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Selection of Suitable Sites for Rainwater Harvesting Structures in the Northern of Iraq: A Review

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Abstract

Since the 1970s, rainwater harvesting has gained more attention, specifically in semi-arid and arid areas. It is essential to take into account how much water can be collected from a single catchment site. Rainfall that has been harvested provides an alternative source of water in the northern region of Iraq. Numerous scholars have developed and executed a range of strategies and guidelines to choose appropriate locations and methods for rainwater harvesting (RWH). However, choosing the optimal method or set of rules for the choice of site is challenging. This study's primary goal was to evaluate previous research regarding the selection of appropriate RWH locations in northern Iraq by assembling a list of the most important techniques and guidelines that evolved over the previous thirty years. The primary factors considered in the process of choosing acceptable locations for RWH were soil type, slope, land use/cover, rainfall, and runoff. A literature review for RWH indicated that these criteria were chosen more frequently and significantly, and the opinions of experts should be used to establish the weight of each criterion. The majority of studies select RHW sites using geographic information systems, hydrological models, and multi-criteria analysis.

1. Introduction

Among all the natural resources, water is perhaps the most important. There is a tremendous quantity of water on Earth, but tragically, less than 1% of it is useful to humans [1], more than 99 percent of it is floating in the atmosphere, on ice caps, in soil, or in the oceans. The three main global factors that are endangering the world's supply of fresh water are population growth, fast industrialization, and climate change [2]. Water scarcity and shortages are currently posing a threat to freshwater resources in numerous areas, particularly in dry and semi-arid regions where domestic demand and agricultural uses are affected by water shortages [3], [4]. Water scarcity is a global issue and one of the biggest threats facing the globe today, according to the World Economic Forum (2011) [5].

There are two types of water scarcity: physical and economic. The restricted availability of water within a nation or area is known as the physical scarcity of water. Contrarily, economic water scarcity results from inadequate water investment or from a lack of the human potential to fulfill the need for water, even in regions with an abundance of it [6]. Numerous nations worldwide, encompassing Iraq, Syria, Jordan, Palestine, and Tunisia, have discovered historical proof of the application of RWH techniques [7]. The southern Jordanian Edom Mountains are believed to have produced the first signs of RWH more than 9000 years ago [8]. RWH has multiple names and definitions. One of the earliest explanations of RWH was provided by Geddes and Myers (1975) cited it: the collecting and storing of any farm runoff or stream flow for use in irrigation [9]. RWH, according to Critchley et al. (1991), is the collection of run-off for functional objectives [10]. Also, Gupta et al. (1997) outlined RWH as a technique used in arid and semiarid areas to create, gather, store, and preserve local surface runoff for agricultural purposes [11]. The description that can be found in the World Overview of Conservation Approaches and Technologies (WOCAT) database is used in this report: The gathering and control of precipitation runoff or floodwater to increase the amount of water available for residential and agricultural use; additionally, ecosystem maintenance [12].

Rainwater harvesting and storage either locally or by transfer is the primary function of RWH. All water harvesting systems consist of the following parts: [13].

1. A catchment encompasses the area that receives a certain amount of precipitation. A run-off area is another name for it. This space may be anything from a few square meters to many square kilometers in area, and it could consist of anything from a rooftop to a farmland, a road, or even difficult terrain.
2. A reservoir: before it is used by people, crops, or animals, the area collects runoff water and stores it. There are several places to store water: the soil, above-ground structures like ponds or reservoirs, and underground tanks like cisterns.
3. A destination: the final destination of a water collection system, when the water is utilized for agricultural or household purposes.
4. In situations of impending water scarcity and flooding, constructing a reservoir for RWH is a top-notch strategy [14]. Locating an appropriate area to install your RWH system is the first step. Water resource systems may be made more efficient by finding the optimal sites for RWH,

which allows us to have more water accessible for a longer period of time [3].

In order to reduce the likelihood of flooding in metropolitan areas, or as a substitute to water demand solutions, multiple studies have shown that RWH is a good option [15], [16].

