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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

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.