GIS based for Pre- selection of suitable site for Water Harvesting in arid areas case study in the West of Iraq

Khamis Naba sayl[a,1] , Nur Shazwani Muhammad [b,2], Elshafie Ahmed[c,3] Ali Dahham[a,4]

a Civil Engineering Department, Faculty of Engineering, University of Anbar, Anbar , Iraq

b Civil and Structural Engineering Department, Faculty of Engineering and built Environment, National University of Malaysia, Malaysia

c Civil Engineering Department, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

1 khamissayle@yahoo.com 2-shazwani.muhammad@ukm.edu.my 3-elshafie@um.edu.my 4-al.taib83@yahoo.com

Abstract— **Planning for construction of water resources infrastructure requires high quality data to explain water demands, environmental conditions, and a range of impacts on economic, social, and natural systems. Where the required data are scarce or of low quality, poor decisions are often made and this has been the case in developing nations for many years. Now, however, the situation has changed as global-scale geospatial data combined with the powerful capabilities of a geographic information system have created the potential to assist greatly in water resources planning. Scope of the study is the determination of appropriate sites and techniques for water harvesting in West Desert of Iraq by using Geographic Information System (GIS) and Multi Criteria Evaluation (MCE) as a tool for decision support. The selection criteria are defined both in a qualitative and quantitative way, and are based on a territorial analysis using geospatial data and hydrological and climatological information that are easily and freely available. Qualitative criteria imply the identification of suitable valleys based on visual interpretation of satellite images. Other qualitative selection criteria concern the distance from settlements and infrastructures. Quantitative criteria are expressed in terms of indexes that synthesise the effectiveness and feasibility of the possible interventions: the evaporation index (d); calculated as a benefit/cost ratio(c)in terms of volume of water that can be stored versus volume of the dam; the hydrologic index (1/P), based on the analysis of the contributing watersheds to each site; the soil water holding capacity(s), estimated from the analysis of vegetation patterns using satellite indices. The methodology, applied in the West of Iraq Horan vally, allowed the individuation of 53 sites, whose only 32 sites passed the proposed selection criteria. The 32 sites are ranked according to the highest scores. The results served to organize the subsequent field Surveys thus considerably reducing the time and cost of the survey.**

Keywords-component; GIS; water harvesting; remote sensing

Introduction

About half of the world's population lives in semi-arid or arid regions. Fresh water is becoming increasingly scarce in these area, due to interrupted water supply[1], or to inefficient water management practices [2]. Additionally, demands are growing because of increasing populations and water systems are overburdened because of poor water management [3]. West desert of Iraq is one of these regions which is classified as arid region and it is generally characterized with the lack of precipitations, highly rates of temperature and evaporation, limited surface water and groundwater resources. The planning and managing of water resources for the arid regions is an indispensable part to increase the freshwater availability and enhance the life quality for the region. Therefore there is a need for an effective solution to overcome the issue of water availability. In the recent past, rainwater harvesting came out as an imperative tool for water conservation in order to make it available during the dry season, herewith contributing to an equalized water distribution throughout the year and diminishing water scarcity during the dry season. Rainwater harvesting (RWH) has been defined by many authors, but simply FAO defined RWH as the collection of runoff for its productive use. In another term, RWH is the collection and concentration of rainfall to make it available for domestic or agricultural uses in dry areas [4]. The identification of potential areas suitable for RWH is therefore the key for a successful RWH intervention. One of the main reasons for failure of RWH structures is the lack of scientifically verified information which could be used to identify areas where RWH can be applied and for which type of RWH techniques. The arid regions are typically characterized by an underdeveloped infrastructure and the lack of appropriate environmental and socioeconomic data. Also, financial constraints of the public sector led to insufficient investments in equipment for data capture and storage. However, over the last decade, the development and application of modern technologies, especially remote sensing (RS) and Geographic information system (GIS), have the ability to tackle the challenging of site selection for RWH structures. GIS and RS could be reduce the expenses and time consuming in site selection by reduce the number of site suggested and select only the optimal locations. GIS and RS as a geospatial techniques have been applied in many studies in selecting the optimal site of RWH in arid and semi-arid regions [5], [6], [7],[8], [9], [10], [11], [12]. The potential of GIS and RS played a significant roles in planning and management of water resources [13],[14],[15], [16]. GIS and observations from satellites provide data on earth and its natural resources in a spatial format. GIS allows the integration of RS maps data, non-spatial (socio-economic) data and other collateral information renders decision making more scientific and people-oriented [17] .

