CRITERIA FOR SELECTION OF SUITABLE SITES FOR RAINWATER HARVESTING IN THE MIDDLE EAST FOR AGRICULTURE USE: A REVIEW STUDY

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ABSTRACT

In arid and semi-arid regions, rainwater harvesting represents an important alternate source of water supply around the globe. The middle east is an integrally dry zone and due to climate change, it has experienced a severe drought for the last decade that made the situation worse. Many countries are suffering from awful water crises due to increasing water demand for agriculture and rapid urbanization. Therefore, unconventional water supply resources practices such as using rainwater harvesting for agricultural purposes can be possibly used to tackle water scarcity. Numerous researchers have established different criteria and methods to identify suitable sites selection techniques for rainwater harvesting (RWH). The main objective of this study was to determine the most commonly effective methods and techniques that have been practiced in the middle-east region to summarize the best methods for rainwater harvesting site selection. These effective common methods of multi-criteria analysis (MCA) were discussed accordingly in this review paper and based on the previous studies the best applicable method was the integration between (MCA) method and the GIS technique. The study employed a method of gathering and recording the main criteria and techniques which were established in the last thirty years. It compared and categorized the main methodologies from previous studies and practices from international organizations and scientific research and identified the most common characteristics and sets of criteria suitable for use in arid and semi-arid regions. The techniques were diverse based on biophysical criteria to methods including socio-economic criteria, precisely in the last two decades. The most effective and significant criteria for suitable site selection of RWH in the arid and semi-arid regions found are: land use/land cover, slope, type of soil, rainfall intensity, streams distant and the cost. The success of RWH selection sites tended to increase when these criteria are measured and based on these criteria.

KEYWORDS: *RWH Selection Suitability, Arid and semi-arid zones, Middle East, Agriculture, GIS, Multi-criteria analysis.*

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1 INTRODUCTION

The growing demand for water for urbanization, industrial, and agriculture use is increasing the pressure on water resources globally, especially under the current climate change conditions (Qi et al, 2019). Freshwater resources are currently under the risk and pressure of water scarcity in many parts of the world, specifically in aridity regions, including the Middle East region that is facing water shortages issues regarding both domestic and agricultural purposes (Alwan et al., 2020 & Sayal et al, 2017). The estimations mentioned that around two billion people will live under water stress by the year 2050, which will be a limiting factor for the continuity of development in many countries, especially the agriculture sector that depends on rain-fed and specifically in the developing countries according to the United Nations Environmental Program (Field at al, 2014).

Globally, the arid and semi-arid regions, are frequently facing water scarcity problems for domestic and agricultural use as the two regions represent about 35% of the land, about 50 million km² and a huge part of this land lies within the middle east zones (Zaidat et al, 2012). Water scarcity can be either a physical or economic issue. The economic water scarcity issue is a result of a poor investment or lack of ability to address the water demands, whereas the physical water sacristy problem is constrained the water availability in a country or a region. The rain-fed agriculture method is the major farming system in these regions and in the middle east as a whole, but climate change and aridity are the two main challenges confronted by farmers who depend on rain (Al- Muqdadi et al, 2016). To increase water availability for harvest irrigation demands and livestock production, the inhabitants of dry regions have developed several techniques for rainwater harvesting systems. Rainwater harvesting (RWH) is defined as the collection of rainwater through the management of the rainfall-runoff process to increase water accessibility for both domestic and agriculture use. It is considered one of the oldest techniques developed by man in history to tackle water shortage and climate change impacts (Mekdaschi & Liniger 2013; Sharafati et al, 2020a, b).

