Water Resour Manage
DOI 10.1007/s11269-016-1350-6

Estimation the Physical Variables of Rainwater Harvesting System Using Integrated GIS-Based Remote Sensing Approach

Khamis Naba Sayl[1] **· Nur Shazwani Muhammad**[1] **·**
Zaher Mundher Yaseen[1] **· Ahmed El-shafie**[2]

Received: 12 March 2016 / Accepted: 5 May 2016

Abstract Geographic Information System (GIS) are an intelligence technique skilled to extract, store, manage and display the spatial information for various applications of water resources management. Practically, arid and semi-arid environments suffer from several restrictions (e.g., lack of socio-economic and physical data, limited precipitation, and poor rain water management). In this research, Remote Sensing (RS) approach was integrated with GIS conducted to estimate the physical variables of reservoir system (i.e., elevation-area-volume curve). First and foremost, computing an accurate and reliable elevation-area-volume curve is a challenging task for the purpose of identifying the optimal depth, minimum surface area and maximum reservoir storage. Accordingly, a field study consisting of three constructed small earth dams were demonstrated the use of the geospatial approach in the western desert of Iraq, where the elevation-area-volume curve was extracted. The surface areas and the reservoir volumes that were obtained from field survey and spatial intelligence techniques were compared. A comprehensive analysis have been carried out for the evaluation purposes. The results indicate that the proposed approach efficiently applied with remarkable level of accuracy.

Keywords Arid and semi-arid environments · Remote sensing · Geographic information system · Elevation-area-volume curve · Iraq

✉ Zaher Mundher Yaseen
zahermundher@gmail.com

[1] Civil and Structural Engineering Department, Faculty of Engineering and Built Environment, National University of Malaysia, 43600 UKM, Bangi, Selangor Darul Ehsan, Malaysia

[2] Civil Engineering Department, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

1 Introduction

1.1 Background

Freshwater is one of the nature's priceless gifts, which sustains life on earth. Out of 2.5 % global fresh water only 1 % is available for human consumption (Singh et al. 2009). Planet water resources are confronting dramatic changes as a result of global climate change, population growth, high water demands, urbanization and industrialization. However, assisting the society by proposing and employing systems that enhance better use of water resources and management in most watersheds is crucial. In this context, arid and semi-arid environments suffered from water resources availability (Begemann et al. 1988; Taffere et al. 2016). Those regions characterized by uneven distribution of precipitation in time and space, as a result, there is a call for more efficient alternatives of water conservation. Rainwater harvesting (RWH) considers as the most promising alternative among others for the provision of water for irrigating vegetable gardens (Liebe 2002; Jha et al. 2014; Paruch et al. 2014; Choong and El-Shafie 2015).

The term "Water harvesting" can best be described as all activities to collect available water resources, temporarily storing excess water for use when required, especially in periods of drought when no water resources are available. This use may include domestic (drinking and other purposes), irrigation (crop use), and even industry (Rockstrom 2000; Al-Adamat 2008; Ahmad et al. 2014). Rainwater harvesting structure is one of the important components of watershed development (Baban and Wan-Yusof 2003; Singh et al. 2009; Thomas et al. 2010; Kanakoudis et al. 2011; Ishaku et al. 2012). However, identifying the appropriate position for a dam and reservoir location is a very important issue. The considerations are not restricted only to the financial terms or economic benefits, but most of all, population and environment aspects. Technically, properly planning, designing and implementing dam's construction would improve rainwater use efficiency, agricultural development, and environment.

1.2 Problem Statement

The prior criteria of constructing a rainwater harvesting structure such as "dams" is to propose the optimal depth. Dam depth has direct relationship with surface area and capacity of the reservoir, therefore, efficient method to extract the elevation-area-volume curve is an essential step for dam site selection. Emerging of Remote Sensing (RS) and Geographic Information System (GIS) based on Digital Elevation Model (DEM) have been effectively utilized for delineating and selecting potential zone rainwater harvesting structure, in addition, play as vital role in plan and manage water resources (Jha et al. 2006; Mwenge Kahinda et al. 2008; Chowdary et al. 2009; Mwenge Kahinda et al. 2009; Pistrika 2010; El-Shafie et al. 2014; Gwenzi and Nyamadzawo 2014). Another essential hydrological aspects of watershed management that need a serious attention from researchers are (i) an effective water management planning hindered by inadequate knowledge of reservoir volumes, (ii) most of the catchments rarely matches the demand during drought periods, (iii) The absence of adequate knowledge on small reservoir storage capacities is a constraint in decision-making process regarding planning and management of existing water resources. Therefore, quantifying available water in these reservoirs, their capacities must be known at any level to assist planners in analyzing the match between water supply and water demand (Hossain and El-shafie 2013). Furthermore, used for planning, development, and management of natural resources at regional, national, and international level, precisely for developing countries.

The Last two decades, several studies have been accomplished regarding the physical and hydrological aspects of water harvesting through the use of GIS. Vorhauer and Hamlett (1996) developed a GIS application for identifying farm irrigation ponds based on qualitative criteria and knowledge. Gupta et al. (1997) estimated water harvesting potential using GIS in semi-arid region. The results demonstrated the capability of a GIS for water harvest planning over larger areas and showed good performance. Nisar Ahamed et al. (2002) extracted the location of outlets for small catchment to identify the appropriate reservoir zone by developing a GIS based algorithm. The research conducted by using a grid-DEM and drainage map as input. Kallali et al. (2007) studied GIS based multi-criteria analysis for potential wastewater aquifer recharge sites in semi-arid region. Forzieri et al. (2008) conducted a research using GIS approach to pre-select a suitable sites for surface and underground small dams in arid environment. Geospatial analysis approach combined with fuzzy multi-criteria decision making for the selection of landfill sites in a fast-growing urban region, have been accomplished by (Chang et al. 2008). Al-Adamat et al. (2010) investigated the capability of the geospatial technique which is combined with multi-criteria decision making for siting water harvesting ponds. The results performed strong capabilities of GIS in handling digital data in order to select the optimal sites for water harvesting ponds in arid area. An assessment of groundwater potential in a semi-arid environment utilizing RS, GIS and multi-criteria decision making (MCDM) carried out by (Machiwal et al. 2011). Publishers concluded that the proposed methodology is powerful tool for evaluating groundwater potential. El Bastawesy et al. (2013) used RS and DEM to determine watershed hydrological parameters for the purpose delineating reservoir location. Researchers concluded that digital elevation models (DEMs) are a very precise tool for watershed delineation and watershed management.