Basically, the process of site selection by using RS and GIS techniques are based on support decision rules where these rules specify how to combine a certain criterion maps so that alternative decisions (locations) can be well-ordered according to some preferences with respect to evaluation criteria [18].

For the present study, many site selection criteria and high quality digital satellite images have been obtained to identify suitable site for water harvesting in the west desert of Iraq. The main objective of this research is to present a reasonably robust methodology based on RS and GIS for better decision making. This methodology consisted of three phases, where each phase has certain utilities and techniques to reduce the number of suggested sites and rank it depend on the priority and benefits. Novelty of this study lies on the fact that unlike earlier researches wherein area-volume curve for RWH structures will be developed from GIS. In additions four main indexes will be extracted from that area-volume curves where these indexes will play a significant roles in ranking of sites and the results served to organize the subsequent field surveys.

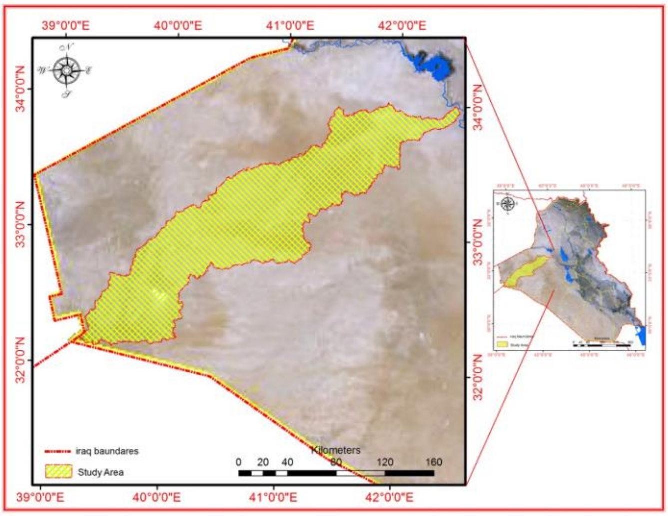

Figure (1) Location of study area

STUDY AREA

"Fig. (1)" show the study area is located at west of Iraq in Al-Anbar governorate specific south of Euphrates River and specific geographic coordinates 32° 10' 44" to 34° 11' 00" north and 39° 20' 00" to 42° 30' 00" east . The catchment area is 13370 km^2 , the annual mean runoff equal at 900 milion m^3. Most of areas bounded horan valley are composed of bare soils which were found suitable for agriculture. The rainy season begins from September to the last of May. The average annual rainfall in this region is 115mm of about 49.5% occurs in Winter, 36.3% in Spring and 14.8% in fall. The average annual evaporation is 3200 mm; the dryness coefficient in this region (Evaporation/rain) is (25-35). The hottest month is July and the coldest is January. The mean annual temperature is 20.6^{o}C. The minimum annual mean appears in Rutba (19^{o}C) and this increases toward Euphrates River, where the elevation decreases in conformity with the increasing rainfall. The relative humidity is between 19%-82%. The ground water level of the area is deep enough so as to not give any recharge to the surface runoff, and it forms an artesian conditions represented by some wells constructed in these area, [19]. The drainage pattern is characterized by a run-off regime strongly influenced by seasonal component of rain regime: during the most of the year the river channels are completely dry, instead in consequence of stormy events, during the rainy season, short but intense flood wave happen. The differences in elevation between start and end of the wadi at 600m. The study area is characterized by considerable temperature range between(0-48)$^{\circ}$ C.

Methodology

The methodology proposed is based on the division of the criteria into three phases. This process is constituted by a first phase of sites identification, by a second phase of qualitative selection based on geomorphic and functional aspects and by a third classification phase based on the estimation of criteria obtained from the impact of the dam, which are depend on area volume curve.