A RWH plan was developed for a semiarid region in India by Gupta et al. (1997) using GIS technology. The results demonstrated the critical importance of GIS technology in WH management [11]. In an effort to better the agriculture sector, Jabr and El-Awar (2005) offered WH a site selection method [17]. Using a decision-support approach based on GIS and data gathered from RS, Mbilinyi et al. (2007) explored potential sites for RWHs [18]. Using multi-criteria decision-making techniques based on RS and GIS, Sayl et al. (2017) also collected data and calculated the ideal placements for RWHs [19]. The area of hydrology and water resources has made considerable use of RS and GIS within the last decade. Using digital image processing techniques, geographic data pertaining to specific watersheds may be retrieved from any region of the world. As imaging and sensor technologies continue to evolve, RS is finding increasing use in hydrological applications [16]. Thus, in the past, research that made use of RS and GIS technology produced better results [15], [20]. Two factors are crucial to the effective operation of RWH systems: locating the right places and making sure they are technically adequate [21].

Numerous methods have been devised to select appropriate sites and RWH procedures [7], [22], [23]. For less extensive areas, field surveys are the gold standard for determining optimal locations and RWH protocols. Choosing the best locations for various RWH technologies across larger areas could prove to be quite a difficulty [24].

Finding appropriate locations for RWH can be done using a variety of criteria, encompassing precipitation, terrain, soil type and depth, hydrology, socioeconomics, ecology, and the consequences of the environment [14]. Thus, gathering all research for the purpose of choosing appropriate RWH sites in northern Iraq was the primary goal of this study, which was to calculate the total volume of water that could be collected.

2. Characteristics of study area

Iraq is a country that lies in the Middle East and has a total area of 435052 square kilometers. Iraq has an arid to semi-arid climate, with high rates of evaporation and little rainfall. October through May sees rain, with an average of 150 mm of precipitation falling on the ground each year as shown in Fig. 1. Iraq's surface area is divided as follows: [15]

1. Elevated mountain ranges, covering 18.3% of the land, receive 500-1200 mm of rain annually.
2. The foothills cover 9.6% of the land and receive 300-500 mm of rain annually.
3. 6% of the total is found in the Jazziarah province, which is west and south of Mosul and receives 150-400 mm of rain a year.
4. With an average yearly rainfall of 150 mm, Mesopotamia accounts for 23.6% of the total (beginning north of Baghdad and extending south to the north of Basrah city).
5. The Western Desert, which receives less than 100 mm of rain on average year, makes up 42.5% of the total.

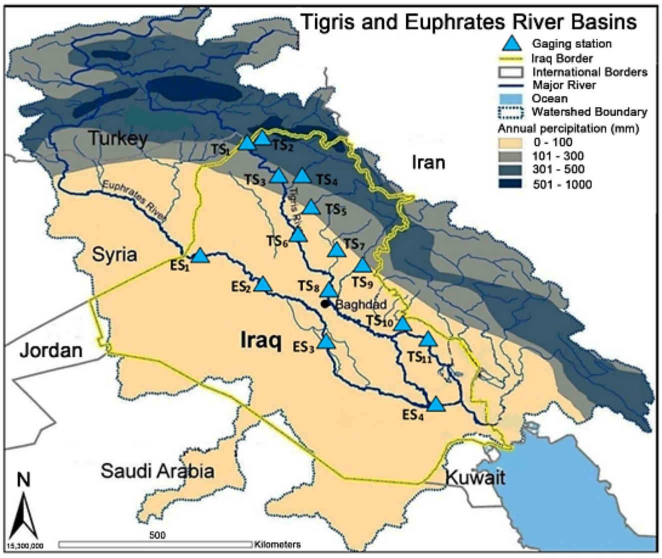

Fig. 1 Physiography of Iraq [16].

Although exact numbers vary widely, Iraq has access to about 100 BCM of renewable water resources year, or 2,338 m³ per person annually, according to the most recent figures in the FAO's AQUASTAT database (2018), Fig. 2.

