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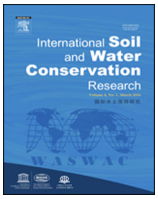

Review Paper

Identification of suitable sites for rainwater harvesting structures in arid and semi-arid regions: A review

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ABSTRACT

Harvested rainwater is an alternative source of water in arid and semi-arid regions (ASARs) around the world. Many researchers have developed and applied various methodologies and criteria to identify suitable sites and techniques for rainwater harvesting (RWH). Determining the best method or guidelines for site selection, however, is difficult. The main objective of this study was to define a general method for selecting suitable RWH sites in ASARs by assembling an inventory of the main methods and criteria developed during the last three decades. We categorised and compared four main methodologies of site selection from 48 studies published in scientific journals, reports of international organisations, or sources of information obtained from practitioners. We then identified three main sets of criteria for selecting RWH locations and the main characteristics of the most common RWH techniques used in ASARs. The methods were diverse, ranging from those based only on biophysical criteria to more integrated approaches including socio-economic criteria, especially after 2000. The most important criteria for the selection of suitable sites for RWH were slope, land use/cover, soil type, rainfall, distance to settlements/streams, and cost. The success rate of RWH projects tended to increase when these criteria were considered, but an objective evaluation of these selection methods is still lacking. Most studies now select RHW sites using geographic information systems in combination with hydrological models and multi-criteria analysis.

Contents

1. Introduction 108
2. Criteria and methods for RWH site selection in ASARs 109
    2.1. Criteria used for selecting suitable RWH sites 109
    2.2. Methods and tools used for identifying suitable sites for RWH 110
        2.2.1. GIS/RS 110
        2.2.2. HM with GIS/RS 111
        2.2.3. MCA integrated with HM and GIS/RS 114
        2.2.4. MCA integrated with GIS 114
3. Discussion and conclusions 117
Acknowledgements 119
References 119

1. Introduction

Climate change and a growing demand for water for agricultural and urban development are increasing the pressure on water resources. Between 75 and 250 million people in Africa are

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projected to be exposed to increased water stress by 2020, yields from rainfed agriculture could be reduced by up to 50% in some regions, and agricultural production, including access to food, may be severely compromised (Field et al., 2014). The United Nations Environment Program estimates that more than two billion people will live under conditions of high water stress by 2050, which would be a limiting factor for development in many countries around the world (Sekar & Randhir, 2007).

Arid and semi-arid regions (ASARs) around the world are already regularly facing problems of water scarcity, both for drinking water and for crops and other vegetation. ASARs represent 35% of Earth's land, about 50 million km^2 (Ziadat et al., 2012). Rainfed agriculture is the predominant farming system in these areas, but aridity and climatic uncertainty are major challenges faced by farmers who rely on rainfed farming. Farmers are faced with low average annual rainfall and variable temporal and spatial rainfall distribution. To increase the availability of water for crop and livestock production, inhabitants of dry areas have constructed and developed several techniques for harvesting rainwater.

Ponds and pans, dams, terracing, percolation tanks, and Nala bunds are the most common types of RWH techniques in ASARs (Oweis, Prinz, & Hachum, 2012). Ancient evidence of the use of rainwater harvesting (RWH) techniques has been found in many countries around the world, including Jordan, Palestine, Syria, Tunisia, and Iraq (Al-Adamat, 2008). The earliest signs of RWH are believed to have been constructed over 9000 years ago in the Edom Mountains in southern Jordan (Boers & Ben Asher, 1982). RWH has several definitions and names. Geddes provided one of the earliest definitions of RWH, as quoted by Myers (1975): *"The collection and storage of any farm waters, either runoff or creek flow, for irrigation use"*. Critchley, Siegert, and Chapman (1991) defined RWH as the collection of runoff for productive use. Gupta, Deelstra, and Sharma (1997) defined RWH as a method for inducing, collecting, storing, and conserving local surface runoff for agriculture in ASARs.

In this report, we use the definition in The World Overview of Conservation Approaches and Technologies (WOCAT) database (Mekdaschi & Liniger, 2013): *"The collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance"*. The main role of RWH is to increase the amount of available water by capturing rainwater in one area for local use or for transfer to another area. All water-harvesting systems consist of the following components (Oweis et al., 2012):

- A catchment: the part of an area from which some of the rainfall is harvested. It is also known as a runoff area. This area can be a few square metres to several square kilometres in size and may be agricultural, rocky, a paved road, or a rooftop.
- A storage facility: the area that holds the harvested runoff water until used for crops, animals, or people. Water can be stored above ground (e.g. reservoirs or ponds), in the soil profile, and in underground storage containers (e.g. cisterns).
- A target: the endpoint of a water-harvesting system, where the harvested water is used for crop production or domestic use.

The success of RWH systems depends heavily on the identification of suitable sites and their technical design (Al-Adamat et al., 2012). Various methodologies have been developed for the selection of suitable sites and techniques for RWH (Ahmad, 2013; Al-Adamat, 2008; De Winnaar, Jewitt, & Horan, 2007). Field surveys are the most common method for selecting suitable sites and RWH techniques for small areas. The selection of appropriate sites for different RWH technologies in larger areas is a great challenge (Prinz, Oweis, & Oberle, 1998).

Various factors such as rainfall, land cover/use, topography, soil texture/depth, hydrology, socio-economics, ecology, and environmental effects can be used for identifying suitable sites for RWH (Prinz and Singh, 2000). In practice, a high diversity of methodologies and criteria are used. Little attention, however, has been paid to the performance of these methods in selecting suitable sites. The main objective of this study was thus to define a general method for selecting suitable RWH sites in ASARs by comparing all methods and criteria developed in the last three decades. We collected and analysed 48 studies published in scientific journals, reports of international organisations, or sources of information obtained from practitioners. The tasks performed were:

- Identifying main sets of site-selection criteria,
- Categorising and comparing the main selection methodologies, and
- Identifying the design criteria (quantitative/qualitative values) for the most commonly used RWH techniques in ASARs.

2. Criteria and methods for RWH site selection in ASARs

Water harvesting has been receiving renewed attention since 1980. Developments in computer technology, geographic information systems (GISs), and remote sensing (RS) have made it possible to develop new procedures to identify suitable sites for RWH and have led to numerous publications focused on the selection of suitable RWH sites. A summary of the RWH type, authors, year, countries, and selection criteria reported in our information sources are presented for each method in Section 2.2.

