Cite this article

Sayl KN, Muhammad NS and El-Shafie A (2019)
Identification of potential sites for runoff water harvesting.
Proceedings of the Institution of Civil Engineers – Water Management **172**(3): 135–148,
<https://doi.org/10.1680/jwama.16.00109>

Research Article

Paper 1600109

Received 01/11/2016;
Accepted 16/10/2017;
Published online 15/11/2017

Keywords: dams, barrages & reservoirs/
environment/hydrology & water resource

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Identification of potential sites for runoff water harvesting

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Runoff water harvesting (RWH) is a potential solution for areas suffering from water scarcity, such as the western desert of Iraq. Site selection based on RWH ranking using a combination of a watershed modelling system, geographic information systems and remote sensing techniques may enable authorities and water engineers to determine potential solutions to water scarcity. In this work, these methods were employed to produce eight thematic maps of the volume of annual floods, basin area, basin length, maximum flow distance, drainage frequency density, lineament frequency density, basin slope and stream order. These maps were used to rank and classify probable sites based on equal weight and statistical weight. The results were then used to classify the selected sites into four classes, namely sites with very high, high, moderate and low RWH potential. The proposed method was shown to be beneficial in the identification of potential RWH sites.

Notation

P	precipitation
Q	runoff depth
R_c	average ranking
S	potential maximum retention after runoff starts
W_c	equal weight
$W_{1/v}$	statistical weight

1. Introduction

The western desert of Iraq is an arid region facing great problems with regard to the availability of water resources (Adham *et al.*, 2016; Reij *et al.*, 1990; Sayl *et al.*, 2017; Taffere *et al.*, 2016). The harsh climate conditions and irregular precipitation in both space and time make water resources planning and management challenging. This area is therefore less populated and less developed than other areas in the country. The availability of a constant water supply, through proper planning and management of water resources, would enhance the overall quality of life in arid regions. In areas suffering from water scarcity, rainwater harvesting is considered to be one of the most significant ways of conserving water and improving life (Jha *et al.*, 2014; Mahmoud, 2014).

Site selection for water harvesting in arid areas depends strongly on the meticulous planning of catchment basins to support human requirements. The formulation of appropriate management plans requires a large volume of accessible multi-disciplinary data (Nooka Ratnam *et al.*, 2005), including morphologic data (size and shape of the watershed, topography, drainage parameters etc.) and information on land use, land cover, soil and its characteristics, which affect the behaviour of the catchment. Therefore, the assessment of a variety of thematic resources for site selection can be a challenging task, especially for large watersheds. Tools such as geographic information systems (GIS) and remote sensing techniques can be employed to manage, analyse and assist site selection processes (Bonacci *et al.*, 2006; Chowdary *et al.*, 2009; Grohmann, 2004; Jamali *et al.*, 2014; Jha *et al.*, 2014; Kadam *et al.*, 2012; Krois and Schulte, 2014; Pandey *et al.*, 2011; Sayl *et al.*, 2016; Singh, 1994). Morphometric analysis of a site provides a quantitative description of the drainage system, which is an important aspect in analysing and formulating targets for water resources development through runoff water harvesting (RWH). Most researchers utilise morphometric analysis for the development of water resources and management tasks, in addition to watershed characterisation and prioritisation (Javed *et al.*, 2011;

Kanth, 2010; Sarma and Saikia, 2012; Suresh *et al.*, 2004; Thakkar and Dhiman, 2007).

Several researchers have recently suggested the method of prioritisation of watersheds for water harvesting using geometric parameter relationships. El Shamy (1992) discussed suitable controlling systems using obstacle stony dams in the upstream river of the hydrographic basin in Wadi ElArish. Using morphometric analysis to obtain potential runoff, Ashmawy *et al.* (2000) researched the risk of flash floods to drainage basins in Sinai. Aher *et al.* (2013) ranked watersheds through an investigation of drainage basins using a fuzzy analytical hierarchy process method. Their aim was to avoid the complexity of data linked with many morphological features by achieving superior accuracy in the prioritisation and identification of watersheds. Rahaman *et al.* (2015) investigated many morphological features and the application of GIS and fuzzy analytical hierarchy processes to identify critical sub-watersheds of Kallar, Tamil Nadu.