The Western Desert covers a considerable part of Iraqi territory in the region south and west of the Euphrates River, (see Fig. 1). It extends west and south into Syria, Jordan and Saudi Arabia, and covers an area of about 220,000 km^2. Many large misfit valleys provide the drainage network of the Iraqi Western Desert. Some of these drain into the Euphrates River such as Houran, Swab, Walaij, Akash, Ratga, Fhada, Qaiam and Al Manai valleys. The Western Desert is a gently sloping plain with a gradient of 5 m/km, towards east and northeast. The dip of the strata is almost horizontal, reaches (1–2) degrees, which recommends that only earth dams harvesting structure suitable for this catchment. The topographical maps that is available for this catchment with contour interval (10) meter. Furthermore, the catchment is located in developing nation where the data availability very poor with low quality. Therefore, encouraging the utility of using geospatial techniques in identifying potential zones and sites for rainwater harvesting, certainly required. Accordingly, based on several studies have been undertaken, which evident that using satellite images integrated with GIS for reservoirs surface area and volume estimation are indeed feasible, less-time consuming and with appreciable costs (Tsihrintzis et al. 1996; Gupta et al. 1997; Liebe 2002; Sawunyama et al. 2006; İrvem 2011; Cvar 2014; Zhang et al. 2014).

1.3 Research Objectives

Previously, EAV curve were extracted from topographical maps or field survey (Sawunyama et al. 2006). Most recently, Digital elevation models (DEM), such as from the Shuttle Radar Topography Mission (SRTM), or the Advanced Spaceborne Thermal Emission and Reflection

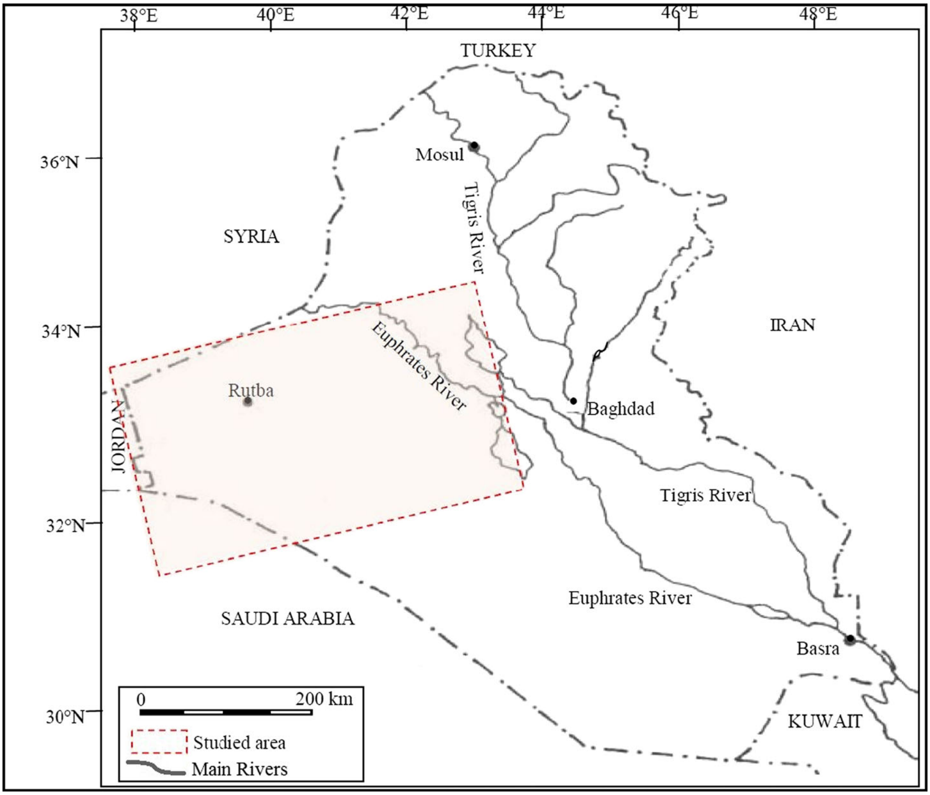

Fig. 1 Location of the case study, the western desert of Iraq

ASTER GDEM product (USGS, Denver, Colorado, USA), have been utilized as an effective tool for watershed analysis (Moore et al. 1991; Tsihrintzis et al. 1996). For the knowledge of the authors, the aim of this research is to propose a relatively new methodology for; (1) extracting and evaluating Elevation-Area-Volume curve and compute the mean water depth utilizing an integrated RS and GIS based on DEM, (2) evaluate and assess the propose method with topographical maps "field survey extraction", and (3) recently, there is a need to establish water harvesting projects at the west desert of Iraq for the purposes (i.e., of more surface water for domestic, agricultural and livestock watering usages, increase ground water recharge, reduce the storm water discharge, and eliminate the desertification).

2 Materials and Methods

2.1 Study Area Characteristics

The study area is located in the Western part of the Iraq, about (450 Km) west from the capital Baghdad as show in Fig. 1. The geographic position of the area is stretched from (32° 10′ 44″ - 34° 11′ 00″) N Latitude and from (39° 20′ 00″ - 42° 30′ 00″) E Longitude. The study area covers approximately (13,370 Km^2). The climate of the catchment characterised by arid climate with dry summers and cooler winters, which reflects drought case of negative impacts on the groundwater recharge (Buday and Hak 1980; Begemann et al. 1988). There are big diurnal changes in temperature, even daily variation with average monthly temperatures higher than 48 C in July and August to below zero in January. The barren land surface becomes intensively heated in daytime and cools during night time, due to high radiation. The mean annual runoff for the catchment is 900 million m^3. More than 90 % of the annual rainfall occurs between November and April, most of it in the winter months from December through March. The mean annual rainfall is very low (75–150) mm, 49.5 % occurs in winter, 36.3 % in spring and 14.8 % in fall. Whereas the mean annual evaporation ranges from 3000 to 3500. In another word, one feature of the aridity of the catchment is the evaporation rates being higher than those of precipitation by thirty times. The monthly average evaporation is various from one season to another. The annual mean of relative humidity is 46.2 % with the big variation from month to another over the year. Where the humid period starts from November to April with highest record in December (76 %) while the lowest relative humidity for the region in July around (21 %). The mean monthly values of air temperature, rainfall, radiation, speed of winds, relative humidity and evaporation which were recorded in five meteorological station distributed through the catchment during the period between 1941 and 2013 are shown in Table 1.