2.1. Criteria used for selecting suitable RWH sites

The selection of suitable sites for RWH depends on several criteria (Mahmoud & Alazba, 2014). Two main groups of criteria, biophysical and socio-economic, have been defined. The criteria for the various RWH techniques that have been used in various methods are presented in the tables in next Section 2.2. Several of the studies in the 1990s (e.g. Gupta et al., 1997; Padmavathy, Raj, Yogarajan, Thangavel, & Chandrasekhar, 1993; Prinz et al., 1998) focused primarily on biophysical criteria, such as rainfall, slope, soil type, drainage network, and land use. Most of the studies after 2000 have tried to integrate socio-economic parameters with the biophysical components as the main criteria for selecting suitable sites for RWH (e.g. De Winnaar et al., 2007; Senay & Verdin, 2004; Yusof, Serwan, & Baban, 2000). In 2003, the Food and Agriculture Organization of the United Nations (FAO), as cited by Kahinda, Lillie, Taigbenu, Taute, and Boroto (2008), listed six main criteria for identifying RWH sites: climate, hydrology, topography, agronomy, soils, and socio-economics.

The most common biophysical criteria used in ASARs to identify suitable sites for RWH were (as a percentage of all studies reviewed): slope (83%), land use/cover (75%), soil type (75%), and rainfall (56%). The distance to settlements (25%), distance to streams (15%), distance to roads (15%), and cost (8%) were the most commonly applied socio-economic criteria.

The most common techniques that have been developed and used in ASARs were (Table 1): ponds and pans, check dams, terracing, percolation tanks, and Nala bunds. Table 1 also lists the most common biophysical criteria that have been applied in planning and implementing these techniques (based on this review).

For example, all five techniques are all suitable in areas with rainfalls of 200–1000 mm/y, ponds are suitable for small flat areas with slopes $<5\%$, percolation tanks and Nala bunds are suitable on moderate slopes of 5–10%, and terracing is suitable for steeper slopes of 5–30%. The most suitable soil type, land use/cover, and catchment size for each RWH technique are also summarised in Table 1.

Table 1
The most common techniques and criteria and their values that have been used for RWH site selection in ASARs.

RWH technique	Rainfall (mm)	Slope %	Soil type	Land use/cover	Catchment area (ha)	References as shown in Tables 3–6
Ponds & Pans	>200	<5	-Sandy clay loam - Silty loam	-Moderately cultivated -Shrub land. -Scrub land	<2	15, 18, 41, 42, 44, 45
Check dams	<1000	<15	-Sandy clay loam	-Barren, shrub and scrub land	>25	14, 24, 18, 26, 44,
Terracing	200–1000	5–30	-Sandy clay, clay loam and sandy loam	-Bushland with scattered trees and shrub land	–	17,33,30
Percolation tank	<1000	<10	-Silt loam -Clay loam	-Barren or scrub land	>25	3, 18, 44,
Nala bunds	<1000	<10	-Silt loam	-Barren or scrub land	>40	15, 41,48

Table 2
Commonly used guidelines to identify suitable sites for RWH in ASARs.

IMSD (1995)	Oweis et al. (1998)	FAO (2003)
Not defined	Rainfall	Climate (rainfall)
Drainage System	Drainage System	Hydrology (rainfall-runoff relationship and intermittent watercourses)
Slope	Slope	Slope
Land use Land Cover (LULC)	LULC	Agronomy (crop characteristics)
Soil texture	Soil type	Soil (texture, structure and depth)
Not defined	Socio-economic (land tenure)	Socio-economic (population density, workforce, people's priority, experience with RWH, land tenure, water laws, accessibility and related cost)

Adapted from Bulcock and Jewitt (2013).

We identified three commonly prescribed sets of criteria (guidelines) for the selection of suitable RWH (Table 2). The first set was proposed by the Integrated Mission for Sustainable Development (IMSD, 1995) and included only biophysical criteria. The second set was proposed by Oweis et al. (1998), who first included socio-economic criteria. The third set was developed by FAO (2003) and included more criteria in both domains. Most publications since 2000 followed or were derived from one of these sets of guidelines.

The various criteria were more flexible in IMSD (1995) guidelines than other two guidelines. For example, different soil textures were given for different RWH types, such as percolation tanks suited to sandy soils and ponds suited to clay soils. Slopes $\leq 15\%$ were considered suitable for some techniques. The land-use guidelines, however, were restrictive and were recommended for land-use classes such as barren, scrubland, or bare soil. These land-use classes are rarely used for agriculture, and RWH in these areas are small and should be close to cultivated areas. The IMSD guidelines thus include suitable sites far from where the water is needed (Durbude & Venkatesh, 2004; Kadam, Kale, Pawar, Sankhua, & Pawar, 2012; Kumar, Agarwal, & Bali, 2008). Moreover, the IMSD guidelines did not define socio-economic criteria, which is a large limitation compared to the other two sets of guidelines.

The guidelines proposed by Oweis et al. (1998) were more comprehensive than the IMSD guidelines. They considered RWH systems in difficult terrain and specified requirements specific to different types of agriculture, such as requirements for trees, field crops, and rangeland. Moreover, criteria for the various types of RWH structures with values for each factor, such as soil texture, mean annual precipitation between 50–300 mm/year, soil depth (<50 cm), slope ($<4\%$), and vegetation, have been determined (Al-Adamat, 2008; Bulcock & Jewitt, 2013; Ziadat et al., 2012). Socio-economic criteria, however, were still limited and needed to be extended.

FAO (2003) guidelines are presently the most comprehensive for the identification of potential RWH sites. They include more parameters and wider ranges relevant to RWH than the other guidelines and consider various socio-economic criteria more associated with the local farmers. In fact, the criteria for various RWH techniques have been determined, and the guidelines set suitable and ideal limits for factors such as crop water requirements for various crops, rainfall ranges, slope, and soil depth/texture. For example, FAO (2003) guidelines consider medium-textured loamy soil the most suitable for agriculture. Mean annual precipitation of 150–750 mm/year is suitable for most RWH techniques. Slopes $<5\%$ are suitable for ponds, slopes $<10\%$ are suitable for percolation tanks, and slopes $<15\%$ are suitable for check dams (Krois & Schulte, 2014; Mati et al., 2006; Munyao, 2010; Ramakrishnan, Bandyopadhyay, & Kusuma, 2009). These wide ranges and broad parameter definitions give more flexibility and reliability to the FAO guidelines for their accreditation by most researchers in ASARs.