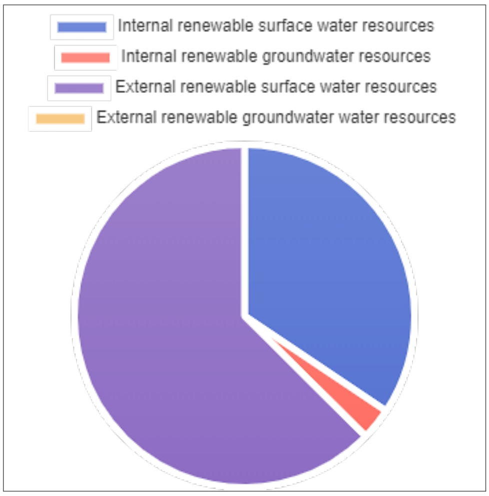

Fig. 2 Iraq's annual renewable water resources estimates.

This comprises approximately 3.5% renewable groundwater resources and approximately 96.5% surface water resources. About 38% of Iraq's renewable water resources come from within the nation; the remaining 62% come from one of its neighbors [17].

One of the natural resources that is most impacted by climate change is rainfall. Because of insufficient rainfall in the research area, RWH and storage technologies may be crucial for guaranteeing the availability of water during dry spells. This is because it is anticipated that climate change will negatively impact the water supply and the necessary RWH processes [18]. Rainfall begins in northern Iraq from October until May and reaches its peak value in March. Figure 3 shows the average monthly precipitation for north Iraq provinces which prepared by authors based on data collected from (www.nasa.gov) from 1981 to 2022.

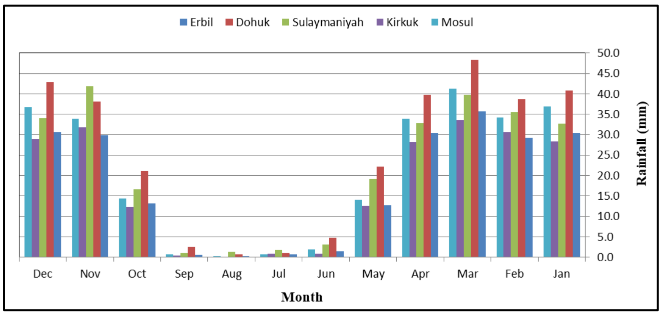

Fig. 3 Average monthly precipitation for north region of Iraq.

Iraq's water resources are managed in large part by rainwater harvesting projects, which typically take form of dams built along wadis. After a period of intense rainfall, they enable the retention of rainwater, which can subsequently be utilized to restore groundwater supplies. In the 1970s and 1980s, small dams were constructed in many wadis across the country to unlock rainwater harvesting potential in light of increasing water scarcity. The accumulation of silt in the reservoirs of many of these dams has reduced their storage capacity [19]. In recent years, numerous studies have been conducted on the current and future suitability of different locations for new rainwater harvesting schemes, both in the north and arid south [20]. However, information on the actual implementation of such projects is sparse.

3. Standards and methods for the selection of RWH sites in Northern Iraq

To deploy the RWH technique, all prior research found ideal locations for the harvesting dams using a Digital Elevation Model (DEM) with the Global Mapper model. The topography of the area had a significant influence over the locations. It is to fulfill, first crosscut with the final main runoff routes of the catchment area. In order to reduce the cost of building the dams and the amount of water lost through evaporation from the reservoir's surface area, the second minimum dam cross section that results in the least ratio of surface area of the reservoir to its storage capacity was adopted. Using the site's DEM, land use, soil type, and rainfall data together with the watershed modeling system (WMS), the second stage involved first identifying the chosen basins and their characteristics, after that, computing the runoff volumes utilizing the Soil Conservation Services-Curve Number (SCS-CN) method. The map of land use and cover (LULC) displays the many characteristics that may be found on the surface of the earth as well as the activities of humans that is connected to them (land use). It is a crucial signal to determine the curve number for the most optimal catchment locations for RWH [32]-[42].