2.2 Database Preparation

The emergence of Geographic Information System and the accessibility of geospatial data have developed the data resources to plan accurately the water resources projects. The United Nation World Water Assessment Program has identified the need for tapping into the mass of geospatial data now available to enhance developing countries in their growing need for wise planning at water resources projects. However, all the after-mentioned features were represented in the thematic map. This map represents a significant tool for the purpose to model Elevation-Area-Volume curve. In the current research, an integrated Digital Elevation Model (DEM) and topographical sheets obtained from field survey data “West Desert of Iraq (WDI)”were used for generation of database and extraction the EAV curve. Details of data

Table 1 The mean monthly climatological features of the case study catchment

Months	Temperature C	Rainfall mm	Wind Speed m/s	Radiation $MJ/m^2/day$	Relative humidity %	Evaporation mm
January	7.6	26.1	2.4	232.2	69.8	78.3
February	9.5	20.4	3.1	312.5	62.7	109.4
March	13.4	15.2	3.2	405.9	54.9	171.9
April	19.5	11.4	3.1	492.1	43.3	247.1
May	24.8	6.5	2.9	583.3	34.8	336.58
June	30.2	0.1	3	634.3	29.5	415.12
July	33.7	0.2	3.4	636.2	28	498.75
August	32.9	0.1	2.7	594.1	28.7	449.91
September	28.1	0.6	2	506	31.9	327.2
October	22.2	14.9	2	393.5	43.7	222.9
November	14.3	16.4	1.8	286.8	56.5	161.1
December	9.4	27.3	2	217.2	69.2	82.8

used in the present study were indicated hereafter. The following procedure was followed for catchment analysis:

i. The topo-sheet of the study area were collected form (General Commission of Dams and Water Resources, Iraq). The surveyed data were suggested for harvesting structure “e.g., small earth dams”, namely Houran 2 (H2), Al-agara 2 (GRA2) and Al-agara 4 (GRA4). The components of the surveyed data are elevation, expected surface area and expected water volume for the reservoirs.
ii. DEM of the WDI catchment was extracted from Shuttle Radar Topographical Mission (STRM) data obtained during February 2000 with resolution of 30 m “downloaded from the USGS”, (see Fig. 2a). The DEM data was geometrically rectified and georeferenced to the ground control points (GCPs).
iii. Landsat 8 satellite imagery (March and August, 2014), (Path 171 and Raw 37). The mentioned data imported to ERDAS Imagine software for geometric correction (projection; UTM, WGS 84 zone 38). Landsat image utilized to generate all the reference parameters of the drainage. In addition, it was manipulated using ArcGIS to determine the surface area of the initiated reservoir (e.g., Houran 1).

2.3 Reference Parameters

In the current research, the reference parameters used to assess the suitability of sites for the establishment of harvesting structure are indicated hereafter. The reference parameters were evaluated by remote sensing analysis based on the interpretation of satellite images. On the other hand, some of the other parameters evaluated using situ surveys of the west desert of Iraq, which grant the possibility to enhance the proposed methodology for selection criteria.

2.3.1 Geomorphic Features

The catchment configured with narrow width. The best narrowness of the catchment is located to construct the dams, is obtained using the SRTM digital elevation model through Global Mapper software (see Fig. 3). Furthermore, the geometric parameters of the watershed were determined using Watershed Modeling System (WMS), which delineates the basin and provides multiple watershed characteristics.

2.3.2 Catchment Slope

The slope of the catchment is one of the important factors that affect the selection of the rainwater harvesting structure. This is because of the water velocity is directly related to the slope angle of the ground. If the catchment slope is less than 5 % of steep valley, the slope will improve and give better storage efficiency for the initiated reservoir. The slope is derived from the Digital Elevation Model (DEM), as clearly indicated in Fig. 2b the generated slope map of the study area.

2.3.3 Vegetation Cover

The Normalized Difference Vegetation Index (NDVI) is an indicator of vegetation cover, which permits to nearly localize what zones are capable to store water resources allowing the

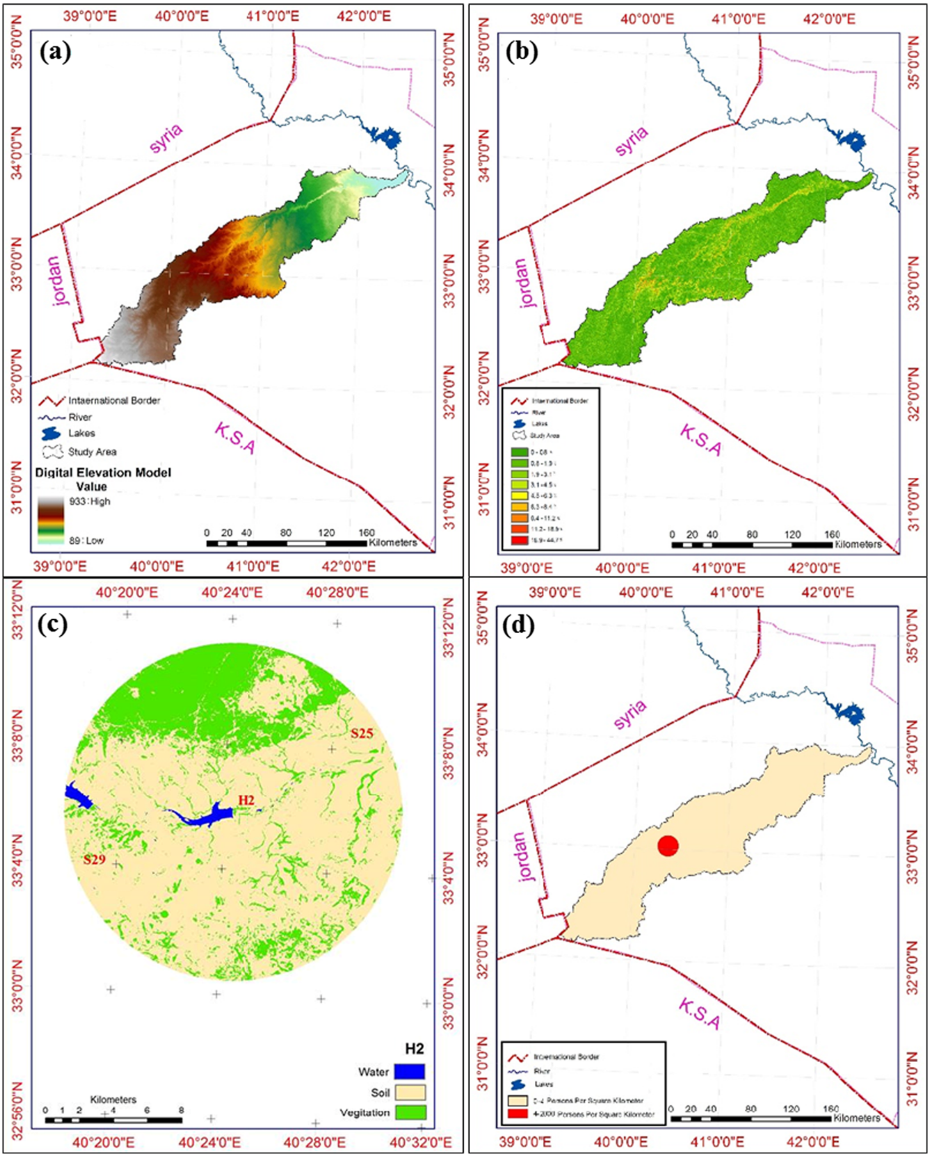

Fig. 2 The associated reference parameters of the catchment that utilized for the analysis. **a** digital elevation model, **b** the slope , **c** vegetation cover and **d** population density