2.2. Methods and tools used for identifying suitable sites for RWH

A variety of methods can be used to integrate the different criteria into a tool for the selection of suitable sites for RWH. We have categorised the methods/tools that have been applied to identify suitable sites in ASARs in the last three decades into four main groups: 1) GIS/RS (e.g. Al-Daghastani, 2010; Forzieri, Gardenti, Caparrini, & Castelli, 2008; Prinz et al., 1998), 2) hydrological modelling (HM) with GIS/RS (e.g. De Winnaar et al., 2007; Gupta et al., 1997; Durbude & Venkatesh, 2004), 3) multi-criteria analysis (MCA) integrated with HM and GIS/RS (e.g. Elewa, Qaddah, & El-Feel, 2012; Sekar & Randhir, 2007; Weerasinghe, Schneider, & Löw, 2011), and 4) MCA integrated with a GIS (e.g. Al-Adamat, Diabat, & Shatnawi, 2010; Pauw, Oweis, & Youssef, 2008; Kahinda et al., 2008; Mahmoud & Alazba, 2014; Mbilinyi, Tumbo, Mahoo, & Mkiramwinyi, 2007). These four groups were categorised based on how GIS/RS, MCA, and HM were applied in previous studies. Each group (method) therefore has its requirements with both pros and cons. Groups 3 and 4 are similar, but the main difference is the integration of HM in group 3. HM needs a lot of data and has requirements beyond the application of MCA with a GIS. The percentages of each group (method) that have been applied by the 48 articles were: 27% for group 1, 15% for group 2, 21% for group 3, and 37% for group 4. A description of each method, their specific requirements of data and systems, their applicability and limitations, and examples of studies that have used these methods in ASARs are provided in the following sections.

2.2.1. GIS/RS

Computer technology has advanced greatly in recent decades, including GIS packages supported by RS that offer cost-effective and time-saving methods for identifying suitable sites for RWH.

RS can be used to derive accurate information with high spatial and temporal resolution. For example, land-cover information and curve numbers (CNs), which are needed for runoff estimation, can easily be extracted in GIS environments. GISs are very useful tools, especially in areas where very little information is available, which is often the case in developing countries (Mahmoud, 2014). A GIS is a tool for collecting, storing, and analysing spatial and non-spatial data (Mati et al., 2006). Various thematic layers can be generated by applying spatial analysis with GIS software. These layers can then be integrated for identifying suitable sites for RWH. The different sites identified by GISs in our sources of information were based on different guideline criteria, such as those by IMSD (1995), Oweis et al. (1998), and FAO (2003) (Table 2).

Ziadat et al. (2012) applied a GIS approach for identifying the suitability for RWH interventions in Jordan. They integrated biophysical criteria such as slope, vegetation cover, soil texture, and soil depth with socio-economic parameters such as land owner and then modified the criteria. Each criterion was assigned one of two ratings: best or second best. These ratings provided more flexibility for determining the suitability of an intervention. The data required for the biophysical criteria were obtained from various sources; contour lines extracted from topographic maps, and slopes were derived from digital elevation models (DEMs) at 20-m resolution. ArcGIS was then used to derive a slope grid, and the grid was converted into polygons for use as land-mapping units in the analysis. A field survey provided other data for the biophysical criteria, such as soil texture/depth and surface cover. The values for unmeasured locations were predicted using the inverse distance weight interpolator of ArcGIS 9.3 (Ziadat et al., 2012). Suitability maps were produced using two approaches for interpreting different layers of the biophysical parameters: a raster-based analysis assigned a suitability class for each pixel by comparing the RWH requirements with land characteristics using arithmetic map algebra, and a polygon-based analysis assigned a suitability class for each slope-mapping unit. The final biophysical maps showed the number of RWHs suitable for each mapping unit or pixel. The suitability maps were overlaid with cadastral maps to apply farm-size criteria, the number of suitable sites was then reduced, and the final suitability map was integrated with socio-economic parameters and farmer discussions. A team visited the areas to validate the results in the field by comparison with the suitability maps. Suitability identified by both approaches indicated good coincidence with suitability on the ground.

The final suitability maps gave farmers the opportunity to state their needs, and users could access information for any location on the map to learn the suitable RWH option, landowner name, and area of the land parcel and could make enquiries based on the name of the owner.

The United Nations Environment Programme (UNEP; Mati et al., 2006) carried out a study to determine if RWH technologies could be mapped at continental and country scales by using RS and a GIS. The project developed a total of 73 thematic maps, 29 for RWH potential in Africa, and 44 for case studies covering Botswana, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia, and Zimbabwe. The main criteria, largely governed by FAO (2003) guidelines, were rainfall, population, land use, slope, soils, and ephemeral streams. The study identified the most suitable sites for main RWH interventions as being (i) rooftop RWH, (ii) pans/ponds, (iii) sand/subsurface dams, and (iv) in-situ systems for storing soil water. Digital GIS data were gathered from laboratories, and non-spatial data were gathered from libraries, local and international organisations, individuals, and the internet. GPS (global positioning system) and satellite RS data were gathered in addition to data from cartographic surveys. A GIS database was developed using ArcGIS and ArcView software to identify potential RWH sites in Africa. The UNEP study produced baseline thematic maps for criteria such as rainfall and soils. Areas where RWH was not applicable or suitable were then eliminated by comparing two or more baseline maps. For example, areas with rainfall >200 mm and a rainfall index $<60\%$ were considered suitable for sand/subsurface dams. A lack of high-resolution input data and soil maps that did not cover the entire continent or had low resolution were some of the constraints faced in the continent-wide mapping of RWH potential in Africa. The resolution of the data could also differ between layers.

The products of the Africa-wide GIS database developed in the UNEP project are best viewed in soft formats; the user can zoom in, overlay different factors, update criteria, and query for a specific question. The database will be quite useful in guiding users at sub-regional/national levels to target RWH projects, but the planning of the activities needs further detailed surveys and inputs of other socio-economic criteria.

GISs and RS complement each other for selecting suitable sites for RWH structures (Forzieri et al., 2008; Prinz et al., 1998; Ziadat, Mazahreh, Oweis, & Bruggeman, 2006). Table 3 presents a summary of the studies, RWH types, and criteria that have been applied in ASARs using GIS/RS. GISs and RS offer a data-reviewing capability that supports both quality control and the identification of errors. GISs and RS also provide a good opportunity to gain a better understanding of any patterns, make a query, update criteria and trends, and produce easy-to-read/use information via maps, posters, and the internet. The maps can also be converted into pictures to enable access by non-GIS users.

The GIS property of spatial analysis makes it effective for use in different regions with differently sized areas and little data. The application of GIS/RS is cost-effective and rapid compared to the three other methods, but GIS/RS analyses must be preceded by field surveys before the actual implementation of RWH to verify suitable sites. In addition, the accuracy of GIS/RS depends highly on the quality (resolution) and availability of the data. This method will therefore be useful as a preliminary method and can be applied as a first step in identifying suitable sites for RWH in ASARs.