4. Previous studies for rainwater harvesting in the North of Iraq

Iraq's water supply from the Tigris and Euphrates is vital. Three nations-Turkey, Syria, and Iraq-share these two international rivers. The main historical user of the water river is Iraq. Under what is known as the Southeastern Anatolia Project (GAP), Turkey has begun a drive to build a number of dams, reservoirs, and diversion tunnels. Turkey has received more water from this project than it has historically received, and Iraq's share has been steadily declining as a result [32].

Even though the environment in Iraq is arid to semi-arid with little rainfall, with appropriate techniques for collecting rainwater, a sizable amount of water might be collected [15]. There are several studies of water harvesting in northern Iraq. In this review, about 49 published studies from 2011 to 2024 were reviewed to get a good result for using rainwater harvesting in northern Iraq.

The authors collected studies from Scopus about rainwater harvesting in northern Iraq and analyzed them based on citation, average year, and keyword occurrence using VOSviewer software as shown in Fig. 4 [44]-[57].

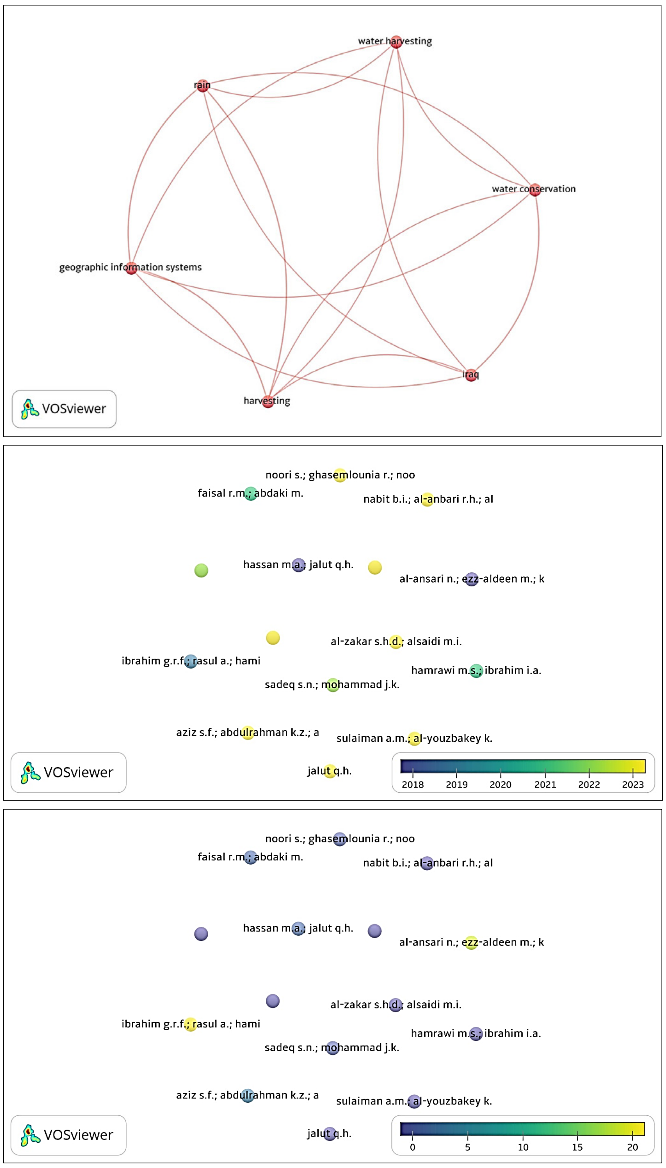

Fig. 4 Analysis of previous studies about RWH in northern Iraq.