In the work reported in this paper, a methodology for RWH site selection was developed by integrating remote sensing, a watershed modelling system (WMS) and GIS. RWH site selection was based on hydrological and hydro-morphometric criteria. Eight thematic maps were developed, namely, the volume of annual floods, basin area, basin length, maximum flow distance, drainage frequency density, lineament frequency density, basin slope and stream order. Additionally, two methods of weighting criteria (equal weight W_c and statistical weight $W_{1/r}$) were compared in order to rank and determine the best RWH sites.

2. Methodology

Figure 2 shows a flowchart of the methodology. Visual interpretation of satellite images was used for site selection, based on the width of valleys, the height of tenacious walls, valley slopes and narrow canyons. These characteristics allowed the use of the location's natural features to support site selection. The interpretation of Landsat 8 satellite images from 2013 using Erdas Imagine 9.3 and geological maps were used to extract the lineaments. A QuickBird satellite image (2006) and digital elevation model (DEM) of 30 m extracted from the Shuttle Radar Topographic Mission (SRTM) were used as input data (Figure 1). As a result, a total of 32 potential RWH sites were selected for calculation of hydrological and hydro-morphological parameters. The SRTM DEM was consequently improved by both ground control points and the height of spots.

For each site, the geometric parameters of the catchment area were deduced using the WMS software Aquaveo. This software defined the basins and afforded numerous features for each catchment. Eight thematic maps – volume of annual flood, basin area, basin length, basin slope, maximum flow distance, drainage frequency density, lineament frequency density and stream order – were extracted in order to determine potential sites for

RWH. Aquaveo software was used to compute the hydro-morphometric features for each watershed, as listed in Table 1. The ArcGIS 10.2 software spatial analyst model used layer manipulation. A geological map of the study area was utilised to identify types of soil. The Soil Conservation Service curve number (SCS-CN) model was used to calculate runoff (Elewa *et al.*, 2012; Hogarth *et al.*, 2004; Jain and Sinha, 2003; Tyagi *et al.*, 2008). The maximum discharges were calculated by Aquaveo using storm data, the DEM and land use/cover and soil data, where the CN was generated. The environmental features related to rainfall-runoff were estimated using the SCS-CN technique. The runoff depth was calculated using (Maidment, 1992)

$$1. \quad Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}$$

$$2. \quad S = \frac{25400}{CN} - 254$$

where Q is the runoff depth (in mm), S is the potential maximum retention after runoff starts (mm), P is precipitation (mm) and CN is the runoff curve number.

To determine the suitability of sites for RWH, hydro-morphometric criteria were considered. Many researchers have found that hydro-morphometric criteria are highly correlated with runoff volume and peak discharge (Elewa *et al.*, 2012; Gregory and Walling, 1985). The main criteria (volume of annual flood, basin area, basin length, maximum flow distance, drainage frequency density, lineament frequency density, basin slope and stream order) were deduced to determine effective sites for RWH (Table 1) using GIS thematic maps.

Using the prepared GIS maps, ranking and classification processes were developed based on two methods of weighting criteria. In the first method, rates and weights were estimated and identified depending on the judgements of previous researchers (Elewa *et al.*, 2012; Mohd Hasmadi *et al.*, 2010; Sadrolashrafi *et al.*, 2008). Hence, all the criteria were given equal weight ($W_c = 0.125$) in the ranking and classification processes. In the second method, the statistical method of the inverse of the variance value ($W_{1/r}$) was used to provide criteria weighting. This method defines the variance as the square of the variation between the site criterion value and the best value of the criterion for all sites. The basin slope and lineament frequency density work negatively in RWH sites. Therefore, these were taken as the inverse for each value, with lowest value representing the highest RWH potential. The other criteria are positive.