2.2.2. HM with GIS/RS

The Soil Conservation Service (SCS) method is the most widely used approach for estimating surface runoff from small catchments after a rainfall event (Gupta et al., 1997). It considers the relationship between land cover and hydrologic soil group, which together make up the curve number (De Winnaar et al., 2007; Kadam et al., 2012; Ramakrishnan et al., 2009). With this approach, the suitable locations for RWH structures were located in areas with the highest capacity for runoff generation and nearby to existing drainage lines. Number of researchers applied the Soil Conservation Service (SCS) with Curve Number (CN) method, focussing on how much runoff could be generated from a runoff area (e.g. De Winnaar et al., 2007; Gupta et al., 1997; Kadam et al., 2012; Senay & Verdin, 2004). Several hydrological models incorporate the SCS-CN method for estimating storm runoff, including TOPMODEL (Warrach, Stieglitz, Mengelkamp, & Raschke, 2002), WMS (HEC-1, HEC-HMS, and HEC, 2001), KINEROS (Woolhiser, Smith, & Goodrich, 1990), and SWAT (Arnold, Williams, Srinivasan, & King, 1996). Integrating these models/methods with advanced tools such as RS and GIS can enhance the accuracy and precision of runoff prediction, allowing faster and less costly identification of potential RWH locations. Table 4 shows the studies that have integrated HM with GIS/RS and applied in ASARs along with the criteria for each RWH technique.

De Winnaar et al. (2007) linked the SCS-CN method with a GIS to identify potential runoff-harvesting sites in a small sub-catchment in South Africa. This study provided a detail of the spatially explicit method and presented suitability maps for RWH sites. The GIS was used as a tool to store, analyse, and manage spatial data.

Table 3
Summary of RWH types and selection criteria that have been applied in ASARs. Group 1: using GIS/RS.

Biophysical criteria

No	Authors	Country	RWH type	Rainfall	Runoff	Slope	Soil type	Soil depth	Land use/ cover	Drainage network	Watershed size	Storage char
1	Oweis, Oberle, and Prinz (1998)	Syria	–	1		1	1	1	1			
2	Prinz et al. (1998)	Syria	–	1		1	1		1	1		
3	Mati et al. (2006)	Africa	Rooftop, ponds, pans and dams	1		1	1		1			
4	Ziadat et al. (2006)	Jordan	Cistern and pits contour			1	1	1	1			
5	Bakir and Xingnan (2008)	Syria	–			1	1		1			
6	Forzieri et al. (2008)	Mali	Small dams	1		1			1		1	
7	Ben Mechlia et al. (2009)	Tunisia	Jessour and tabia		1	1						
8	Al-Daghastani (2010)	Iraq	Dams and channels						1	1		
9	Kamel and Ahmed (2010)	Iraq	–			1					1	
10	Al-Shamiri and Ziadat (2012)	Jordan	Contour ridge and runoff strips			1	1	1				
11	Salih and Al-Tarif (2012)	Iraq	Reservoir						1	1	1	1
12	Ziadat et al. (2012)	Jordan	Dams, ponds and runoff strips			1	1	1	1		1	
13	Bamne, Patil, and Vikhe (2014)	India	Check dams and percolation tank			1	1		1	1		

Socio-economic criteria

No	Authors	Country	RWH type	Cost	Distance to					population density	Infrastructures	Household char./ landowner
					Settlements	Streamflow	Boarders	Roads	Agricultural area			
1	Oweis et al. (1998)	Syria	–									
2	Prinz et al. (1998)	Syria	–									
3	Mati et al. (2006)	Africa	Rooftop, ponds, pans and dams							1		
4	Ziadat et al. (2006)	Jordan	Cistern and pits contour									
5	Bakir and Xingnan (2008)	Syria	–									
6	Forzieri et al. (2008)	Mali	Small dams	1	1	1					1	
7	Ben Mechlia et al. (2009)	Tunisia	Jessour and tabia									1
8	Al-Daghastani (2010)	Iraq	Dams and channels									
9	Kamel and Ahmed (2010)	Iraq	–									
10	Al-Shamiri anhd Ziadat (2012)	Jordan	Contour ridge and runoff strips									
11	Salih and Al-Tarif (2012)	Iraq	Reservoir									
12	Ziadat et al. (2012)	Jordan	Dams, ponds and runoff strips									1
13	Bamne et al. (2014)	India	Check dams and percolation tank									

The input data, including biophysical and socio-economic data, were gathered from available data and from field surveys. A DEM with 20-m resolution was used to extract slope information, digital images and aerial photographs were used in ArcGIS 8.2, and a soil survey provided soil data. The SCS method has been adapted for southern Africa and has become an accepted and widely used technique (De Winnaar et al., 2007; Senay & Verdin, 2004). The SCS method requires information on soil form to classify the hydrological soil groups (A, B, C, and D). The CN is an index indicating a catchment's runoff response to rainfall event, and varies from 0 to 100; a higher CN represents a greater proportion of surface runoff. A CN was calculated for each hydrological soil group, and a CN map was generated based on the hydrological soil groups and land cover. The map layers used for the suitability analysis included the slope, CN map, and socio-economic criteria such as distance to settlement and distance to crop area. RWH sites were ranked on a scale from most to least suitable for each map based on the criteria of each data set. The final step was to combine different factors to identify the most suitable sites for RWH. Seventeen percent of the catchment had a high potential for generating surface runoff, whereas an analysis of all factors influencing the location of such a system found that 18% was highly

Table 4
Summary of RWH types and selection criteria that have been applied in ASARs. Group 2: HM with GIS/RS.

No.	Authors	Country	RWH type	Biophysical criteria								
				Rainfall	Runoff	Slope	Soil type	Soil depth	Land use/ cover	Drainage network	Watershed size	Storage char
14	Gupta et al. (1997)	India	Check dams	1	1	1	1		1	1		
15	Durbude and Venkatesh (2004)	India	Nala bunds, ponds and percolation tanks		1	1	1		1			
16	Senay and Verdin (2004)	Africa	Ponds	1	1						1	
17	De Winnaar et al. (2007)	South Africa	–	1		1	1		1			
18	Ramakrishnan et al. (2009)	India	Check dams, percolation tanks, pond and subsurface dykes		1	1					1	
19	Kadam et al. (2012)	India	Check dams, ponds, percolation tank		1	1	1		1	1		
20	Ahmad et al. (2013)	Pakistan	–		1					1		

No.	Authors	Country	RWH type	Socio-economic criteria								
				Cost	Distance to					population density	Infrastructures	Household char./ landowner
					Settlements	Streamflow	Boarders	Roads	Agricultural area			
14	Gupta et al. (1997)	India	Check dams									
15	Durbude and Venkatesh (2004)	India	Nala bunds, ponds and percolation tanks									
16	Senay and Verdin (2004)	Africa	Ponds							1		
17	De Winnaar et al. (2007)	South Africa	–		1				1			
18	Ramakrishnan et al. (2009)	India	Check dams, percolation tanks, pond and subsurface dykes									
19	Kadam et al. (2012)	India	Check dams, ponds, percolation tank		1							
20	Ahmad et al. (2013)	Pakistan	–			1						

suitable for RWH. Incorporating runoff information is consequently an important step for identifying suitable RWH sites using the SCS-CN method. The SCS method provides a useful strategic-planning tool for managers of water resources and offers some guidelines for large-scale studies. RWH, however, is highly location-specific, and applying the SCS approach needs more detailed data, which means that applying the SCS approach will be difficult for larger areas.