growth of the plants. This reference parameter was determined by multispectral analysis of satellite imagery in the red and near-infrared bands. Figuer 2c displays the NDVI for Houran 2 dam as an example. The following formula indicates the NDVI parameter:

$$\mathrm{NDVI} = \left[\frac{\text{near infrared}-red}{\text{near infrared}+red}\right] \tag{1}$$

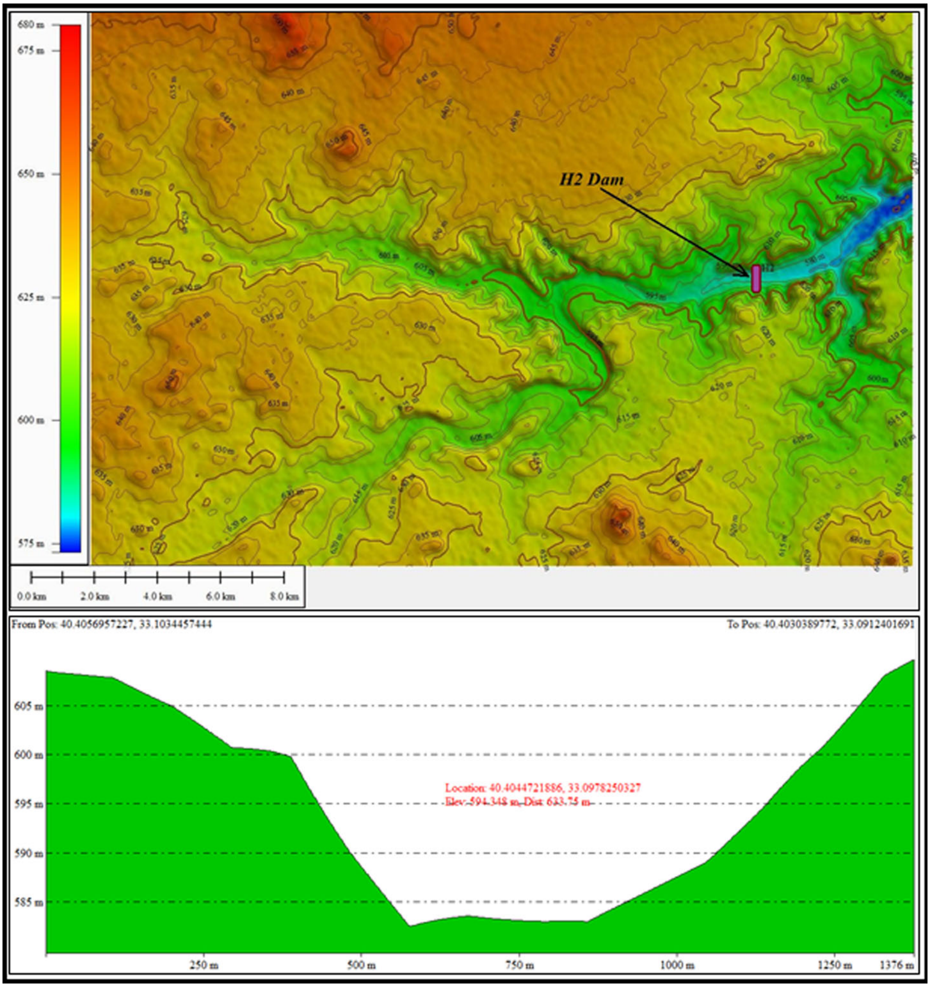

Fig. 3 The topographic map and cross section of Houran 2 dam, extracted from DEM

2.3.4 Number of Population

Population density is another essential parameter associated with RWH structure initiating. This is certainly associated with the agriculture, domestic, and hydropower uses. The population distribution along with the drainage of the catchment was indicated in a representable thematic map as shown in Fig. 2d. Finally, all the foregoing thematic maps were further manipulated and combined through spatial analysis to produce a suitable targeted RWH structure site.

2.4 Design Phase

In general, design phase involves analysing a sit of possible solutions to problem identified (Durga Rao and Bhaumik 2003). However, in the case of initiating rainwater harvesting structure involves action to identify "the suitable type of structure" as well as "the optimal depth of crest that obtains maximum storage of water with minimum surface area of reservoir, especially in arid environment zone, Iraq. This is for the reason that arid environment influenced by the evaporation process. Control of evaporation from land based water bodies, has thus remained one of the main planks of water conservation strategies. This assumes greater significance in arid regions, where water scarcities are already a common problem.

Worth to mention, the main factors that associated with evaporation process are water surface area and the depth of water. On the other hand, the metrological factors “e.g., relative humidity, nature of precipitation, wind velocity and temperature” are mostly the same and have slight effect, Fig. 4 clearly indicates the distributions of the mentioned factors for the targeted catchment. Therefore, water surface area and the depth of water were considered in the evaluation of the present research. However, the methodology has been carried out based on several steps. In the first step, the EAV curve has been extracted. The Triangular Irregular Network layer was used to estimate the storage capacity of the dam via ArcGIS. The final thematic maps showed different layers, representing water level at different depths. The survey data as an actual data has been used to validate by comparing the results based on the performance measurements. In the second step, the three dams examined based on two performance indicators which are the degree of matching and the relative error (RE) between the GIS and the survey data for both area and. Finally, the evaluation of the identical between the delineation of the open surface area water bodies extracted from Landsat 8 image and the surface area which was developed by GIS using SRTM data for Houran 1 (H1) dam “as it is initiated and operated in the studied catchment”.