1- site identification: the best site for the dam is a place where a wide valley with high walls leads to anarrow canyon with tenacious walls. This allows the reduction of dam dimensions and reduce costs and steep valley slopes should be given low priority as dam sites on such slopes are rarely economical [20]. Slope steepness is a very important factor for assigning and implementing rainwater harvesting . The ground slope is a key limiting factor to water harvesting. Water harvesting is not recommended for areas where slopes are greater than 5% due to uneven distribution of run-off and large quantities of earthwork required which is not economical.

The best of narrows width is obtained by shuttle radar topography mission (SRTM) data and satellite images (LANDSAT 8, 2013) The estimate of narrows width is obtained by visual interpretation procedure elaborated by(SRTM) in GIS (global mapper 10). The identification phase is conducted by visual interpretation of satellite images and analysis of large-scale cartography (Fig. 2 and Fig. 3 a,b).

2- qualitative selection: At this stage of the study many qualitative criteria must be consider. The negative response in any one of these criteria eliminates site selection:

2-1 geological condition : it is possible to evaluate the subsurface dam to some extent by surface geology studies. The foundations of dam must rest on a layer of impermeable rock. Horan valley is located in stable zone of Iraq. No major folded and foulted structure in the area. The major stratigraphic formation in Horan valley is the Zor Horan formation. Which consists of a sequence of limestone and marl layer[21].

2-2- Distance from road communications network: roads have a great socio-economical value for the local community in the study area. Through these roads, they can move their trucks