With reference to Table 1, the values of the criteria are not on the same scale. Therefore, it was necessary to convert the

Figure 1. (a) QuickBird satellite image. (b) DEM

criteria to a standardised scale before starting the weighting process. Normalisation was performed by assigning the same dimensionless continuous scale, from 0 to 1. The statistical weighting ($W_{1/r}$) of each criterion, that is, basin area, basin length, maximum flow distance, volume of annual runoff, stream order, drainage frequency density, slope basin and lineament frequency density was 0.15, 0.13, 0.13, 0.12, 0.17, 0.13, 0.11 and 0.06 respectively. The maximum rate of RWH was considered to be 100%, with five classes of 0–20%, 20–40%, 40–60%, 60–80% and 80–100%. Therefore, the average ranking, R_c , for each class is 10, 30, 50, 70 and 90%, respectively. Based on the ranking and classifying process using the

two methods of weighting criteria, the selected sites in the study area were classified into classes of RWH potential.

3. Study area

The study area is Wadi Horan, which is the largest valley in the western desert of Iraq. This valley lies south of the Euphrates River, with geographic coordinates 32°10'44" to 34°11'00"N (latitude) and 39°20'00" to 42°30'00"E (longitude), as shown in Figure 3. The total length of Wadi Horan is 362 km, with a catchment area of 13 370 km², a width of 49.3 km, a perimeter of 1307 km and a shape coefficient of 0.13. The area suffers from severely arid climate conditions.

Figure 2. Flowchart of methodology

Table 1. Hydro-morphometric criteria extracted by WMS

Site	Longitude (E): degrees	Latitude (N): degrees	Basin area: km ²	Basin length: km	Basin slope	Maximum flow distance: m	Annual flood: m ³ /year (SCS-CN method)
1	42-42144	33-92855	12 543	351 767	0-0176	491 165	951 899 649
2	42-25638	33-86908	12 385	335 519	0-0176	470 173	939 732 697
3	42-18277	33-87777	12 095	330 386	0-0176	461 863	917 682 600
4	42-10432	33-89357	11 998	325 139	0-0176	449 849	910 327 731
5	42-03424	33-89789	11 935	320 315	0-0176	442 241	905 545 272
6	41-99692	33-90625	11 874	317 317	0-0175	437 469	900 970 961
7	41-77822	33-81171	10 928	294 935	0-0178	406 074	826 541 205
8	41-72391	33-80540	10 893	290 870	0-0177	400 406	826 541 212
9	41-61457	33-75036	10 596	279 693	0-0179	387 682	803 956 977
10	41-50907	33-69491	10 535	267 748	0-0177	373 872	797 018 435
11	41-43116	33-64195	10 463	258 639	0-0176	363 646	794 282 672
12	41-36391	33-64339	10 358	253 998	0-0177	356 389	785 912 177
13	41-24602	33-58462	10 158	241 223	0-0176	340 876	774 256 594
14	41-19207	33-56646	9844	235 686	0-0178	333 838	746 931 250
15	41-08821	33-54545	9702	227 290	0-0178	323 034	736 123 933
16	41-01743	33-52603	9059	221 128	0-0174	313 872	687 345 674
17	40-96254	33-48766	8723	214 525	0-0173	306 152	661 910 036
18	40-87706	33-41605	8630	201 566	0-0172	310 034	65 365 080
19	40-84494	33-38292	8552	198 594	0-0171	283 267	648 897 907
20	40-71420	33-32392	8172	186 181	0-0168	264 248	620 048 848
21	40-68003	33-30662	8081	180 517	0-0167	257 002	613 156 300
22	40-89329	33-49887	462	32 399	0-0194	42 126	18 873 111
23	41-03449	33-42040	498	48 328	0-0260	64 541	18 221 821
24	40-63865	33-32663	386	17 594	0-0188	22 872	8 107 106
25	40-61890	33-26507	351	34 166	0-0147	47 024	18 200 045
26	40-47635	33-13571	6885	154 581	0-0162	223 684	522 416 514
27	40-40570	33-10345	6659	147 217	0-0159	214 883	505 291 250
28	40-31074	33-06174	5693	137 755	0-0152	199 302	452 430 733
29	40-06835	32-94038	5090	113 246	0-0125	167 249	386 211 497
30	40-03646	32-88597	4741	159 906	0-0118	167 130	359 743 793
31	40-23177	32-87280	623	25 694	0-0274	37 151	30 997 066
32	39-99599	32-82596	4676	100 894	0-0114	152 656	78 920 084

