Resources, Conservation and Recycling 83 (2014) 96–111

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

# Rainwater harvesting planning using geospatial techniques and multicriteria decision analysis

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ARTICLE INFO

*Article history:*
Received 17 June 2013
Received in revised form
28 November 2013
Accepted 4 December 2013

*Keywords:*
Rainwater conservation
RWH planning
Geospatial techniques
Multicriteria analysis
Distributed CN method
Water scarcity

ABSTRACT

Growing water scarcity and global climate change call for more efficient alternatives of water conservation; rainwater harvesting (RWH) is the most promising alternative among others. However, the assessment of RWH potential and the selection of suitable sites for RWH structures are very challenging for the water managers, especially on larger scales. This study addresses this challenge by presenting a fairly robust methodology for evaluating RWH potential and identifying sites/zones for different RWH structures using geospatial and multicriteria decision analysis (MCDA) techniques. The proposed methodology is demonstrated using a case study. The remote sensing data and conventional field data were used to prepare desired thematic layers using ArcGIS© software. Distributed Curve Number method was used to calculate event-based runoffs, based on which annual runoff potential and runoff coefficient maps were generated in the GIS (geographic information system) environment. Thematic layers such as slope, drainage density, and runoff coefficient and their features were assigned suitable weights and then they were integrated in a GIS to generate a RWH potential map of the study area. Zones suitable for different RWH structures were also identified, together with suitable sites for constructing recharge structures (check dams and percolation tanks along the streams). It was found that the study area can be classified into three RWH potential zones: (a) 'good' (241 $km^2$), (b) 'moderate' (476 $km^2$), and (c) 'poor' (287 $km^2$). About 3% of the study area (30 $km^2$) is suitable for constructing farm ponds, while percolation tanks (on the ground) can be constructed in about 2.7% of the area (27 $km^2$). Of the 83 sites identified for the recharge structures, 32 recharge sites are specially suited to the inhabitants because of their proximity. It is concluded that the integrated geospatial and MCDA techniques offer a useful and powerful tool for the planning of rainwater harvesting at a basin or sub-basin scale.



## 1. Introduction

Freshwater is the lifeblood of the biosphere and the backbone of socio-economic development of a country. Owing to increasing population, growing industrialization and unabated pollution of freshwater, freshwater scarcity is a serious problem in several parts of the world, especially in developing nations (Biswas et al., 2009). How to achieve water security is one of the biggest challenges of the 21st century. India is one of the countries that adopted Millennium Development Goals (MDGs) in September 2000. United Nations have set up an eight-goal program popularly known as MDGs to fight against various socio-economic and environmental problems ranging from poverty to removal of HIV/AIDS till 2015 (http://www.un.org/millenniumgoals/). Water is in the heart of first, third and seventh MDGs, and is also indirectly associated with the achievement of other MDGs. Hence, to achieve these daunting goals, we must conserve and efficiently manage our precious water and land resources.

Though India receives sufficient rainfall in a year (mean annual rainfall = 1100 mm), because of unique characteristics of the monsoon such as uneven distribution of rainfall, rainy period restricted to a few months of a year and high intensity of rainfall, the country often faces serious problems of floods and droughts in the same year. In particular, water scarcity prevails in several parts of the country during summer seasons (Garg and Hassan, 2007). Growing water scarcity and gradual deterioration of water quality due to point and non-point sources of pollution are posing a serious threat to sustainable human development. Rainwater harvesting has emerged as one of the important tools for water conservation, which can ensure safe, accessible and affordable water for drinking and other domestic uses, agriculture, livestock and small-scale industries, besides its significant contribution to the augmentation of groundwater resources (Agarwal et al., 2001; Samra et al., 2002). There are several other benefits of rainwater harvesting, viz.,

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http://dx.doi.org/10.1016/j.resconrec.2013.12.003

no excessive runoff, flood control in the downstream catchment, improved soil moisture availability and soil conservation (Samra et al., 2002; Singh et al., 2009).

The term 'rainwater harvesting' is generally used to describe collection, storage, distribution and use of rainwater. Rainwater harvesting in the broad sense is defined as the methods for concentrating, storing and collecting runoff from rainwater for domestic and agricultural uses (Rockstrom, 2000; Sutherland and Fenn, 2000). Water harvesting systems can be grouped into three main types: (a) in situ conservation (soil and water conservation), (b) concentration of runoff to crops in the field, and (c) collection and storage of runoff water from roofs and land areas in different structures for some beneficial uses (Falkenmark and Rockstrom, 2004). There are six key factors which must be considered while selecting rainwater harvesting sites (FAO, 2003): climate (rainfall), hydrology (rainfall–runoff relationship and intermittent watercourses), topography (land slope), agronomy (crop characteristics), soil (texture, structure and depth) and socio-economic condition (population density, work force, people's priority, people's experience with rainwater harvesting, land tenure, water laws, accessibility and related costs). Emerging geospatial technologies such as such as remote sensing (RS) and geographic information system (GIS) have been found to be effective tools for delineating rainwater harvesting (RWH) potential zones and selecting sites for RWH structures, and play a vital role in the planning and management of water resources (e.g., Jha and Peiffer, 2006; Jha et al., 2007; Kahinda et al., 2008; Chowdary et al., 2009; Jasrotia et al., 2009; Jha et al., 2010; Weersinghe et al., 2010).

