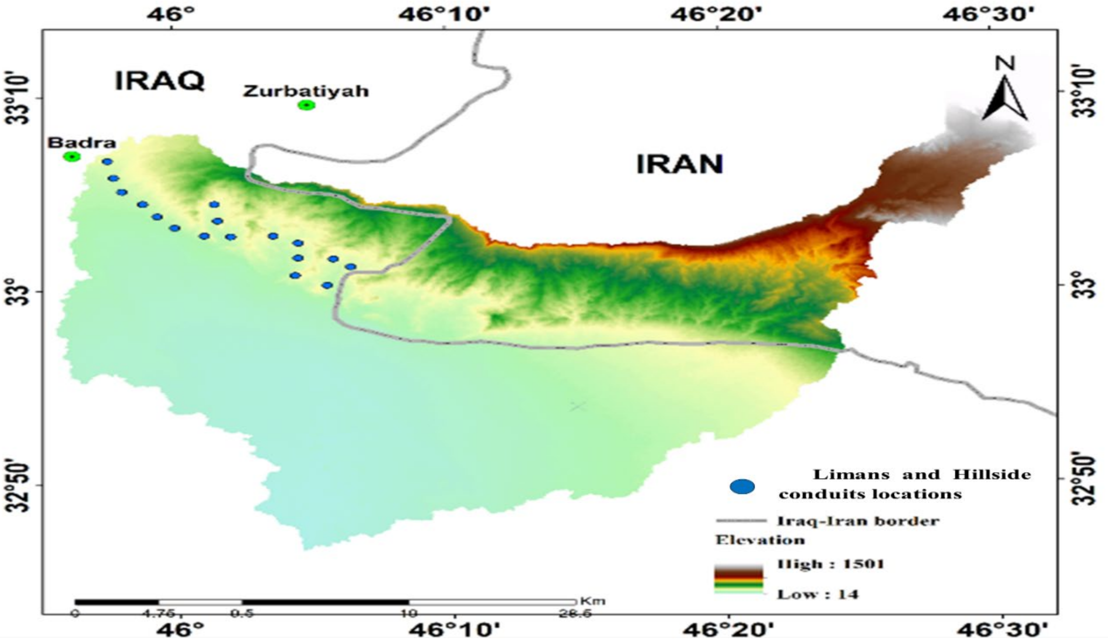

Figure (10) Proposed Sites of Implementing Limans and Hillside Conduits Systems.