Figure 3. Study area map

The key climate characteristics of the study area include tremendously low and uneven rainfall. The area is cold in winter and very hot in summer, with great seasonal and diurnal temperature differences. The maximum average annual temperature, typically recorded in July and August, is 42.8°C. The lowest average annual temperature is 2.6°C, typically recorded in December to February. The months of June to September are the dry season in the area, whereas the rainy season covers December to May; the average annual rainfall

is 115 mm. The mean record annual runoff is 900 million m³, while the annual mean of relative humidity, which varies from month to month throughout the year, is about 46.2%. The average annual evaporation rate is estimated to be about 3200 mm, with a dryness coefficient between 25 and 35. The area is characterised by a deep groundwater level with no recharge to the surface runoff, and hence some artesian wells have developed in the area (Kamel and Mohammed, 2010).

A slight change in elevation was deduced for the topography of the catchment area, with a moderate slope to the Euphrates River valley. A height difference of only 600 m was recorded between the start and end of the catchment. Sandstones available in the area could be used as a suitable base for dam construction.

4. Results and discussion

The previously mentioned criteria were transformed into ready to use data in GIS for storage and manipulation after describing the basin characteristics inside the platform of the WMS with the DEM. The range of each criterion was manipulated in GIS thematic maps. Based on the rating and weighting method, the incorporation of all criteria in the GIS produces maps to identify suitable RWH sites. The eight thematic maps developed using the methodology proposed in the previous section are now discussed.

4.1 Volume of annual runoff

The success of RWH depends strongly on the quantity of water that can be collected under the given climatic conditions. Rainfall data covering the period 1941 to 2013 were used to calculate the annual runoff volume using the SCS-CN method. The thematic map of annual runoff volume for the study area is shown in Figure 4(a). There are five classes of potential RWH: very high (>900 million m³/year), high (700–900 million m³/year), moderate (500–700 million m³/year), low (300–500 million m³/year) and very low (<300 million m³/year). As shown in Figure 4(a), the highest classification of annual runoff (>900 million m³/year) was observed in the northeast of the study area whereas sites with very low and low classes of annual runoff volume were identified in the southwestern parts of the study area.

4.2 Lineament frequency density

Analysis of lineament frequency density is significant for the mapping of potential RWH sites as fractures and joints increase infiltration of the soil. Hence, the higher the lineament frequency density, the lower the RWH potential. Visual interpretation of Landsat 8 satellite imagery (acquired in 2013) was used to extract lineament frequency density, which was confirmed by comparing with lineaments and structures shown on the geological map. The density of lineament frequency was determined by categorising the area into 20 km by 20 km frames.

The resulting lineament frequency density map is shown in Figure 4(b). Five classes were assigned for RWH potential: very low (11–13 lineaments per 400 km²), low (9–11 lineaments per 400 km²), moderate (6–8 lineaments per 400 km²), high (3–5 lineaments per 400 km²) and very high (<3 lineaments per 400 km²). Northeastern and central parts of the study area showed low lineament frequency density and therefore high potential for RWH. The sites that occupied a very

low and low lineament frequency density were in the southwestern part of the study area (Figure 4(b)).

4.3 Drainage frequency density

A Landsat 8 satellite image was used to prepare the drainage network map. Analysis of drainage frequency density has significant importance for RWH potential as the amount of runoff losses through infiltration are affected by the drainage frequency density: the lower the drainage frequency density, the lower the RWH potential. A drainage frequency density map in terms of the number of streams per 20 km by 20 km area was constructed. The resulting map is shown in Figure 5(a), with five divisions of drainage frequency density: very low (22–26 streams per 400 km²), low (26–30 streams per 400 km²), moderate (30–34 streams per 400 km²), high (34–38 streams per 400 km²) and very high (>38 streams per 400 km²). The mean stream frequency density for the study area was determined to be 0.61 km². As shown in Figure 5(a), a very high drainage frequency density was found in the central part of the study area, with very low drainage frequency density class in the northeastern part.