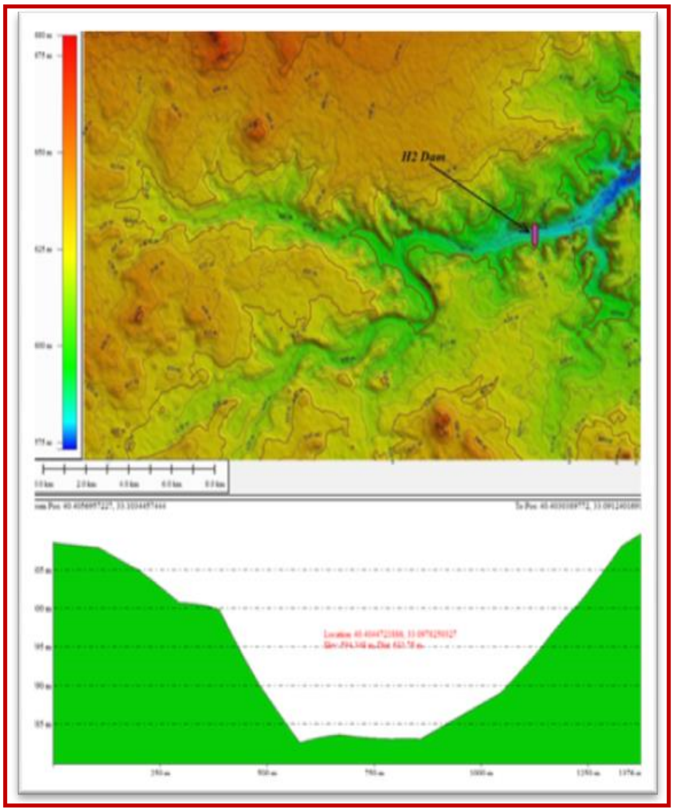

Figure (2) The topographic map and cross section of Houran 2 dam

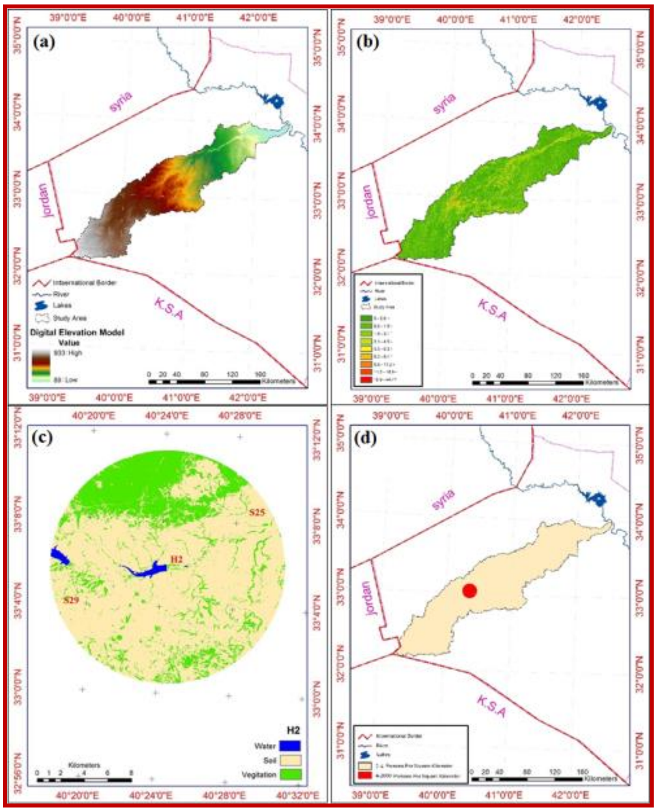

Figure. 3: The associated reference parameters of the catchment that utilized for the analysis. a) DEM of study area , b) the slope , c) vegetation cover and d) population density.

and tankers from one place to another when moving with livestock searching for grass and water. Selection the sites of dams very far from preexistent road, needs an additional road infrastructure, whose needs additional cost.

2-3 Distance from villages: in order to avoid the construction of the dam in a remote location on the presence of the population, it is very important to consider the distance from the villages. Taking into account the proximity to villages is very important to find the necessary skilled manpower to construct the dam. Selection the sites too distance from the villages present additional costs during the construction phase. In this study, most of the users are nomadic shepherds and the villagers are prevalently built along the road communication and far from the valley. For these reasons, it is not possible to identify suitable sites near villages.

2-4 Influence area of barrage: The influence area after realization of the dam corresponds to the upstream narrows will benefit to estimate the surface area and volume are obtained by shuttle radar topography mission (SRTM) data and GIS techniques (Fig. 3-c).

2-5 Vegetation cover. NDVI. The normalized difference vegetation index is an index of vegetation cover and it is used to quantify vegetable biomass. The index was determinated by multispectral analysis of satellite imagery in the red and near infrared bands (Fig. 3-c).

2-6 Number of people benefit from dam : The information of number of people benefit from barrage obtained from situ survey (Fig. 3-d).

***2-7 Land Cover / Land* Use**: Land cover was extracted from Satellite Imagery (Landsat 8 -2013 with a spatial resolution of 30 meters. A different land cover/land use classes were applied through supervised classification. The maximum likelihood algorithm was used to classify land cover using the mean, variances and covariance data from the signature. Four types of land cover were found in the study area: bare soil, built up, water, and grass (Fig. 4". Land cover is an important criterion when selecting suitable areas for water harvesting. On the other hand, land cover can be used to estimate the runoff depth by using the Soil Conservation Service Model. The vegetation plays a significant role on the infiltration capacity of the soil. The amount of runoff lost to interception on leaves and stacks of vegetation which depends on the growth stage and the type of vegetation.

2-8 Geometric parameters: The geometric parameters of the watersheds were determined using Watershed Modeling System (WMS) , which delineates the basins and provides

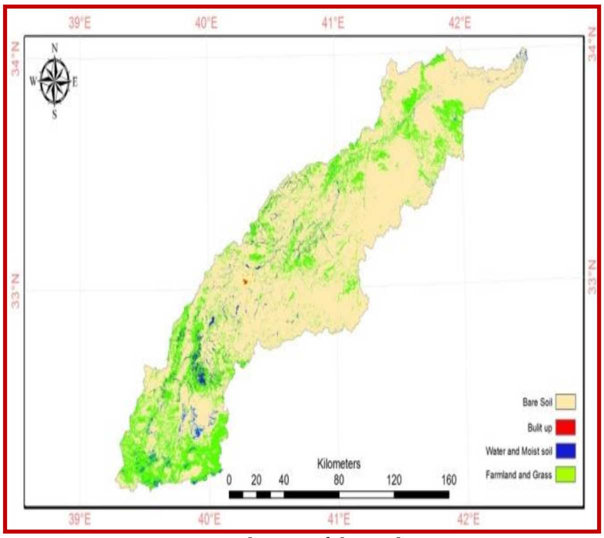

Figure 4: Land cover of the study area

multiple watershed characteristics. The WMS software calculated the hydromorphometric characteristics for each watershed value used. These values are provided for each of the delineated watersheds. These multi layers were manipulated within the ArcGIS 9.3.3 ® software spatial analyst module (ESRI, 2009) (Fig. 5).