Other studies on water harvesting include details of the volumes of harvested water, the number of dams, and their lengths, and heights, as presented in Table 1. Where, in Mosul, four locations with unique hydrological and geomorphologic features have been selected by Taha et al. (2011) for the building of storage facilities on the Wadi Al-Kassab basin's main channel, forming surface storage reservoir and a model of the weir has been designed based on Bligh theory. In this study where DEM file is used to draw a line of water divide of Wadi Al-Qassab basin by River Tool Software V 3.0, this program is designed to analyze hydrological and morphological features of drainage system of river basin.150 million cubic meters could be the total amount of storing water behind the four locations' dams [25]. The hydro-engineering characteristics of Al-Ajeej basin, which was located within the south Sinjar plain in north-west Iraq, were analyzed by Al-Taiee et al. (2012) to predict the possibility of surface runoff harvesting during rainfall season in the upstream sites in this basin using WMS. The proposed dam height was 12.5 meters with a dam length of 1277 m, while the normal storage volume of the reservoir is 38.8 million m^3 [47]. Also, Zakaria et al. (2012 and 2013) [26]-[28] estimated RWH in Sinjar Mountains in Mosul using the (SCS-CN) with WMS and GIS software for the period of 1990-2009. The runoff volume was calculated for six basins that were selected at Northern Sinjar Mountain which had a total area of 614.19 km^2. The combined amount of harvested water for all six basins was between 0.6-42.4 Mm^3. The estimated harvested runoff volume at East Sinjar Mountain ranged from 0.11 to 28.11 Mm^3, covering a total area of 435.14 km^2. RWH modeling techniques were also applied to the Southern Sinjar Mountain for agricultural purposes by two reservoirs. There is a chance that the equivalent runoff will reach 68.7 mm. In a similar vein, Zakaria et al. (2013)[30] used the (SCS-CN) technique with WMS to predict the Sulaymaniyah runoff. The selected study area consists of five separated basins with total area of 176.79 km^2. Their area ranged between 7.35 to 98.08 km^2 and average basins slope between 6.8 % to 28.3%, mean basin elevation between 855 to 1211 (m a.s.l.). After reviewing rainfall data from 2002 to 2012, they settled on an average season (2010-2011) and ran the numbers through the WMS model, which came up with a potential harvest of around 10.76 Mm^3. Zakaria et al., (2013) [22], [23] also applied RWH technique in Koya City in Erbil. Four basins were identified with total area of 228.96 km^2 for the study period (2002-2011). Based on the combined results of the four basins that were chosen, the total captured runoff varied between 14.83 and 80.77 Mm^3. The weighted sum method (WSM) and the fuzzy analytic hierarchy process (AHP) were both employed and compared to choose appropriate dam locations. A total of 14 layers were used as input dataset (i.e., lithology, tectonic zones, distance to active faults, distance to lineaments, soil type, land cover, hypsometry, slope gradient, average precipitation, stream width, Curve Number Grid, distance to major roads, distance to towns and cities, and distance to villages). Based on the criteria, Othman et al. (2020) [24] identified 11 locations in the Al-Khabur River that would be ideal for the placement of dams for runoff harvesting. The overall accuracies of the 11 dams ranged between 76.2% and 91.8%. The two most suitable dam sites are located in the center of the study area, with favorable geology, adequate storage capacity, and in close proximity to the population centers. The two selection methods, the AHP method performed better as its overall accuracy is greater than that of the WSM. The results of this study provide decision-makers with a useful and reasonably priced tool to help them narrow down the number of locations that are most suited for building dams, those with the fewest restrictions and eliminate those with significant constraints. Faisal et al. (2021) [48] identified and selected potential suitable sites for selection of dams for water harvesting in the northern Al-Tharthar watershed. The study focuses on building an integrated GIS-based multi-criteria model and by using AHP, where relative importance is obtained from (AHP) through use of ArcGIS 10.5. Three potential dams have been identified as highly suitable with storage capacity from the first to the third (37359680.5, 76273409.9, and 9690685.6) m^3 respectively. Furthermore, in the 503.88 km^2 Qara-Hanjeer sub-basin, east of Kirkuk in North Iraq, Sadeq et al. (2022) [31] explored the feasibility of using tiny dams for water collecting. Direct surface runoff is calculated using the (SC-SCN) method with data collected from the Kirkuk meteorological station from 1995 to 2020. There are six distinct zones within the basin, and their CN values vary. There is 12.99 Mm^3 of captured runoff in total per year. In 2024, Zakaria et al. [49] tested the reservoir operations for single and multi-reservoirs of rainwater harvesting systems to address the deficit in supplying water and electric power for remote rural communities in the semi-arid region of AL-Khoser watershed, Mosul. The main basin was divided into four sub-basins: 1B, 2B, 3B, and 4B. The Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) was applied to estimate the water volumes of the above-proposed reservoirs. The annual harvested water in the reservoirs of Main Basin, 1B, 2B, 3B, and 4B ranged between 0.7790-4.1788, 2.1256-11.4010, and 5.10158-28.1985 MCM for the three seasons.