2.5 Evaluation Performance Indicators

One of the most important consideration that provides an objective basis for the proposed approach is the performance measure. A good evaluation of model performance must be include at least one “goodness-of-fit” and at least one absolute error indicator (Yaseen et al.

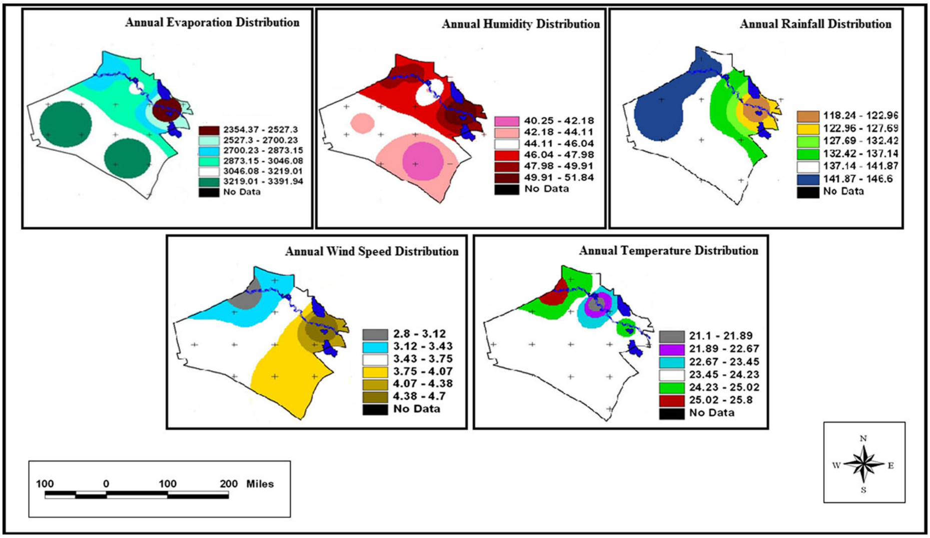

Fig. 4 The drainage climate characteristics of the presented case study

2015). Thus, in this research Relative Error (RE) statistical measure indicators carried out to examine the accuracy of the proposed approach. The performance indicator can be expressed:

$$\mathrm{RE} = \left[\frac{GIS_d - S_d}{S_d}\right]100 \tag{2}$$

Where, GIS_d and S_d are the geographic information system data and the survey catchment data, respectively.

3 Application and Analysis

The current research presents the utilization of RS integrated with GIS application to extract the EAV curve. Accordingly, the application of the proposed method was effectively accomplished on three constructed small earth dams, western desert of Iraq. Elevation-area and elevation-volume curves were created using the spatial intelligence approach and were compared with the obtained using the situ survey data to evaluate the accuracy of the proposed method. As shown in Fig. 5, the results were mostly similar with slight difference in the area and capacity at the first two meters of elevation. In fact, this variation is because the SRTM might be strongly influenced by topography. Here also, it should be noted that the greater error values were associated with rugged terrain while the smaller error values were associated with the coastal plain that caused an obvious measure between the compared methods. At the same time, DEM contains inherent errors that might be due to the primary data acquisition technology. However, generally the statistical indicator for the relative error showed a remarkable agreement.

In order to perform a valid assessment, the results demonstrated with the relative error performance measure (see Fig. 6). If we closely analyze this indicator, we might notice the error distribution does not exceed 10 % for both surface area and reservoir capacity. Meanwhile, there is a high percentage of error for the first four meters elevation. Indeed, this is because the fluctuation of the surface area of the catchment that cause an obvious measure between the compared methods. In general, the statistical indicators for best fit line and relative error show a remarkable agreement.

Another vital analysis have been carried out to examine the proposed method, which is the mean depth index (shape index) for the reservoirs. The mean depth index is the ratio between the mean reservoir volumes to the mean surface area at each level. Theoretically, the main assumption of this indicator is based on the capacity of a reservoir that can be estimated by computing the surface area at any level, which represents the volume of the pyramid. The main merit of this index, it refers to the shape of the reservoir body. Another important advantage, it represents the evaporation losses that might be extremely high with the increase of the surface area of the stored water. As mentioned previously, the greater error values were associated with rugged terrain. Thus, the first two meters of water elevation were excluded in the evaluation to reduce the error of calculation of average proportion indices. The shape index for the three dams, i.e. H2, GRA 2, and GRA 4 were 2.72, 2.57, and 2.46 m belonging to the GIS. Whereas, they were 2.55, 2.36, and 2.49 m using the survey data, respectively. The results obtained