Ahmad (2013) investigated potential RWH sites in Pakistan by studying the runoff pattern using a hydrological model with the GIS/RS approach. The Geospatial Hydrologic Modeling Extension developed by the Hydrologic Engineering Center (HEC-GeoHMS), a public-domain software package for use with ArcView, was used for the delineation of water channels and drainage lines. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) was used to simulate rainfall-runoff and to estimate runoff generation in each outlet of a sub-catchment. A DEM with 90-m resolution was used as a source of elevation data in a catchment to determine flow direction, drainage lines, and runoff. The HEC-HMS model has two main processes for simulating flow: parameter optimisation with model calibration, and model validation. The results obtained by the HEC-HMS model were comparable to the observed results and found that a considerable amount of generated runoff could be stored at different sites, which represented the suitable sites for RWH. Moreover, 60% of the study area was potentially suitable for RWH.

The application of the water-balance equation a good way to understand the water regime of a specified area. The water-balance equation represents the relative values of inflow, outflow, and change in water storage for an area or water body. Durbude and Venkatesh (2004) applied the Thornthwaite and Mather (TM) models with the help of RS and a GIS to identify potential runoff zones and sites suitable for RWH in the Hire watershed in the state of Karnataka in India such as contours, farm ponds, gully plugs, and percolation tanks. The TM model is one of the simplest and most widely used methods for calculating the water balance (Durbude & Venkatesh, 2004). Thematic maps of land use, soil texture, and slope were created in a GIS, and the average annual runoff for the study area was estimated from the calculation of the water balance. The map of runoff potential was generated and reclassified into areas of no, low, moderate, and high runoff potential. All sites suitable for RWH techniques were examined and were found to be close to or on the outflow point. Water availability for these structures could thus be confirmed. The final decision rules for identifying suitable sites for RWH were formalised based on IMSD (1995) guidelines. Water balance can be applied to obtain a general estimate of the water-balance regime for variously sized areas, from individual fields to small watersheds (Gupta et al., 1997).

HM can generally be applied to simulate runoff in an entire watershed to determine the amount of runoff and to better understand of the water regime and the relationship between up- and downstream structures. The validation results of previous studies (Ahmad, 2013; De Winnaar, 2007; Durbude & Venkatesh, 2004; Senay & Verdin, 2004) confirmed that HM is reliable, flexible, produces highly accurate results, and, when integrated with GIS, provides a rational means to facilitate decision-making and offers a time-efficient and cost-effective method for the identification of suitable RWH sites. Each HM has its pros and cons, and the accuracy of the results is highly dependent on the model complexity, users, and data availability. The use of some models, however, also requires a purchased license.

2.2.3. *MCA integrated with HM and GIS/RS*

MCA is a commonly used method of analysis that combines data for various criteria. The analytical hierarchy process (AHP) is an MCA tool that has been applied widely to identify potential RWH sites (e.g. Krois & Schulte, 2014; Munyao, 2010; Sekar & Randhir, 2007). One of the main rules of MCA is to estimate a relative weight for each criterion, rather than assuming the same weight for all criteria (Banai-Kashani, 1989), and then compare two or more alternatives.

AHP is a multi-criteria decision-making method, providing a structured technique for organising and analysing complex decisions based on mathematics and expert knowledge (Saaty, 2008). AHP was developed by Thomas Saaty in the 1970s (Saaty, 1990) and since then has been applied extensively in various disciplines. The essential principle of AHP is to represent the elements of any problem hierarchically to organise the relationships between each level. The uppermost level is the main goal (objective) for resolving a problem, and the lower levels consist of more detailed criteria that influence the main objective. The weights for each criterion are determined by applying a matrix of pairwise comparisons. Pairwise comparisons determine the relative importance of two criteria involved in assessing the suitability for a given objective. Two criteria are compared and rated using a 9-point continuous scale. The odd values 1, 3, 5, 7, and 9 correspond respectively to equally, moderately, strongly, very strongly, and extremely important criteria when compared to each other, and the even values 2, 4, 6, and 8 are intermediate values (Saaty, 1990). For example, a rating of 5 between two criteria such as rainfall and slope indicates that the relationship between rainfall and slope is strongly correlated with the main objective.

MCA integrated with HM and GIS is a good tool for identifying suitable sites for RWH and is widely used in ASARs. Several studies have applied this integrated approach, taking advantage of the strengths of MCA together with those of HM and GISs, as shown in Table 5.

Jabr and El-Awar (2005) integrated MCA using AHP with HM, the watershed modelling system (WMS), and a GIS to identify suitable sites for RWH in Lebanon. Firstly, all spatial manipulations, analyses, and representations were performed within a GIS. ArcGIS was used for producing pertinent spatial coverages, including base soil maps, land cover, and topography. Secondly, WMS software was used to simulate runoff in watersheds at the sub-watershed level. WMS is a comprehensive HM environment that uses a conceptual model approach. WMS was selected because it supports the HEC-1 rainfall-runoff model. HEC-1 is suitable in regions with insufficient available runoff data, provides tools for all watershed modelling, including geometric and hydrological parameters, and analyses runoff for each outlet (Al-Ansari, Ezz-Aldeen, Knutsson, & Zakaria, 2012; Jabr & El-Awar, 2005). HM was used simultaneously with a GIS to estimate the necessary spatial hydrological parameters and to determine the site attributes associated with various decision criteria. Thirdly, a hierarchical decision structure using AHP was developed and implemented using calculated attributes to rank potential RWH sites. The application of the integrated methodology was highly flexible for the number of criteria and confirmed that this methodology was efficient; the results for the study reservoir were actually excavated at the outlet of the watershed with the highest rank.

Krois and Schulte (2014) presented a method to identify suitable sites for RWH (terraces and bund systems) in the Ronquillo watershed in Peru by integrating MCA, SCS-CN, and a GIS. The site assessment consisted of four steps. Firstly, input data were transferred into vector or grid maps, each of which represented a particular criterion of an RWH technique. Secondly, a GIS procedure created criteria maps by reclassifying the spatial maps based on the suitability level for each RWH technique. Thirdly, pairwise comparison matrix method, AHP, calculated the relative-importance weight of each criterion for each RWH technique. The selection criteria, based on the FAO guidelines, were: rainfall, runoff coefficient, slope, land use, soil texture, and soil depth. The assessment of the dominance of one criterion over another was based on the authors' expertise and a literature survey. Fourthly, the weighted overlay process in GIS determined the suitability maps for each RWH technique.