The most common types of RWH techniques in arid and semi-arid regions and the Middle East are dams, ponds and pans, terracing, separation tanks, and Nala (Oweis, Prinz & Hachum, 2012). The earliest indication shows the global use and techniques of rainwater harvesting (RWH), for instance in several countries and specifically in the middle-east region such as Syria, Jordan, Palestine, Sudan, Iraq, and Tunisia (Al-Adamat, 2008). There are many classifications for rainwater harvesting systems around the world, such as the collection and management of runoff water, or the collection and storage of the runoff water. However, Gupta and Sharma (1997), defined RWH as the method of collecting, conserving, and storing the surface run-off water for agricultural purposes, especially in the arid and semi-arid zones. The important purpose of rainwater harvesting is to increase water availability by seizing the rainwater in one place for domestic or irrigation use. Most rainwater harvesting systems contain the following mechanisms (Owies et al, 2012):

- A catchment area or known as a runoff area that can be small starting from a few square meters to several square kilometers as a large one and it can be a roof-top, a valley, or a road.
- A storing facility that represents the area that holds the runoff water in pounds, tanks above or underground cisterns to be used for irrigation or domestic purposes.
- The purpose of the water harvesting process, where the harvested water to be used for crops production or domestic use.

A successful RWH system depends mainly on the selection of suitable sites and the technical design of the system as many methods have been developed for site suitability selection (Ahmed, 2013). Some numerous historical studies and factors reported effective RWH suitable sites selection such as rainfall, topography, land cover and land use, soil texture, hydrology including the flow direction, flow accumulation, and socio-economic factors (Garget al, 2017).

Although there are many criteria and methods, that were considered for selecting and design of RWH globally, there are not enough focus studies and methods considered in the Middle Eastern region, therefore this research is conducted to fill that gap. In the present work, the comparison has been made for all criteria and methods that are utilizing GIS and Remote Sensing/RS for selecting and identifying the suitable RWH locations in arid and semi-arid regions in the middle-east.

2 CRITERIA AND TECHNIQUES USED FOR SUITABLE RWH SITE SELECTION

The suitable selection of RWH sites depends on many criteria (Mahmoud & Alazba, 2014). There are two main criteria for identifying and selecting a suitable site, these are biophysical and socio-economic criteria. Since the early nineties of the last century, many studies focused on biophysical criteria that include, rainfall, soil texture, slope, drainages, land use, and land cover while many studies after the year 2000 have tried to make an integration between both biophysical and socio-economic criteria (Yalew et al, 2016). The Food and Agriculture Organization of the United Nations (FAO) has itemized six key criteria for selecting RWH sites as cited by Khudhair, Sayal, and Darama (2020), these are hydrology, topography, climate, soils, agronomy, and socio-economic. Table 1. shows the most common techniques and criteria that have been used in the middle east and arid and semi-arid regions.

Table 1. The most common techniques and criteria that have been used in selection for RWH in the middle east

RWH techniques	Rainfall (mm)	Slope (%)	Type of Soil	Land Cover/Use	Catchment Area (ha)	References. Year and country
Check dams	<1000	<15	loam clay Sandy	Barren, shrub, and scrubland	N/A	Al-Daghastani (2010), Iraq Ziadat et al, (2012). Jordan Hameed (2013), Iraq
Ponds and pans	>200	<5	Clay loam sandy. and silty loam	Moderately cultivated, Shrub-land	< 2	Al- Adamat et al, (2008) Al-Adamat et al, (2010) Jordan
Percolation tanks	<1000	<10	Clay loam and silt	Barren or scrub-land	> 25	Al-Adamat et al, (2012) Jordan
Terracing	200-1000	5-30	Sandy clay, clay loam and sandy loam	Bushland with scattered trees and shrub-land	N/A	Weerasinghe et al, (2011) Egypt

3 TOOLS AND METHODS USED FOR SUITABLE SITES SELECTION FOR RWH

Multiple methods and criteria can be integrated with specific tools that can be used to identify suitable RWH sites. These tools can apply to arid and semi-arid regions including the middle - east, are categorized as the following:

- GIS integrated with RS tools.
- Multi-criteria analysis method integrated with hydrological modeling, GIS, and RS tools.
- Multi-criteria analysis method integrated with GIS.