4.4 Stream order

Stream order is based on the connection of tributaries. The order of streams is used to denote hierarchical connections among stream segments and permits drainage basins to be categorised according to their size. Analysis of the stream order has significant meaning for mapping RWH potential: a lower stream order results in higher permeability and infiltration. Moreover, dendritic drainage patterns shaped by the linking of streams indicate homogeneity in texture and a lack of structural control. In the resulting map of stream order (Figure 5(b)), potential RWH sites were classified as having very low stream order (<fourth order), low (fifth order), moderate (sixth order), high (seventh order) and very high (>seventh order). The highest stream order (eighth order) was observed in the northeastern part of the study, and this area thus represents very high RWH potential. The total length of the highest stream order was 80 km. The total length of the very low class (fourth order) was 890 km. In total 144 fourth-order streams, 13 fifth-order streams, four sixth-order streams, two seventh-order streams and one eighth-order stream were observed among the 11 034 streams in the study area.

4.5 Maximum flow distance

Horton (1945) defined the maximum flow distance as the maximum distance of the water path in a drainage basin. For a drainage basin, the maximum flow distance is vital in defining RWH potential, with a higher maximum flow distance indicating the higher probability of available sites for RWH. In addition, the maximum flow distance is a function of basin area. Figure 6(a) shows the resulting thematic map of the maximum flow distance factor, which was classified as very low (<100 000 m), low (100 000–250 000 m), moderate

Figure 4. Thematic maps of (a) annual runoff volume and (b) lineament frequency density. A full-colour version of this figure can be found on the ICE Virtual Library (www.icevirtuallibrary.com)

(250 000–300 000 m), high (300 000–400 000) and very high (>400 000 m). Very high and high classes of the maximum flow distance are in the northeastern part of the study area,

with the moderate class comprising a large portion of the study area. The very low class of maximum flow distance occurred in the southwestern part of the study area.

Figure 5. Thematic maps of (a) drainage frequency density and (b) stream order. A full-colour version of this figure can be found on the ICE Virtual Library (www.icevirtuallibrary.com)

4.6 Basin area

Basin area represents the total land area bounded by basin borders (Horton, 1945). It is recognised as a vital

hydro-morphometric criterion for guiding watershed runoff patterns, attributable to greater volumes of rainfall resulting in higher peak discharges (Pitlick, 1994). Additionally, basin area

Figure 6. Thematic maps of (a) maximum flow distance and (b) basin area. A full-colour version of this figure can be found on the ICE Virtual Library (www.icevirtuallibrary.com)

is strongly associated with other watershed morphometric features that affect surface runoff (i.e. maximum flow distance and basin length).

The thematic map (Figure 6(b)) shows five classes for basin area: very low (<1000 km²), low (1000–8000 km²), moderate (8000–9000 km²), high (9000–10 000 km²) and very high

Figure 7. Thematic maps of (a) basin slope and (b) basin length. A full-colour version of this figure can be found on the ICE Virtual Library (www.icevirtuallibrary.com)

(>10 000 km²). The map indicates that the very high class of the basin area is in the northeast of the study area. The areas with very low basin area (<100 km²) occur in different areas

of the study area. The southwestern part of the study area comprises a large portion of low basin areas, with moderate and high basin area classes occurring in the central part.

Table 2. Ranking and weighting of criteria and their influence class used for mapping RWH site potential