2.9 Soil Conservation Service - Curve Number model

Estimation of runoff depth is an important component for determination of suitable areas for rainwater harvesting. The runoff depth is used to assess the potential water supply during a runoff event. Soil Conservation Service and Curve Number (SCS) modeling was used to estimate the runoff depth in the study area. ArcGIS 9.3 was used to interpolate the rainfall data and the soil map of the study area. The output of the Soil Conversation Service model has been used to extract the depth of the runoff from the rainfall for water harvesting planning [22]. The equation of the Soil Conservation Service model can be expressed as below [24]:

$$Q = \frac{(P - I_a)^2}{(p - I_a) + s} \qquad (1)$$

Where :

Q = runoff depth (mm).
P = rainfall (mm).
S = potential maximum retention after runoff starts (mm).
Ia = initial abstraction (mm).

Initial abstraction includes all losses before runoff starts, infiltration, evaporation and water intercepted by vegetation.[24] was estimated Ia =0.2S by analyzing the data of rainfall for many small agriculture basins. Therefore, referring to equation 2, the Soil Conservation Service equation can be expressed as:

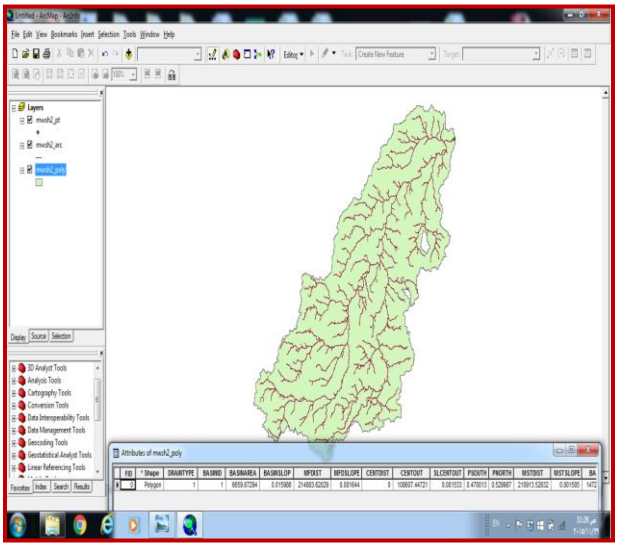

Figure 5: Geometric properties of the watershed choice

$$Q = \frac{(P - 0.2S)^2}{(p + 0.8S)} \qquad (2)$$

Potential maximum retention (S) can be calculated by the Curve Number (CN) as below [24]:

$$Q = \frac{25400}{CN} - 254 \qquad (3)$$

The soil conservation service (SCS) model depends on the runoff Curve Number (CN). Curve Number is predictable via the effect of soil and land cover on the rainfall runoff processes. Curve Number is estimated per pixel for the study area, via the land cover map and soil map that was reclassified into Hydrologic Soil Groups and hydrologic condition. Fig. 6 illustrates the run off depth in the study area.