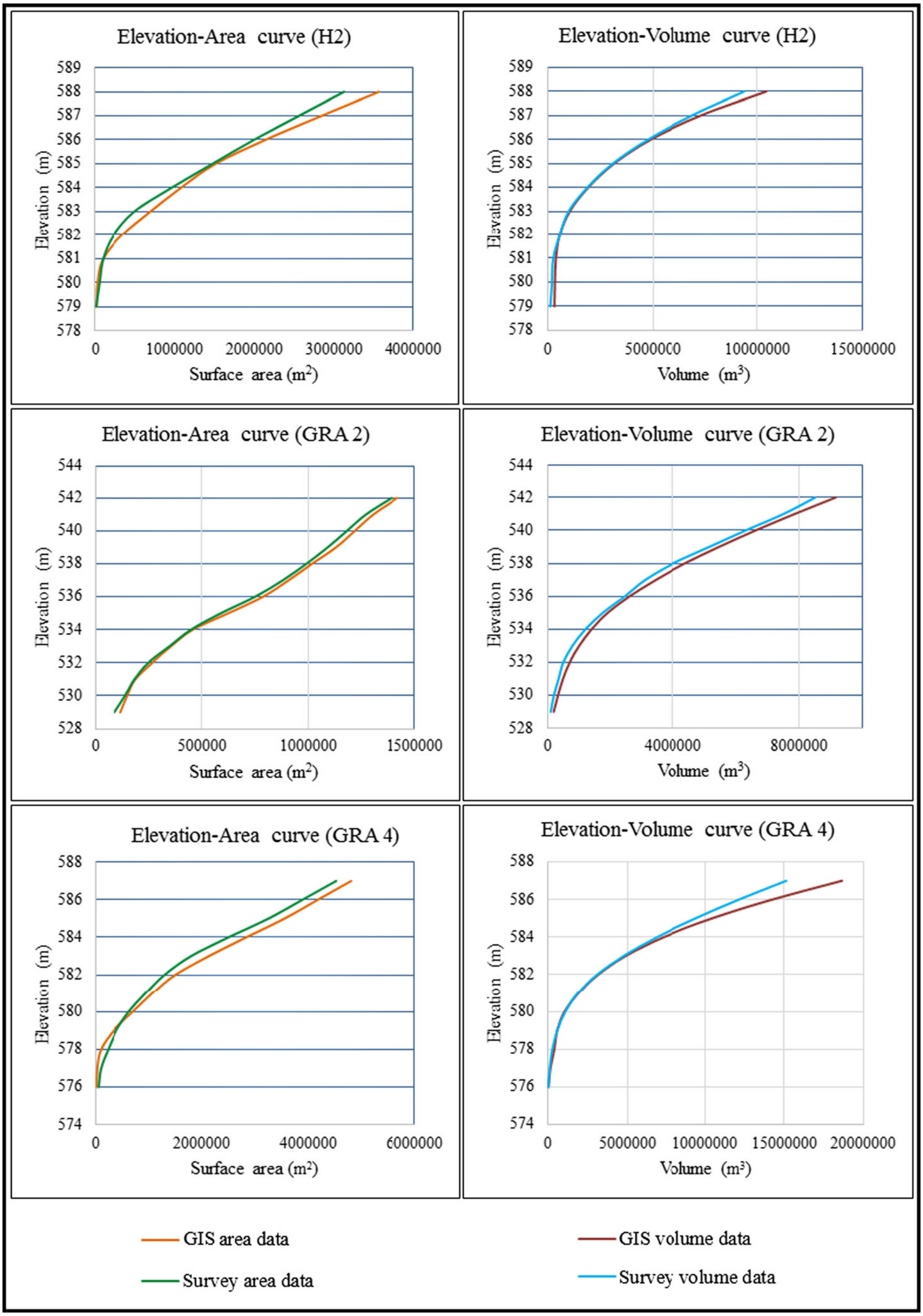

Fig. 5 Elevation-Area-volume curves for (H2, GRA 2, and GRA 4) dams, using spatial intelligence and situ survey data

using GIS application slightly higher than the survey calculation. This is due to relative error of the image resolution (30m * 30m). However, the maximum different between spatial

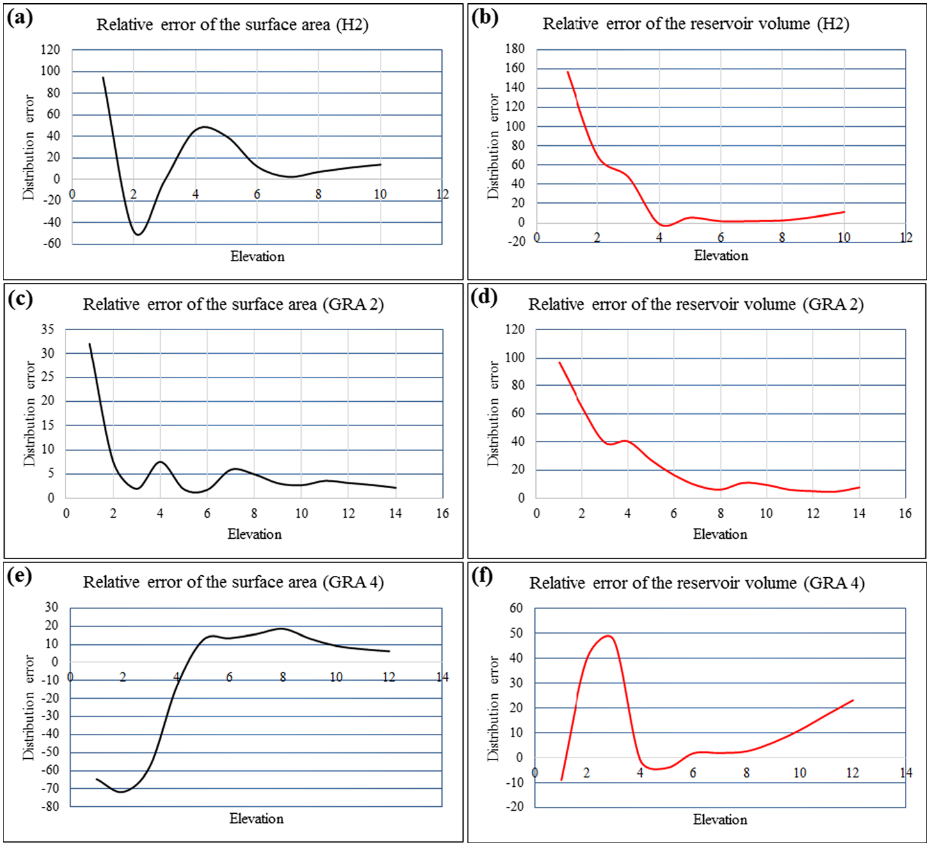

Fig. 6 The relative error distribution graphs among spatial intelligence and situ survey data (surface area and volume capacity) for the three dams

intelligence and the situ data survey does not exceed 20 cm, which is quite acceptable as a hydrological concept. Moreover, this indicator represents that EAV curve determined with high level of accuracy. In addition, the convergence values of shape index for the small studied dams represent the variation in the storage capacities of small reservoirs is strongly influenced by surface areas, with small influence due to the height.

Water level detection is a vital concern in reservoir operation and management. The detection and delineation of open surface area water bodies using optical system such as Landsat was the most effective tool that accomplished with imagery from the infrared and visible part of the spectrum. Fig. 7 indicates the capability of remote sensing integrated with GIS to extract the water depth of the reservoir during the rainy and dry seasons. Houran 1 (H1) reservoir used to demonstrate this capability. H1 dam is already exist in the mention drainage; therefore, it was utilized to extract the depth and reservoir capacity of water through the surface area of the reservoir using (Landsat 8 imagery, 2014). Fig. 7a and b present the water depth in both rainy and drought seasons (March and August). This analyzing carried out by matching the open surface area (using Landsat Imagery) with the computed EAV curve results. Accordingly, the matched surface area indicated the water depth and the capacity of the reservoir.