The required data were gathered from a variety of sources. For example, topographic data were provided by a DEM with 30-m resolution, slopes were calculated in an ArcGIS environment, land-use data were generated from Quickbird data, and the SCS-CN model estimated direct runoff in the catchment. The analysis found that the Ronquillo watershed was generally well suited for implementing RWH (terrace and bund systems) and indicated that 44% of the catchment was highly suited for terracing and that 24% was highly suited for bund systems. The choice of RWH technique, however, ultimately depended on land use and management practices. A preliminary site assessment should therefore be considered as the first step, which could lead to the adoption of the measure or ultimately to the continued use.

2.2.4. *MCA integrated with GIS*

The adoption of a GIS for combining sets of criteria to select suitable sites for RWH is generally based on using decision rules (Malczewski, 2004). We adopted two generally applied methods based on the application of MCA and a GIS (Table 6): the application of MCA in a GIS environment, and the application of a GIS followed by the definition of weights and scores for the criteria by AHP. In this group (group 4) of methods for selecting suitable sites for RWH, 37% of the 48 articles integrated MCA with a GIS without using HM, as in group 3. Table 6

In the first method, a suitability model was developed in Model Builder of ArcGIS to generate RWH suitability maps (Kahinda et al., 2008) by integrating input criteria maps using the weighted overlay process (WOP), also known as MCA within a GIS environment. WOP allowed the combination of data from several themes by converting cell values to a common scale, assigning weights, and aggregating the weighted cell values. MCA can be achieved by using weighted linear combination (WLC) and/or the Boolean operators that are the most often used decision rules in a GIS (Al-Adamat et al., 2010). The WLC method provides better site selection because of its flexibility (range of scale) in selecting optimum sites, and the Boolean method, which uses either OR or AND operations, selects RWH sites limited to small separated locations (Malczewski, 2004).

The GIS-based RWH suitability model (RSM) developed by Kahinda et al. (2008) combined, by using MCA, the physical, ecological, socio-economic, and constraint layers for assessing the suitability of RWH sites in South Africa. The RSM model was developed using Model Builder in ArcView 3.3. Suitability values were assigned for different criteria based on a literature review. WOP was applied for a combination of data from several input grid themes to convert the values to a common scale. The model produced three types of RWH maps for in-field and ex-field RWH: physical, potential, and suitability maps. The RSM model was applied and tested in two catchments, and the results indicated that about 30% and 25% of the sites were highly suitable for in-field and

Table 5
Summary of RWH types and selection criteria that have been applied in ASARs. Group 3: multi-criteria analysis (MCA) integrated with hydrological modelling (HM) and GIS/RS.

No.	Authors	Country	RWH type	Biophysical criteria								
				Rainfall	Runoff	Slope	Soil type	Soil depth	Land use/ cover	Drainage network	Watershed size	Storage char.
21	Banai-Kashani (1989)	USA	–			1				1		
22	Jabr and El-Awar (2005)	Lebanon	Reservoir		1	1	1		1			
23	Sekar and Randhir (2007)	USA	Storage and Ground water recharge	1	1		1		1			
24	Ramakrishnan et al. (2008)	India	Check dams, percolation tanks and subsurface dykes	1		1	1		1	1		
25	Munyao (2010)	Tanzania	Micro and Macro catchment	1		1	1		1			
26	Weerasinghe et al. (2011)	Brazil and Egypt	Tanks, reservoir, dams, pits and terrace		1	1	1	1	1	1		
27	Elewa et al. (2012)	Egypt	–		1	1	1			1	1	
28	Khan and Khattak (2012)	Pakistan	Check dams, ponds, Nigarim and gully plugs	1		1	1		1	1		
29	Hameed (2013)	Iraq	Dams	1		1	1		1	1		
30	Krois and Schulte (2014)	Peru	Terrace and bund	1		1	1	1	1			

No.	Authors	Country	RWH type	Socio-economic criteria								
				Cost	Distance to					Population density	Infrastructures	Household char./ landowner
					Settlements	Streamflow	Boarders	Roads	Agricultural area			
21	Banai-Kashani (1989)	USA	–	1								
22	Jabr and El-Awar (2005)	Lebanon	Reservoir									
23	Sekar and Randhir (2007)	USA	Storage and Ground water recharge	1								
24	Ramakrishnan et al. (2008)	India	Check dams, percolation tanks and subsurface dykes									
25	Munyao (2010)	Tanzania	Micro and Macro catchment		1			1				
26	Weerasinghe et al. (2011)	Brazil and Egypt	Tanks, reservoir, dams, pits and terrace									
27	Elewa et al. (2012)	Egypt	–									
28	Khan and Khattak (2012)	Pakistan	Check dams, ponds, Nigarim and gully plugs									
29	Hameed (2013)	Iraq	Dams									
30	Krois and Schulte (2014)	Peru	Terrace and bund									

ex-field RWH, respectively. The RSM model has a high degree of flexibility to change or update criteria/weights. Moreover, determining the weights is ultimately a political decision, which is the best compromise amongst competing interests (Kahinda et al., 2008).

Al-Adamat et al. (2010) applied both the WLC and the Boolean techniques within a GIS environment to identify suitable locations for RWH (ponds) in northern Jordan. Six WLC criteria, rainfall, slope, soil type, distances to roads, distances to urban centres, and distances to wadis, were then given weights and were rated and justified. The Boolean criteria eliminated some sites that had been selected by WCL. Seven Boolean criteria were used in this study: distances to international borders, distances to urban centres, distances to farms, distances to wadis, distances to roads, distances to geological faults, and distances to wells. The constraint factors and their justifications based on those used by Al-Adamat (2008) were: distances (metres) to international borders, wadis, roads, urban centres, faults, and wells. ArcGIS 9.1 generated both WLC and Boolean maps; 25% of the total area had high potential for implementing RWH (ponds), 43% was unsuitable, and 32% was least suitable.

In the second method, AHP provided a systematic approach to conducting MCA and decision-making. In this group, AHP and a GIS were used as a tool to make decisions based on expert and indigenous knowledge and on comparisons between alternatives. Firstly, a GIS was applied for collecting, analysing, and storing thematic maps. MCA was then applied within a GIS environment (as in the first method), with the integration of AHP at the end to identify the weights for each criterion (Moges, 2009), or AHP was applied separately, without applying MCA in a GIS, for various criteria to determine the relative weight of each criterion (Mahmoud & Alazba, 2014; Tsiko & Haile, 2011). Secondly, suitable sites

Table 6
Summary of RWH types and selection criteria that have been applied in ASARs. Group 4: integrated MCA and GIS.