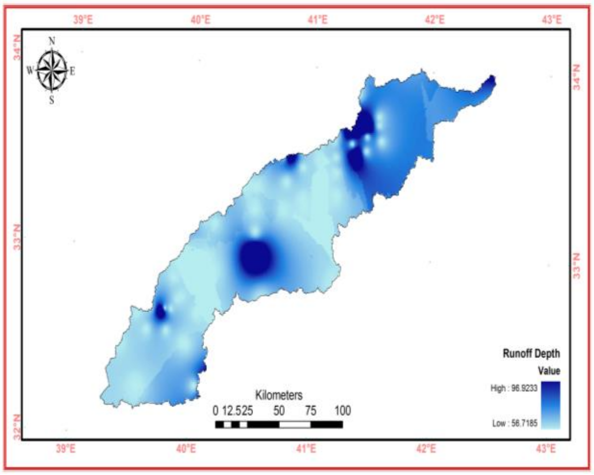

Figure 6: Run off depth of the study area

3- Quantitative classification: This phase involves analysing a site of possible solutions to problem identified. the parameters are defined to compute the value of the effective of each possible choice. The area volume curve that have been extracted from Remote sensing and GIS is the most important factor which is used to assess the site classification. The final thematic maps that represent the water level at different depth, surface area and reservoir capacity for the established dams, are displayed in Fig. 6. The legends described in (Fig. 6) indicate the surface area and volume capacity with the accumulative elevation depth level. The ideal height of the dam can be determined from the intersection of elevation – capacity curve with area- elevation curve. The available storage capacity of a reservoir depend on the topography of the site and the height of the dam. These parameters (storage capacity, water spread area at different elevation and height of the dam) are used to generate four different indexes based on combination of the main parameters:

3-1 The ratio between mean volume storage V_{mean} and mean surface area A_{mean} at specific elevation is calculated . This index(d_{mean}) refer to evaporation losses. Naturally, the shape of the reservoir will have an impact on how much water is lost to evaporation. A narrow deep reservoir will have a much smaller evaporation loss than abroad shallow reservoir. 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. Therefore, water surface area and the depth of water were considered in the evaluation of the present research.

3-2 The ratio between the volume of potential storage(V_w) generated by the realisation of dam and the volume of the structure(V_{st}), is carried out to indicate the Benefit cost ratio in the word which indicate economic desirability. This index( ) can be considered as a gross estimate of the cost.

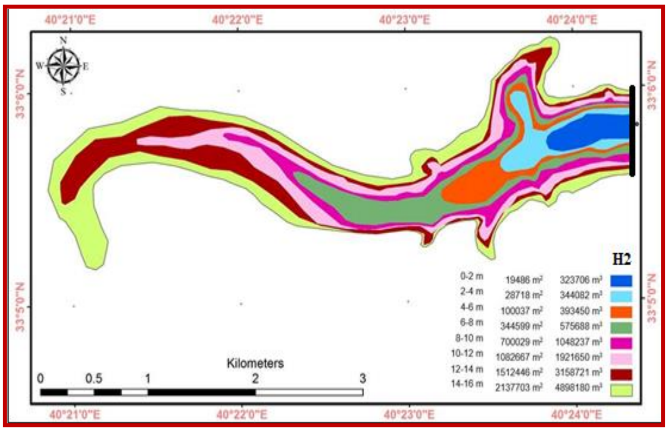

Figure 6: Thematic maps represent area volume curve for the established dam

The cost of dam construction is basically a function of the volume of earthworks .

3-3 The ratio between the volume of water storage(V_w) and the catchment area(A_c). Estimate the precipitation height(p) necessary to fill the live storage volume. According to the following hypothesis : soil infiltration capacity which depend on geology and pedology is neglected; the characteristics of rainfall regime are uniform in all catchment area. The precipitation height is very determinant to evaluate the site effectiveness and which indicate the probability for the occurrence of a rainfall season capable of filling the estimated net storage volume.

3-4 The ratio between the volume of potential storage (V_w) and the volume of sediment(V_s) of catchment. The standard (s) procedure that needs to be carried out for planned storages requires an assessment of the importance of the problem to classify the reservoir sedimentation problem as insignificant, significant, or serious. Assessment of reservoir sedimentation problem, in a particular case may be made by comparing the expected average annual volume of sediment deposition with the gross capacity of the reservoir planned.

The criteria were calculated from different scales, and therefore it is necessary to convert the criteria to a standardized scale .The standardized criteria membership values are calculated by using the minimum and maximum values as scaling points.

In this study, a Weighted Linear Combination (WLC) is used. This weighted linear combination is employed to calculate the sum of the weighted criteria. The weighting is done by multiplying the weight of the factor by its standardized membership value as shown in Equation :

$$S = \_ \; wi \, . \, xi \qquad (4)$$

Where

S is suitable area.
wi is weight of criteria i.
xi is the membership value of criteria i.