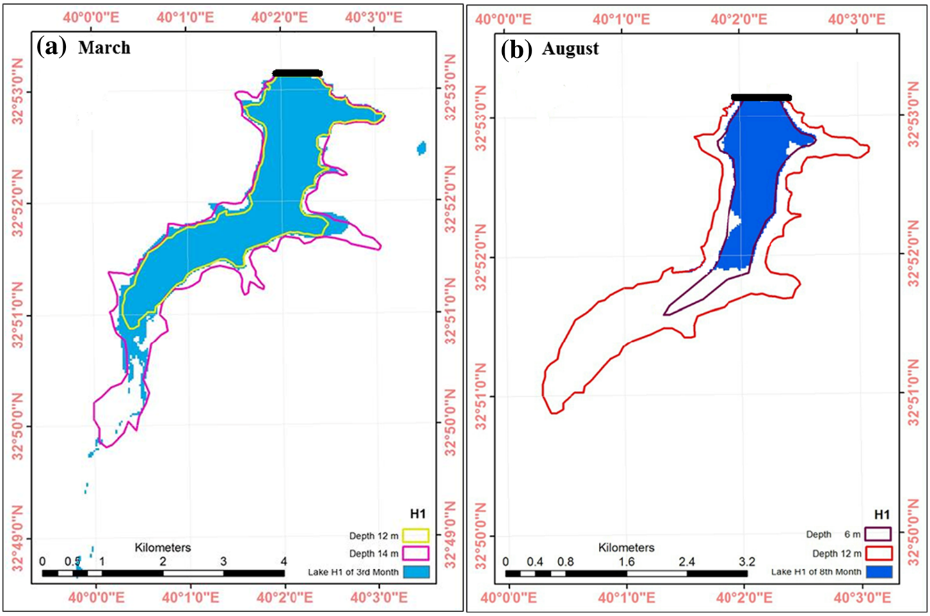

Fig. 7 Extracted water depth for H1 reservoir (**a**). rainy season "March" (**b**). drought reason "August"

Finally, the studied reservoirs data (H2, GRA 2, and GRA 4) were modeled into 3-dimentions visualization. The generated thematic maps that represent the water level at different depth, surface area and reservoir capacity for the established dams, are displayed in Fig. 8. The legends described in (Fig. 8) indicate the surface area and volume capacity with the accumulative elevation depth level.

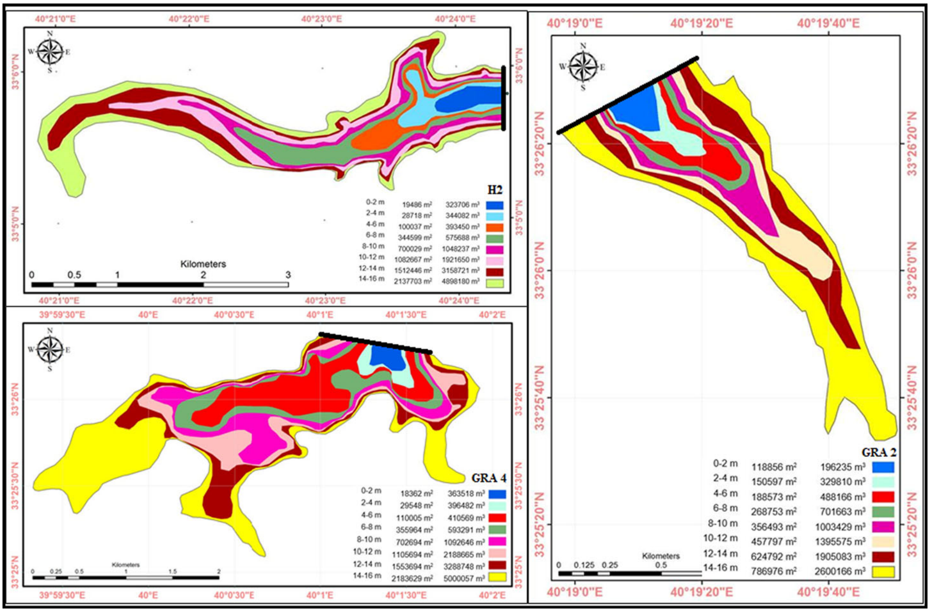

Fig. 8 The final thematic maps represent the EAV curve for the established dams (H2, GRA 2 and GRA 4)

Future research efforts should be devoted, an extension work to the current research are (i) studying the amount of the evaporation variable in selecting the suitable position of the rainwater harvesting structure based on the computed physical parameters; (ii) further work is considering the amount of sediment, cost benefit ratio regarding earth dam initiating, and the rainfall quantity received by catchment.

4 Conclusion

The main objective of this research was to determine the elevation-area-volume curve in the western desert of Iraq using spatial intelligence approaches. EAV curve acts as the main principal for initiating rainwater harvesting structure “dam”. This research demonstrates the capabilities of utilizing global data sets and Geographic Information Systems (GIS) in spatial analysis modelling. According to the foregoing application analysis, it was remarkably observed that the presented approach was adequate to develop and extract the EAV curve for arid environment. In addition, it was found that the proposed methodology highly recommended for such a kind of catchment that characterized by less fluctuation in the ground. Furthermore, establishing accurate model to detect water level using Landsat imagery.

References

Ahmad A, El-Shafie A, Mohd Razali SF, Mohamad ZS (2014) Reservoir optimization in water resources: a review. Water Resour Manag 28:3391–3405

Al-Adamat R (2008) Gis as a decision support system for siting water harvesting ponds in the basalt aquifer/Ne Jordan. J Environ Assmt Pol Manag 10:189–206. doi:10.1142/S1464333208003020

Al-Adamat R, Diabat A, Shatnawi G (2010) Combining GIS with multicriteria decision making for siting water harvesting ponds in northern Jordan. J Arid Environ 74:1471–1477. doi:10.1016/j.jaridenv.2010.07.001

Baban SMJ, Wan-Yusof K (2003) Modelling optimum sites for locating reservoirs in tropical environments. Water Resour Manag 17:1–17. doi:10.1023/A:1023066705226

Begemann L, Mulder, P, Reij C (1988) Water harvesting for plant production. The World Bank, Washington, DC. World Bank Technical Paper, p 91

Buday, T and Hak J (1980) Report on geological survey of the western part of the Western Desert, Iraq

Chang NB, Parvathinathan G, Breeden JB (2008) Combining GIS with fuzzy multicriteria decision-making for landfill siting in a fast-growing urban region. J Environ Manag 87:139–153. doi:10.1016/j.jenvman.2007.01.011

Choong S-M, El-Shafie A (2015) State-of-the-art for modelling reservoir inflows and management optimization. Water Resour Manag 29:1267–1282

Chowdary VM, Ramakrishnan D, Srivastava YK, et al. (2009) Integrated water resource development plan for sustainable Management of Mayurakshi Watershed, India using remote sensing and GIS. Water Resour Manag 23:1581–1602. doi:10.1007/s11269-008-9342-9

Cvar A (2014) GIS-based reservoir planning with limited data in developing nations: A case study of the lower Mekong River basin (Doctoral dissertation, Colorado State University).