3.1 GIS INTEGRATED WITH RS TOOLS

Recent advances in computing technology have contributed to numerous ways of identifying suitable sites for RWH. This included the use of GIS and RS tool packages that reduced cost and time effectively. Remote sensing (RS), can be used to develop precise information with a very high resolution. For instance, curve numbers (CNs) and land-cover, which are needed to calculate the runoff, can be easily obtained by using GIS applications. This is helpful and useful, especially, in places where very little information and data are available specifically in the developing countries (Mahmoud, 2014). GIS tool can also be used for collecting, storing, and analyzing spatial and non-spatial data in different layers applying the integration spatial analysis to identify suitable RWH sites (Mati et al, 2006). The integration use of GIS and RS tools for suitable sites selection for RWH can offer an effective reasonable spatial analysis that employs the integrated tool in a rapid easy to read/use and give a good opportunity to understand different patterns and produce information through maps. The accuracy of the GIS/RS tools depend on the resolution of the available data, therefore it can be very useful and applicable to identify the suitable sites for RWH in arid and semi-arid regions (Forzieri et al, 2008; Prinz et al, 1998; Ziadat, Mazahreh, Oweis, & Bruggeman, 2006). Table 2. summarizes the rainwater harvesting types and the studies and criteria applied in the Middle East countries when using GIS and RS tools.

Table 2. Summary of RWH types and criteria that have been applied by using GIS and RS tools

RWH types	Country and References
N/A	Syria, Oweis, Oberle,& Prinz (1998)
Cistern and pits contour	Jordan, Ziadat et al, (2006)
N/A	Syria, Bakir & Xingnan (2008)
Jessour and tabia	Tunisia, Ben Mechlia et al,(2009)
Dams and channels	Iraq, Al-Daghastani (2010)
N/A	Iraq, Kamel & Ahmed (2010)
Contour ridge and runoff strips	Jordan, Al-Shamiri & Ziadat (2012)
Reservoir	Iraq, Salih and Al-Tarif (2012)
Dams, ponds runoff and strips	Jordan, Ziadat et al, (2012)

3.2 MULTI-CRITERIA ANALYSIS METHOD INTEGRATED WITH HYDROLOGICAL MODELLING, GIS, AND RS TOOLS

Multi-criteria analysis (MCA) is a widely commonly used method for analyzing the combined data from different criteria. One of those methods is the analytical hierarchy process (AHP, which is an MCA method that has been applied extensively for identifying the potential RWH sites (Sekar & Randhir, 2007, Munyao, 2010, Krois & Schulte, 2014). One of the main procedures in the MCA method is the assessment of relative weight for each criterion, rather than assuming the same weight for all criteria and then comparing two or more alternatives. AHP is a multi-criteria decision-making method, providing a designed technique for organizing and analyzing composite decisions based on mathematics and expert knowledge (Saaty, 2008). The integration of the MCA method with GIS and hydrological modeling is a good and widely used method for detecting suitable sites for RWH in arid and semi-arid regions.

Numerous studies in the middle east region have been applied this integrated method, taking benefit of the MCA strengths together with those of hydrological modeling and GISs, as shown in Table 3. The table gives a summary of RWH types and criteria that have been applied using the integration of the MCA method with hydrological modeling and GIS/RS tools.

Table 3. Summary of RWH types and criteria that have been applied by using the integration of the MCA method with hydrological modeling and GIS/RS tools.

RWH types	Country and References
Reservoir	Lebanon, Jabr & El-Awar,(2005)
N/A	Egypt, Weerasinghe et al, (2011)
N/A	Egypt, Elewa et al, (2012)
Dams	Iraq, Hameed (2013)

3.3 MULTI-CRITERIA ANALYSIS METHOD INTEGRATED WITH GIS

Multi-criteria analysis (MCA) is a commonly wide used method of analysis that combines data from different criteria. One of those methods is the analytical hierarchy process (AHP, which is an MCA tool that has been applied extensively to identify potential RWH sites (Sekar & Randhir, 2007, Munyao, 2010, Krois & Schulte, 2014). One of the main procedures in MCA is the assessment of relative weight for each criterion, rather than assuming the same weight for all criteria and then comparing two or more alternatives. AHP is a multi-criteria decision-making method, providing a designed technique for organizing and analyzing composite decisions based on mathematics and expert knowledge (Saaty, 2008). MCA integrated with GIS is a good tool for detecting suitable sites for RWH and is widely used in arid and semi-arid regions. Numerous studies in the Middle East have applied this integrated approach, taking advantage of the strengths of MCA together with GIS techniques, as shown in Table 4. The table gives a summary of RWH types and criteria that have been applied using MCA integrated with GIS tools.