In the recent past, the effectiveness of geospatial techniques in identifying potential zones and sites for rainwater harvesting has been reported by some researchers (Gupta et al., 1997; De Winnaar et al., 2007; Mbilinyi et al., 2007; Kahinda et al., 2008; Kumar et al., 2008; Ramakrishnan et al., 2008; Jasrotia et al., 2009; Kahinda et al., 2009; Ramakrishnan et al., 2009; Singh et al., 2009; Weersinghe et al., 2010). Proper selection of factors (thematic layers) is of great importance for the identification of sites for different RWH structures. The review of the literature revealed that a varying number/type of thematic layers has been used by the researchers depending on the availability of data for delineating rainwater harvesting potential zones and/or identifying suitable sites for rainwater harvesting. Generally, the Weighted Linear Combination technique has been used for the integration of thematic layers in GIS environment. In several studies related to the evaluation of groundwater prospect and water harvesting/artificial recharge potential and the identification of water harvesting sites and/or artificial recharge sites, weights were assigned to only themes and ranks to the features of individual themes, and the range of weights was decided arbitrarily. In most studies, weights were assigned on the scale of 1–5 or 1–100, while only a couple of studies (Saraf and Choudhury, 1998; Krishnamurthy et al., 2000; Ghayoumian et al., 2005; Mbilinyi et al., 2007; Kumar et al., 2008; Chowdary et al., 2009; Chowdhury et al., 2010; Chenini et al., 2010; Jha et al., 2010; Machiwal et al., 2011) assigned weights on the standard scale of 1–9 as suggested by Saaty (1980). On the other hand, some researchers reported that the Boolean logic analysis involving certain suitability criteria for different water harvesting structures for Indian conditions could be successfully implemented in the field and could also be used in similar terrain conditions with appropriate modifications (Saraf and Choudhury, 1998; Ravi Shankar and Mohan, 2005; Chowdary et al., 2009; Ramakrishnan et al., 2009; Singh et al., 2009). Recently, a combination of Weighted Linear Combination technique and Boolean logic has been applied by a few researchers for the delineation of artificial recharge zones and for the identification of suitable sites for artificial recharge (Jasrotia et al., 2009; Chowdhury et al., 2010). Based on the review of past studies, it can be inferred that the selection of suitable thematic layers, proper assignment of weights, suitable analysis of weights, proper use of multicriteria decision analysis techniques, and the adoption of realistic suitability criteria (for site selection) are the key to the successful application of geospatial and multicriteria decision analysis (MCDA) techniques in identifying RWH potential and suitable sites for water harvesting structures.

The main objective of this study is to present a reasonably robust methodology for assessing rainwater harvesting potential and identifying suitable sites/zones for different rainwater harvesting structures using RS, GIS and MCDA techniques. The proposed methodology is demonstrated through a case study. Novelty of this study lies in the fact that unlike earlier studies wherein the easily available thematic layers have directly been used for multicriteria decision analysis, in this study, derived thematic layers and distributed curve number approach have been applied. Such an approach is not only scientifically sound but also it is most likely to reduce the bias involved in GIS-based multicriteria analysis.

## 2. Overview of study area

In the present study, two administrative blocks Binpur-I and Binpur-II of West Medinipur district, West Bengal, India were selected as a study area (Fig. 1); blocks/districts usually form a practical basis for the planning and management of land and water resources in most developing countries. The study area is geographically located between 22°47′ to 22°21′ N latitude and 86°33′ to 87°9′ E longitude, with a total geographical area of 1006.5 $km^2$. It has 20 *Gram Panchayats*, which consists of 814 villages. The study area has humid to sub-humid climate having four distinct seasons: (a) summer season, (b) monsoon season, (c) post-monsoon season, and (d) winter season. The average annual rainfall of the study area is about 1400 mm, with average rainy days of 77 in a year. The majority of the rainfall occurs during the monsoon season (June to October). Drainage of the study area is mainly controlled by the Kangsabati River. The Bhairabbanki River and the Tarafeni River are important tributaries of the Kangsabati River and are perennial in nature. The total cultivated area in Binpur-I block is 200.72 $km^2$ and that in Binpur-II block is around 218 $km^2$. These blocks are economically backward blocks of West Medinipur district. The major source of irrigation is groundwater, together with canal water and some minor surface water sources. Paddy, wheat, oil seeds, pulses, potato and vegetables are the crops grown in the study area. Paddy cultivation occupies a major portion of the cultivated area during rainy (monsoon) season.

The hydrogeological condition of West Medinipur district can be divided into two broad groups: (i) fractured/fissured formation, and (ii) porous formation. Hard crystalline rocks occur around Binpur-II block in the extreme northwestern part of the district, where groundwater occurs under unconfined condition in the weathered residuam of the hard rocks and the interconnected fractures, fissures, joints, etc. The thickness of the weathered zone varies from a very thin layer to as much as 15–20 m. On the other hand, the porous formations are very extensive both laterally and vertically; groundwater in these formations occurs under both unconfined and confined conditions. Binpur-I block is comprised of older alluvium/tertiary alluvium underlain by Granite Gneiss. However, most parts of Binpur-II block are comprised of Granite Gneiss. The upper aquifer within 40 m below the ground level (bgl) is under unconfined condition and the lower aquifer below 50 mbgl is under confined condition. Low-duty tubewells tapping granular zone of 12–15 m within 50 m depth have a well yield of 15–25 $m^3$/h, whereas the medium-duty tubewells tapping granular zone of 30–40 m within 200 m depth have a well yield of 50–100 $m^3$/h. In hard-rock regions, dug wells, dug-cum-borewells and borewells are suitable, which have a well yield