No.	Authors	Country	RWH type	Biophysical criteria								
				Rainfall	Runoff	Slope	Soil type	Soil depth	Land use/cover	Drainage network	Watershed size	Storage char.
31	Padmavathy et al. (1993)	India	Check dams			1	1		1			
32	Yusof et al. (2000)	Malaysia	Reservoir			1	1		1			
33	Mbilinyi et al. (2007)	Tanzania	Storage and terrace	1		1	1	1	1	1		
34	Ould C. Ahmed et al. (2007)	Mauritani	–			1			1	1		
35	Al-Adamat (2008)	Jordan	Ponds	1		1	1		1			
36	Pauw et al. (2008)	Syria	Micro and Macro catchments	1		1	1	1	1			
37	Kahinda et al. (2008)	South Africa	In-field and ex-field	1			1	1	1	1		
38	Kumar et al. (2008)	India	Check dams, bunding, pits and terracing			1			1	1		
39	Jothiprakash and Sathe (2009)	India	Tanks, storage and GW recharge	1							1	1
40	Kahinda et al. (2009)	South Africa	In-field, ex-field and domestic	1			1	1	1			
41	Moges (2009)	Ethiopia	Ponds and in-situ	1		1	1	1	1			
42	Al-Adamat et al. (2010)	Jordan	Ponds	1		1	1					
43	Tsiko and Haile (2011)	Eritrea	Resrvoir	1		1	1					
44	Al-Adamat et al. (2012)	Jordan	–	1		1	1					
45	Isioye et al. (2012)	Nigeria	In-situ, ponds and dams	1		1	1		1	1		
46	Mahmoud (2014)	Saudi Arabia	Ground water recharge	1	1	1	1		1			
47	Mahmoud and Alazba (2014)	Saudi Arabia	In-situ	1	1	1	1		1			
48	Tumbo et al. (2014)	Tanzania	Ndiva, terrace and boda	1		1	1	1	1	1		

No.	Authors	Country	RWH type	Socio-economic criteria										
				Cost	Distance to					population density	Infrastructures	Household char./ landowner	GIS based MCA	MCA (AHP), GIS
					Settlements	Streamflow	Boarders	Roads	Agricultural area					
31	Padmavathy et al. (1993)	India	Check dams											1
32	Yusof et al. (2000)	Malaysia	Reservoir		1			1					1	
33	Mbilinyi et al. (2007)	Tanzania	Storage and terrace										1	
34	Ould C. Ahmed et al. (2007)	Mauritani	————											1
35	Al-Adamat (2008)	Jordan	Ponds		1	1	1	1	1		1		1	
36	Pauw et al. (2008)	Syria	Micro and Macro catchments											1
37	Kahinda et al. (2008)	South Africa	In-field and ex-field		1		1	1			1	1	1	
38	Kumar et al. (2008)	India	Check dams, bunding, pits and terracing		1			1					1	
39	Jothiprakash and Sathe (2009)	India	Tanks, storage and GW recharge	1										1
40	Kahinda et al. (2009)	South Africa	In-field, ex-field and domestic		1	1		1				1	1	
41	Moges (2009)	Ethiopia	Ponds and in-situ											1
42	Al-Adamat et al. (2010)	Jordan	Ponds		1	1							1	
43	Tsiko and Haile (2011)	Eritrea	Resrvoir		1	1		1	1					1
44	Al-Adamat et al. (2012)	Jordan	–		1	1	1		1				1	
45	Isioye et al. (2012)	Nigeria	In-situ, ponds and dams										1	
46	Mahmoud (2014)	Saudi Arabia	Ground water recharge											1
47	Mahmoud and Alazba (2014)	Saudi Arabia	In-situ											1
48	Tumbo et al. (2014)	Tanzania	Ndiva, terrace and boda										1	

for RWH were identified based on the AHP weights. The relative weights between criteria were determined by applying pairwise comparison matrices and assigning the weights to the thematic layers. Pairwise comparison is most likely to reduce bias in the weights, making AHP a more effective MCA technique (Tsiko & Haile, 2011).

Moges (2009) used a GIS with MCA to identify suitable sites for RWH (ponds and in-situ systems) in Ethiopia. Six criteria were selected for the identification of suitable ponds: soil texture, soil depth, rainfall surplus, topography, land cover, and groundwater depth. The same criteria except groundwater depth were selected for the identification of suitable in-situ systems. WLC was used in the decision rules in the GIS. ArcGIS Model Builder was used to build the suitability model, which generated five suitability classes using WOP: very high, high, moderate, low, and very low suitability. AHP was then applied to develop the weight for each criterion based on its relative importance to the other criteria and to the main objective. The criteria were rated based on a literature review, field-survey information, and expert opinion. Maps for each criterion and for the overall suitability of sites for RWH were produced. Finally, two suitability maps were produced, one for ponds and another for in-situ systems. Forty-nine percent of the total area was very highly or highly suitable for ponds, and 60% was highly suitable for in-situ systems. The results from the suitability model were validated using field-survey information, and the validation results indicated that the produced maps have given a reliable map of the spatial distribution of suitable areas. Moreover, the suitability maps provided an easy resource for quickly identifying the most suitable areas.

3. Discussion and conclusions

The main objective of this study was to define a general method for selecting suitable RWH sites in ASARs based on methods developed throughout the last three decades. The success of RWH systems depends heavily on the identification of suitable sites and on their technical design (Al-Adamat et al., 2012). The 48 articles we reviewed indicated that the way sites are selected has shifted over time, reflected in the three sets of guidelines: IMSD (1995), Oweis et al. (1998), and FAO (2003) (see Table 2). The main sources of criteria used by most of the 48 studies followed or were derived from one of these three sets.

The selection criteria for suitable RWH sites was the first important change. Studies in the 1990s (e.g. Gupta et al., 1997; Padmavathy et al., 1993; Prinz et al., 1998) focused primarily on biophysical criteria. After 2000, socio-economic parameters were integrated with the biophysical criteria (e.g. De Winnaar et al., 2007; Senay & Verdin, 2004; Yusof et al., 2000). Studies concluded that socio-economic criteria were needed to improve the selection of suitable sites following the general trends, such as integrated watershed management (Gregersen et al., 2007) in which the development and management of water are linked to economic and social welfare.