Table 4. Summary of the RWH types and criteria that have been applied to use the integration of MCA and GIS tools

RWH types	Country and References
Ponds	Jordan, Al-Adamat (2008)
Micro and Macro catchments	Syria, Pauw et al, (2008)
Ponds	Jordan, Al-Adamat et al, (2010)
N/A	Jordan, Al-Adamat et al, (2012)
Groundwater recharge	Saudi Arabia, Mahmoud (2014)
In-situ	Saudi Arabia, Mahmoud & Alazba (2014)
Groundwater recharge	Iraq, AL- Shammari et al, (2021)

4 CONCLUSION

The main objective of this study was to review the most effective and common methods that are used for selecting and identifying the suitable sites of RWH arid and semi-arid countries, specifically in the Middle East region that have been developed in the past years. The success of RWH depends mainly on both site identification and the technical design (Ammar et al, 2016). The study also discussed the development of criteria selection through the years specifically in the middle-east countries. The study reviewed the most numerous effective most common and widely used methods and techniques that were used in selecting the suitable sites of RWH sites in the arid and semi-arid zones and precisely in the middle-east region. This study focuses on the most common and effective methods that have been used to select the suitable sites of RWH in the middle east countries through reviewing the most recent studies that have been used different techniques and criteria to conduct the studies in that region and were represented in table 1. Based on the previous review studies that have been conducted in the middle-east countries, it is obvious that the integration between the MCA method that is supported by the GIS/RS techniques has been widely applied and used as shown in above table 2. While there were limited and fewer studies that have been used the combination of the MCA method with hydrological modelling by using and applying GIS/RIS techniques and tools in the middle-east region as shown in the above table 3. On the other hand, using the combination of the MCA method that is supported by the GIS techniques has been used and applied in many studies in the middle east region. It is a great challenge to determine the most useful and effective method for selecting suitable RWH sites, however, it is clear that there are limited studies in the middle east using the combination of the MCA method with GIS/RS and hydrological modelling compared with the two others methods that are using MCA supported by GIS/RS techniques. Therefore, the following table 5 summarizes and presents the comparison between the three methods and tools based on the features and requirements for arid and a semi-arid region, the limitations and accuracy of each method, specific data requirements for various countries. The three methods have been applied discretely. The analysis through this review study suggests that the integration of using MCA with GIS is the most innovative and applicable method that can provide a rational and unbiased technique for identifying suitable sites for RWH while there should be more investigations and studies in near future regarding using the combination between MCA with hydrological modelling that is supported by GIS/RS techniques. The following table 5. summarizes each method identification, advantages, and limitations that have been applied in the arid and semi-arid regions and specifically in the middle - east countries.

Table 5. Summary of each method identifications, advantages, and boundaries

Method and tools	Method identification	Advantages	Limitations
MCA with GIS/RS techniques	Use GIS/RS technique and properties to produce many thematic maps to select suitable RWH site	Accurate, good spatial resolution, saving time, cost-effective, easy to use, used in remote sensing places, and can identify RWH suitable sites.	The results accuracy is highly dependent on input data. Cannot provide a real image of a watershed and lacks between up and downstream relationship. Need a field survey for validation
MCA with hydrological model and GIS/RS techniques	Many criteria can be combined by applying MCA to assess a relative weight for each one. Applying the properties of the hydrological model and GIS/RS to select RWH suitable sites.	It is flexible and can be applied in different regions, MCA (AHP) can check reliability, providing validity to decide the suitability of RWH site selection	The weight of each criterion in MCA is highly affected by the proficiency of the author, therefore weights should be calculated carefully
MCA with GIS technique	Implementation of a GIS for combining groups of criteria to select suitable sites for RWH based on using decision rules to integrate with MCA.	Greatly flexible for applying MCA with GIS for various regions, can be applied in many regions, can identify suitable sites for RWH	The weight of each criterion in MCA is highly affected by the proficiency of the author, therefore weights should be calculated carefully, checking data quality and availability.

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