Previous studies showed that there are large amounts of water that can be harvested in the northern region of Iraq, amounting to about 1084.59 Mm^3, through the construction of small dams whose height does not exceed 6 meters, as shown in the Table 1.

Table 1. Details about harvested water in the Northern of Iraq.

Location	Govern	No. of dams	Height of dams (m)	Length of dams (m)	Harvested water (Mm^3)	References
Southern Sinjar Mountain	Mosul	7	4.5-20	630-1800	96	[27]
Northern Sinjar Mountain		6	3.5-5.7	706-1893	42.4	[26]
Eastern Sinjar Mountain		4	2.5-6	636-904	28.11	[28]
Wadi Al-Kassab		Weir	--	--	150	[25]
AL-Khoser watershed		--	--	--	28.19	[49]
Al-Ajeej basin		1	12.5	1277	38.8	[47]
Al-Tharthar watershed		3	12-22	250-550	76.27	[48]
Koya city	Erbil	4	6	110-290	80.77	[23]
Sulaymaniyah	Sulaymaniyah	5	--	--	10.76	[30]
Qara-Hanjer	Kirkuk	--	1-1.5	--	12.99	[31]
Duhok	Khabur River Basin	11	--	372- 1109.9	520.3	[24]
Total					1084.59	

Although the water harvesting technique was studied in different areas in the northern Iraq, all previous researchers agreed on basic points:

1. It is practiced in arid and semiarid regions, where surface runoff often has an intermittent character.
2. It is based on the utilization of runoff and requires a runoff producing area and a runoff receiving area.
3. Because of the intermittent nature of runoff events, storage is an integral part of the water harvesting system.
4. The height of the proposed dams does not exceed 22 meters, and their length does not exceed 2000 meters.
5. These dams are low-cost, reduce runoff water loss, enhance agricultural through tourism, and add impetus to the ecosystem programs in the north of Iraq.
6. All prior research found ideal locations for the harvesting dams using the site's DEM, land use, soil type, and rainfall data together with WMS.
7. To apply the RWH technique, the methodology involved first identifying the chosen basins and their characteristics and, after that, computing the runoff volumes utilizing the SCS-CN method.

4. Conclusions

All projections for the future point to Iraq's water resources experiencing more severe shortages. It is thought that using rainwater gathering techniques can significantly aid in resolving this issue. Iraq suffers from a lack of surface water resources and water scarcity as a result of its location in an arid and semiarid environment. The aim of this study is to collect studies for rainwater harvesting in Iraqi Kurdistan Region. The discovery of suitable RWH locations using RS and GIS technology has the potential to boost water availability. The city can directly address the water crisis in dry and semi-arid areas by using rainwater gathering. Since some of these sites may be impacted socially by small villages, cramped quarters, or other hydraulic manufacturing building prevention, no location in the area has been deemed suitable. Rainwater development should be implemented through a field study since the spatial scope of the survey does not ensure that all locations in a region are designated as low-appropriate places.

In conclusion, this research found that the drought effects on Iraq, specifically in the Kurdistan region, are on the rise due to climate change. So management of the water resources has become necessary to solve this problem. Also there is a lack of research on the RWH technique in northern Iraq. Most of the papers reviewed are small basin-focused only. The authors found that the multi-criteria evaluation is supporting determination of suitable areas for rainwater harvesting, and suitable zones to construct small and medium dam sites. To select a good location for water collecting, the review's conclusion highlighted the significance of the key criteria used in rainwater technology development. Studies on rainwater harvesting can primarily take into account the following factors: soil texture, slope, drainage density, land use/cover, and rainfall. According to earlier research, it is possible to extract a significant volume of water-roughly 1084.59 Mm^3 from the northern region of Iraq by building modest dams that don't rise higher than 22 meters.

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