The biophysical criteria are similar for all types of RWH, but no consensus has been reached for the social-economic criteria to use for the selection of suitable sites and RWH techniques. The most common criteria applied in ASARs along with the RWH techniques (as a percentage of all studies reviewed) were: slope (83%), land use/cover (75%), and soil type (75%) (Tables 3–6). Rainfall is a major component in any RWH system, and RWH systems can only function if a catchment receives sufficient rainfall to store, but only 56% of all studies reviewed included rainfall. Slope was the commonest criterion. Slope plays a significant role in the amounts of runoff and sedimentation, the speed of water flow, and the amount of material required to construct a dyke (the required height). The most commonly applied socio-economic criteria were: distance to settlements (25%), distance to streams (15%), distance to roads (15%), and cost (8%). These technical and socio-economic criteria are closely linked with each other, but we can distinguish between primary and secondary criteria. For most RWH techniques, rainfall (distribution and rain intensity over the year), soil type (texture and saturated hydraulic conductivity), and slope are the basic criteria that determine the technical suitability of a location. The primary criteria are based on the goals of both RWH and the biophysical conditions and determine the technical suitability of a location and/or RWH system. Primary criteria, however, does not guarantee success. Failure is often due to other reasons associated with socio-economic parameters. Our results show less consensus about these secondary criteria, which may be case-specific.

Selecting the most relevant socio-economic criteria requires not only good insight into the local situation and stakeholders involved, but also access to data on costs and benefits and insight into the indirect economic effects and social parameters such as labour availability, land and water rights, and risks of flooding. The literature review, however, indicated that insufficient insight into the socio-economics was one of the main reasons that RWH sites failed to function properly in ASARs. FAO (2003) guidelines may therefore be the most comprehensive set of instructions for the efficient planning and implementation of new RWH systems. These guidelines contain most of the factors that directly affect the performance of RWH and those directly related to the crop and water requirements, and the FAO has a wide range of suitability values for various factors such as slope, soil texture, and rainfall. Moreover, the FAO guidelines include several socio-economic criteria, e.g. population density, people's priorities, experience with RWH, and land tenure, which are important factors to ensure the success of RWH and to increase the adoption of new RWH technology by local farmers.

We identified four main methods from the sources of information reviewed that have been used for selecting suitable sites for RWH in ASARs. A GIS supported by RS has been extensively applied either alone or integrated with HM and/or MCA (Tables 3–6). MCA integrated with GIS (group 4) was used to identify RWH sites in ASARs in 37% of the 48 studies reviewed, which was the highest percentage amongst the four groups, whereas the group 2 methods were used in about 15% of the sources, which was the lowest percentage.

Determining the most helpful method for selecting suitable RWH sites is a great challenge. Table 7 presents a comparison of the four methods/tools based on the characteristics and requirements of the ASARs, the properties of each method, specific data requirements, applicability to different regions, accuracy and limitations, previous studies, and the ability of a method to be applied in different regions.

Each of the four methods has been applied separately in different regions with different criteria, but most sources of information provided little information on the RWH success rate for the selected sites. Field results comparing two or more methods used in the same watershed to identify the main similarities and contrasts are therefore not available. Our analysis of strengths and weaknesses suggests that the integration of MCA and GIS is the most advanced method and provides a rational, objective, and unbiased method for identifying suitable sites for RWH. Isioye, Shebe, Momoh, and Bako (2012), Moges (2009), and Al-Adamat et al. (2010) reported similar conclusions. MCA with a GIS has been found to be a robust method that is highly compatible with the indigenous knowledge of the farmers (Tumbo, Mbilinyi, Mahoo, & Mkilamwinyi, 2014).

The most suitable method for application in a particular case is highly dependent on the main objectives and needs of the project

Table 7
A comparison of four methods (identification, pros, cons, and notes) that have been applied in ASARs in the last three decades.

	Method identification	Advantages	Limitations	Notes
GIS/RS (group 1)	Uses the properties of GIS/RS to produce several thematic maps to identify suitable sites for RWH.	Provides accurate information with high spatial and temporal resolution. Cost-effective and time-saving and is an especially useful tool in remote areas where very little information is available. Provides an easy way to better understand patterns and allows queries about the suitability of any area that has been analysed.	The accuracy of results is highly dependent on input data, but high-resolution input data are lacking. Does not provide a real image of the hydrology of a watershed, and the relationship between up- and downstream is lacking. Needs a field survey for validation.	This method will be very useful for application as a first step in identifying suitable sites for RWH in ASARs.
HM and GIS/RS (group 2)	Applies HM to study the rainfall-runoff relationship and to simulate runoff in an entire watershed for a better understanding of the water regime. Then integrate HM with GIS/RS to identify suitable sites for RWH.	HM is reliable, flexible, gives highly accurate results, and when integrated with a GIS, provides a rational means to facilitate decision-making and offers a time-efficient and cost-effective method. HM represents a fundamental way to simulate runoff in any watershed and provides a good understanding of the relationship between up- and downstream wadies or rivers. Most common models are easily accessible (free) on the internet.	The accuracy of results is highly dependent on the model complexity, users, and data availability. Most of the models are applicable at catchment scales, and most of these models need a lot of data for calibration and validation, which may not be available, especially in ASARs. These models are mostly related to rainfall-runoff simulation and neglect other important criteria such as socio-economic parameters.	Integration of HM and GIS/RS with other tools such as MCA is highly recommended to obtain more accurate results for RWH suitability.
MCA, HM, and GIS/RS (group 3)	Combines various criteria by applying MCA to estimate a relative weight for each criterion, rather than assuming the same weight for all criteria. Then applies the properties of HM and GIS/RS to identify suitable sites for RWH.	This integrated method is highly flexible in dealing with both qualitative and quantitative factors. Applicable to different criteria and in different regions. MCA (AHP) has the ability to check the consistency of expert judgment, providing more reliability and validity for deciding the suitability of RWH sites.	The weight (rank) of each criterion in MCA (AHP) is highly affected by expertise and author performance. Weights should thus be calculated carefully. Limitations of GISs and HM, such as model complexity and data quality and availability, should kept in mind.	GIS-based HM and MCA are highly recommended for data-rich regions.
MCA with GIS (group 4)	Adoption of a GIS for combining sets of criteria to select suitable sites for RWH based on using decision rules or applies a GIS separately then integrates with MCA.	Highly flexible for applying a GIS-based MCA in different regions, and changing or updating criteria is easy. This methodology can be applied in differently sized areas and in regions with little available information. MCA with a GIS is effective and can be used reliably to predict potential sites for RWH in ASARs.	The relationship between up- and downstream sites is still unclear. A sensitivity analysis should assess the robustness of the integrated model. The limitations of each tool GIS and MCA that are discussed in previous methods should be taken into consideration.	MCA (AHP) offers a high potential for data-poor regions.

(e.g. flexible, widely applicable, efficient, and accurate) and on the quality, availability, and reliability of the data. We highly recommend that future studies apply two or more of these four methods in the same region to identify the best method.

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