Site	Annual flood		Basin area		Basin length		Basin slope		Maximum flow distance		Drainage frequency density		Stream order		Lineament frequency density		W_c	$\sum R_c \times W_c$	$\sum (R_c \times W_{1/v})$
	R_c	$W_{1/v}$	R_c	$W_{1/v}$	R_c	$W_{1/v}$	R_c	$W_{1/v}$	R_c	$W_{1/v}$	R_c	$W_{1/v}$	R_c	$W_{1/v}$	R_c	$W_{1/v}$			
1	90	0.12	90	0.15	90	0.13	30	0.11	90	0.13	30	0.13	90	0.17	50	0.06	0.125	70	74
2	90	0.12	90	0.15	90	0.13	30	0.11	90	0.13	30	0.13	90	0.17	50	0.06	0.125	70	74
3	90	0.12	90	0.15	90	0.13	30	0.11	90	0.13	30	0.13	90	0.17	50	0.06	0.125	70	74
4	90	0.12	90	0.15	90	0.13	30	0.11	90	0.13	30	0.13	90	0.17	50	0.06	0.125	70	74
5	90	0.12	90	0.15	90	0.13	30	0.11	90	0.13	30	0.13	90	0.17	50	0.06	0.125	70	74
6	90	0.12	90	0.15	90	0.13	30	0.11	90	0.13	50	0.13	90	0.17	50	0.06	0.125	73	76
7	90	0.12	90	0.15	90	0.13	30	0.11	90	0.13	50	0.13	90	0.17	50	0.06	0.125	73	76
8	90	0.12	90	0.15	90	0.13	30	0.11	90	0.13	50	0.13	90	0.17	70	0.06	0.125	75	78
9	70	0.12	70	0.15	90	0.13	30	0.11	70	0.13	50	0.13	90	0.17	50	0.06	0.125	65	68
10	70	0.12	70	0.15	70	0.13	30	0.11	70	0.13	50	0.13	90	0.17	70	0.06	0.125	65	67
11	70	0.12	70	0.15	70	0.13	30	0.11	70	0.13	70	0.13	90	0.17	70	0.06	0.125	68	70
12	70	0.12	70	0.15	70	0.13	30	0.11	70	0.13	70	0.13	90	0.17	50	0.06	0.125	65	68
13	70	0.12	70	0.15	70	0.13	30	0.11	70	0.13	70	0.13	90	0.17	50	0.06	0.125	65	68
14	70	0.12	70	0.15	70	0.13	30	0.11	70	0.13	70	0.13	90	0.17	30	0.06	0.125	63	67
15	70	0.12	70	0.15	70	0.13	30	0.11	70	0.13	70	0.13	90	0.17	30	0.06	0.125	63	67
16	70	0.12	70	0.15	70	0.13	30	0.11	70	0.13	70	0.13	90	0.17	30	0.06	0.125	63	67
17	50	0.12	70	0.15	70	0.13	30	0.11	70	0.13	70	0.13	90	0.17	30	0.06	0.125	60	65
18	50	0.12	70	0.15	70	0.13	50	0.11	70	0.13	70	0.13	90	0.17	30	0.06	0.125	63	67
19	50	0.12	70	0.15	70	0.13	50	0.11	50	0.13	70	0.13	90	0.17	10	0.06	0.125	58	63
20	50	0.12	50	0.15	70	0.13	50	0.11	50	0.13	70	0.13	90	0.17	10	0.06	0.125	55	60
21	50	0.12	50	0.15	70	0.13	50	0.11	50	0.13	70	0.13	90	0.17	10	0.06	0.125	55	60
22	10	0.12	10	0.15	30	0.13	30	0.11	10	0.13	10	0.13	30	0.17	50	0.06	0.125	23	21
23	10	0.12	10	0.15	30	0.13	10	0.11	10	0.13	10	0.13	30	0.17	90	0.06	0.125	25	22
24	10	0.12	10	0.15	30	0.13	50	0.11	10	0.13	10	0.13	30	0.17	90	0.06	0.125	30	26
25	30	0.12	10	0.15	30	0.13	70	0.11	10	0.13	10	0.13	50	0.17	90	0.06	0.125	38	34
26	50	0.12	50	0.15	50	0.13	50	0.11	30	0.13	70	0.13	50	0.17	70	0.06	0.125	53	52
27	50	0.12	50	0.15	50	0.13	50	0.11	30	0.13	70	0.13	70	0.17	70	0.06	0.125	55	55
28	50	0.12	30	0.15	50	0.13	70	0.11	30	0.13	70	0.13	70	0.17	50	0.06	0.125	53	53
29	50	0.12	30	0.15	50	0.13	90	0.11	30	0.13	70	0.13	70	0.17	70	0.06	0.125	58	57
30	30	0.12	30	0.15	50	0.13	90	0.11	30	0.13	90	0.13	70	0.17	90	0.06	0.125	60	58
31	30	0.12	30	0.15	10	0.13	10	0.11	10	0.13	70	0.13	50	0.17	90	0.06	0.125	38	36
32	30	0.12	10	0.15	30	0.13	90	0.11	30	0.13	50	0.13	50	0.17	90	0.06	0.125	48	44