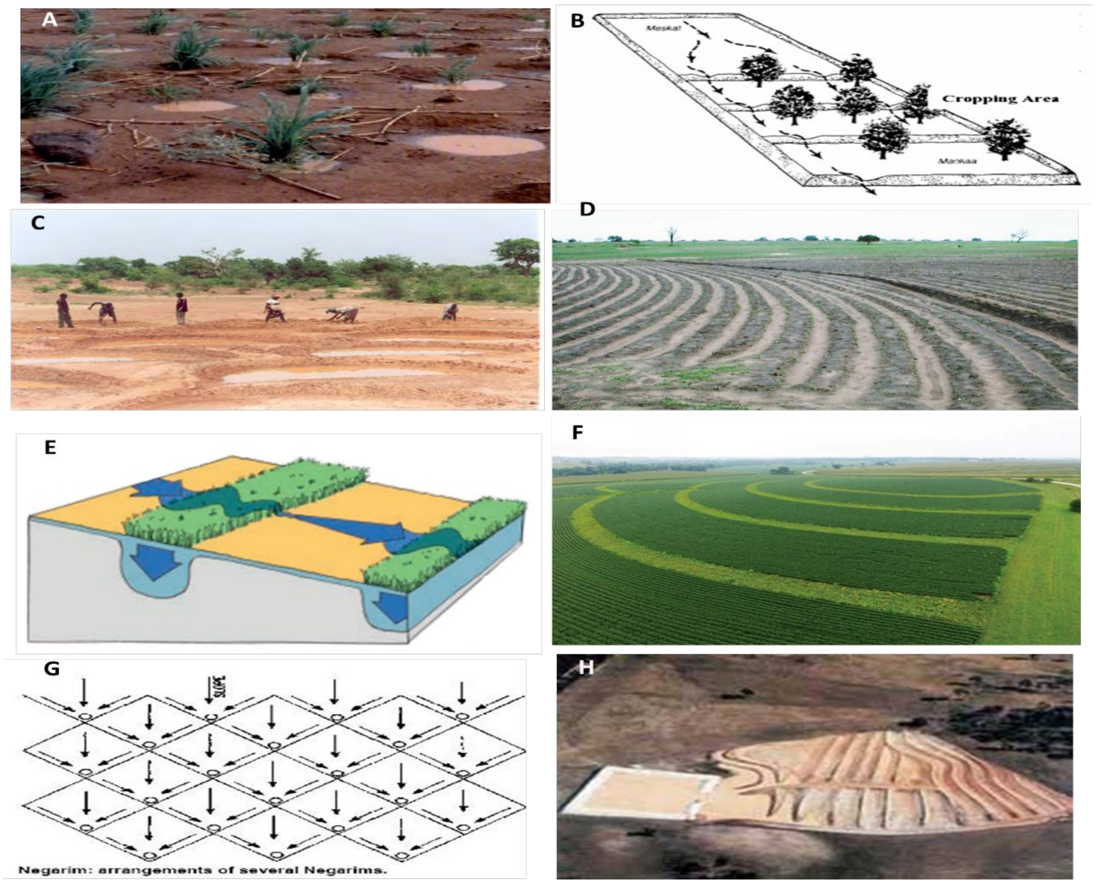

Figure (11) Micro-catchment RWH Systems, (A) Small Pits (Zai), (Critchley and Sieger, 1991), (B) Meskat, (Prinz, 1996), (C) Small Semicircular or Half-moons, (AFDB, 2008), (D) Contour Ridges, (Oweis, *et al.*, 2001), (E) Living (Vegetative) Barriers, (Mekdaschi and Liniger, 2013), (F) Runoff Strips, (Oweis, *et al.*, 2001) (G) Small Runoff Basins (Negarim), (Critchley and Sieger and (H) Roaded catchment (Inter-row Systems), (Oweis, *et al.*, 2001).

Also, the land ownership factor may constitute one of the determinants in the implementation process of any of the systems, so the form of application may be limited accordingly, but in general the area possesses all the ingredients that enable the establishment of water harvesting systems with a high degree of flexibility to choose the most appropriate among them. The reliance of these systems on direct fallen rains and their unique design as the harvest area is the area of application itself, which gives it high flexibility in application even within small areas, as well as saves a lot of effort and costs compared to other harvesting methods.

Depending on the availability of funds and labor, any of these systems can be implemented gradually, starting with the lowest requirements such as small pits, semi-circuits and Negarim. Water harvesting in this region achieves many direct and indirect benefits, the most important of which are:

-support the agricultural sector and increased production, especially since the region mostly does not have a surface water source.

-Using harvested water in supplemental irrigation in areas that depend on well water.

-Enhance the underground storage, where the SWAT simulation showed the absence of re-charging groundwater in normal conditions.

-Reducing soil erosion rates and providing new lands for agriculture while improving the quality of agricultural soils by utilizing sediments.

- Minimizing the negative effects of floods.

-Improving income for the region's residents.

Conclusion

Wadi Sarkhar appears as one of the promising and suitable areas for implementing various water harvesting systems of both types, FWH and RWH, with what it possesses in terms of land, terrain and annual rainfall rates. Considering the amount of rain, FWH systems showed more applicability than RWH systems, but the first needs for more effort and costs makes the application of RWH systems more appropriate, especially since most of them can be implemented with individual effort within small areas and without the need for large structures.

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