Durga Rao KHV, Bhaumik MK (2003) Spatial expert support system in selecting suitable sites for water harvesting structures — a case study of song watershed, Uttaranchal, India. Geocarto Int 18:43–50. doi:10.1080/10106040308542288

El Bastawesy, M , Gabr S, White K (2013) Hydrology and geomorphology of the upper White Nile lakes and their relevance for water resources management in the Nile basin. Hydrol Process 27:196–205. doi:10.1002/hyp.9216

El-Shafie A, El-Shafie AH, Mukhlisin M (2014) New approach: integrated risk-stochastic dynamic model for dam and reservoir optimization. Water Resour Manag 28:2093–2107. doi:10.1007/s11269-014-0596-0

Forzieri G, Gardenti M, Caparrini F, Castelli F (2008) A methodology for the pre-selection of suitable sites for surface and underground small dams in arid areas: a case study in the region of Kidal, Mali. Phys Chem Earth 33:74–85. doi:10.1016/j.pce.2007.04.014

Gupta KK, Deelstra J, Sharma KD (1997) Estimation of water harvesting potential for a semiarid area using GIS and remote sensing. Remote Sens Geogr Inf Syst Des Oper Water Resour Syst:53–62

Gwenzi W, Nyamadzawo G (2014) Hydrological impacts of urbanization and urban roof water harvesting in water-limited catchments: a review. Environ Process 1:573–593. doi:10.1007/s40710-014-0037-3

Hossain MS, El-shafie A (2013) Intelligent Systems in Optimizing Reservoir Operation Policy: a review. Water Resour Manag 27:3387–3407

İrvem A (2011) Application of GIS to determine storage volume and surface area of reservoirs: the case study of Buyuk Karacay dam. Int J Nat Eng Sci 5:39–43

Ishaku HT, Majid MR, Johar F (2012) Rainwater harvesting: an alternative to safe water supply in Nigerian rural communities. Water Resour Manag 26:295–305. doi:10.1007/s11269-011-9918-7

Jha MK, Chowdhury A, Chowdary VM, Peiffer S (2006) Groundwater management and development by integrated remote sensing and geographic information systems: prospects and constraints. Water Resour Manag 21:427–467. doi:10.1007/s11269-006-9024-4

Jha MK, Chowdary VM, Kulkarni Y, Mal BC (2014) Rainwater harvesting planning using geospatial techniques and multicriteria decision analysis. Resour Conserv Recycl 83:96–111. doi:10.1016/j.resconrec.2013.12.003

Kahinda JM, Lillie ESB, Taigbenu AE, Taute M, Boroto RJ (2008) Developing suitability maps for rainwater harvesting in South Africa. Phys Chem Earth 33:788–799. doi:10.1016/j.pce.2008.06.047

Kallali H, Anane M, Jellali S, Tarhouni J (2007) GIS-based multi-criteria analysis for potential wastewater aquifer recharge sites. Desalination 215:111–119. doi:10.1016/j.desal.2006.11.016

Kanakoudis V, Tsitsifli S, Samaras P, Zouboulis A, Demetriou G (2011) Developing appropriate performance indicators for urban water distribution systems evaluation at Mediterranean countries. Water Utility Journal 1:31–40

Liebe J (2002) Estimation of water storage capacity and evaporation losses of small reservoirs in the upper east region of Ghana. University of Bonn, Germany

Machiwal D, Jha MK, Mal BC (2011) Assessment of groundwater potential in a semi-arid region of India using remote sensing, GIS and MCDM techniques. Water Resour Manag 25:1359–1386. doi:10.1007/s11269-010-9749-y

Moore IDD, Grayson RBB, Ladson ARR (1991) Digital terrain modelling: a review of hydrological, geomorphological and biological Aapplications. Hydrol Process 5:3–30. doi:10.1002/hyp.3360050103

Mwenge Kahinda J, Taigbenu AE, Sejamoholo BBP, et al. (2009) A GIS-based decision support system for rainwater harvesting (RHADESS). Phys Chem Earth 34:767–775. doi:10.1016/j.pce.2009.06.011

Nisar Ahamed TR, Gopal Rao K, Murthy JSR (2002) Automatic extraction of tank outlets in a sub-watershed using digital elevation models. Agric Water Manag 57:1–10. doi:10.1016/S0378-3774(02)00047-1

Paruch AM, Mæhlum T, Robertson L (2014) Changes in microbial quality of irrigation water under different weather conditions in Southeast Norway. Environ Process:115–124. doi:10.1007/s40710-014-0054-2

Pistrika A (2010) Flood damage estimation based on flood simulation scenarios and a GIS platform. Eur Water 30:3–11

Rockstrom J (2000) Water resources management in smallholder farms in eastern and southern Africa: an overview. Phys. Chem. Earth, part B Hydrol. Ocean Atmos 25:275–283

Sawunyama T, Senzanje A, Mhizha A (2006) Estimation of small reservoir storage capacities in Limpopo River basin using geographical information systems (GIS) and remotely sensed surface areas: case of Mzingwane catchment. Phys Chem Earth 31:935–943. doi:10.1016/j.pce.2006.08.008

Singh JP, Singh D, Litoria PK (2009) Selection of suitable sites for water harvesting structures in Soankhad watershed, Punjab using remote sensing and geographical information system (RS&GIS) approach- a case study. J Indian Soc Remote Sens 37:21–35. doi:10.1007/s12524-009-0009-7

Taffere GR, Beyene A, Vuai SAH, et al. (2016) Characterization of atmospheric bulk deposition: implications on the quality of rainwater harvesting Systems in the Semi-Arid City of Mekelle, northern Ethiopia. Environ Process 3:247–261. doi:10.1007/s40710-016-0133-7

Thomas P, Howlett PG, Piantadosi J (2010) Investigating the optimal management of the Helps Road drain urban stormwater harvesting system within the city of Salisbury (Doctoral dissertation, EW Publications)

Tsihrintzis VA, Hamid R, Fuentes HR (1996) Use of geographic information systems (GIS) in water resources: a review. Water Resour Manag 10:251–277

Vorhauer CF, Hamlett JM (1996) GIS: a tool for siting farm ponds. J Soil Water Conserv 51:434–438

Yaseen ZM, El-shafie A, Jaafar O, et al. (2015) Artificial intelligence based models for stream-flow forecasting: 2000–2015. J Hydrol 530:829–844. doi:10.1016/j.jhydrol.2015.10.038

Zhang S, Gao H, Naz BS (2014) Monitoring reservoir storage in South Asia from multisatellite remote sensing. Water Resour Res n/a–n/a doi:10.1002/2014WR015829