Figure 8. Thematic maps displaying potential sites for RWH using (a) equal weight and (b) statistical weight. A full-colour version of this figure can be found on the ICE Virtual Library (www.icevirtuallibrary.com)

4.7 Basin slope

The gradient of the drainage basin, or basin slope, is a key issue in the selection of sites for maximum storage capacity for

water harvesting. A high basin slope results in a shorter time of concentration of peak flow. The channel slope is the most significant criterion in determining water infiltration, with

channel slope being inversely proportional to infiltration. Figure 7(a) shows the study region mapped into five slope classes, namely very low (>0.0205), low (0.0170 – 0.0205), moderate (0.0152 – 0.0170), high (0.0133 – 0.0152) and very high (<0.0133). High and very high slope classes occur in the south-western part of the study area. A decrease in slope (moderate class) is observed slightly further north. The central and north-eastern parts of the study area comprise very low and low classes of basin slope.

4.8 Basin length

Basin length is defined as the distance through which a basin is cut into two similar sectors (Horton, 1945). Basin length plays an important role in predicting the chances of the basin being flooded: the longer the basin length, the lower the probability of flooding in the basin. Therefore, the longer the basin length with a lower slope, the higher the potential for RWH. Macro-catchment procedures for water harvesting are more effective in longer basins, while micro-catchment techniques are more appropriate for shorter basins. The resulting thematic map of basin length is shown in Figure 7(b), with five classes of basin length: very low ($<71\,500$ m), low ($71\,500$ – $122\,000$ m), moderate ($122\,000$ – $192\,000$ m), high ($192\,000$ – $270\,000$ m) and very high ($>270\,000$ m). The map indicates that sites with very low and low basin length are in the southwestern part of the study area, with very high and high classes in the northeastern part.

4.9 Selecting criteria weights

A key part of this investigation was to identify potential RWH sites that were rated and categorised utilising the eight thematic maps demonstrating the influence of different criteria on RWH. The criteria were therefore classified into five divisions, from those with very high influence to very low influence.

In order to achieve ranking and classification, each site was scored by the summation of the rank average multiplied by the weight of each criterion (Table 2). The highest summation is ranked first. Based on the two methods of weighting the criteria (equal weight (W_c) and statistical weight ($W_{1/v}$)), the summation results for the 32 selected sites were categorised into four classes: <30 (low), 30 – 50 (moderate), 51 – 69 (high) and >69 (very high). Two output maps were constructed using a GIS platform based on the two weighting methods (W_c and $W_{1/v}$). Figures 8(a) and 8(b) show the sites across the region classified as having low, moderate, high and very high RWH potential. The two output maps show that the proposed method (based on $W_{1/v}$) is consistent with the first method (based on W_c) and is thus an ideal method for identifying the potential of RWH sites.

5. Conclusion

In this work, the contemporary examination methods of WMS, GIS and remote sensing techniques were used in an investigative process, as well as in modelling and mapping.

A combination of these tools was used to develop a methodology to rank and identify potential sites for RWH in Wadi Horan valley, located in Iraq's western desert. Sites across the entire region were classified as having low, moderate, high or very high RWH potential. Sites with very high potential were identified in 25% of the study area, with 53%, 13% and 9% of the study area identified as having high, moderate and low potential, respectively. The sites identified as having very high, high and moderate RWH potential are promising for the provision of water along the catchment, and could be investigated further using other qualitative and quantitative criteria in order to define suitable sites for realising water harvesting in finer detail.

In conclusion, through the application of WMS, GIS and remote sensing techniques, this paper proposes a methodology for improved water resources management and the sustainable development of arid regions through the identification of potential RWH sites.

Acknowledgement

The authors thank the Ministry of Education, Malaysia, for financial support through the Fundamental Research Grant Scheme (FRGS) (grant number FRGS/2/2014/TK02/UKM/03/2).

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