Results

The first phase brought to the identification of 53 different potential sites with very different narrows characteristics.

Only 32 of these sites passed the second phase selection (Table 1). On the ground of above mentioned considerations, a site is considered potentially suitable about morphologic aspects if it presents alluvial plan coefficient height and potentially suitable about hydrologic aspects if it is characterised by probability P height.

-suitable sites about evaporation index are (23,30) these sites present maximum depth height with minimum surface area.

- suitable sites about cost benefit ratio are (30,21) these sites present maximum storage water with minimum volume of the structure which represent minimum cost of dam construction.

Table 1 Sites classification and estimation of some reference parameters

CO.	LONG.	LAT.	d_{mean}	C	$1/P$	S	RANK
1	33.928554	42.421438	2.78	7.61	6.03	0.1833	27
2	33.869081	42.256377	2.65	6.52	5.88	0.1866	30
3	33.877775	42.182766	3.38	21.8	1.42	0.7833	8
4	33.893571	42.104316	3.31	16.78	2.42	0.4633	17
5	33.897892	42.03424	2.27	19.74	3.1	0.366	24
6	33.906254	41.99692	3.11	12.44	1.71	0.633	21
7	33.811705	41.778217	4.28	21.19	0.81	1.39	2
8	33.805396	41.723906	3.94	11.36	2.05	0.6	6
9	33.750355	41.614569	3.66	17.7	1.69	0.713	5
10	33.694913	41.509074	3.3	15.45	1.46	0.8233	4
11	33.641954	41.431164	3.87	25.76	0.67	1.78	3
12	33.643389	41.36391	2.48	19.39	1.16	1.0266	16
13	33.584622	41.246025	3.62	5.47	2.92	0.4	15
14	33.566456	41.192068	2.84	21.6	1.42	0.8133	20
15	33.54545	41.088211	3.49	9.97	4.32	0.2733	14
16	33.526035	41.01743	3.78	8.28	3.44	0.3366	12
17	33.487655	40.96254	2.92	2.34	4	0.28	28
18	33.416046	40.877058	2.68	2.4	5.25	0.22	26
19	33.382925	40.844941	3.66	9.57	1.85	0.6366	13
20	33.323918	40.714195	3	10.39	2.3	0.51	23
21	33.306615	40.680032	3.33	26.02	0.46	2.706	9
22	33.498866	40.893292	3.26	11.08	0.06	4.6	19
23	33.420396	41.034487	4.21	8.05	0.13	3.37	7
24	33.326629	40.638652	3.37	17.07	0.08	6.648	18
25	33.265066	40.6189	2.17	22.59	1.65	0.79	32
26	33.135705	40.476352	3.07	24.67	0.57	2.066	11
27	33.103446	40.405696	3.65	19.31	1.26	0.93	10
28	33.061742	40.310735	2.8	12.08	1.08	1.086	29
29	32.940381	40.068355	3.06	5.5	0.82	1.5	25
30	32.885972	40.036463	4.08	33.37	0.2	6.01	1
31	32.872795	40.231772	3.08	13.86	0.05	6.6	22
32	32.82596	39.99599	2.63	17.6	0.45	2.78	31

- suitable sites about hydrologic condition are (1,2,18) these sites present minimum depth of precipitation necessary to fill the live storage volume.
- suitable sites about sediment are (23,30) these sites present maximum live storage .

Conclusion

The study probes the use of the new technologies for the assessment of the suitability of sites for the pre-selection of small dams. The selection criteria are defined both in a qualitative and quantitative way, and are based on geospatial data and GIS that are easily and freely available. The methodology is particularly indicated in remote areas where very little territorial information is available, such as most developing countries which does not provide adequate information on environmental and morphological parameters.

The methodology, applied in West Desert of Iraq Wadi Horan allowed the individuation of 53 sites, whose only 32sites passed the proposed selection criteria. The 32 sites are ranking by taking into account the morphologic and hydrologic conditions of each site. The results served to organize the subsequent field surveys, thus considerably reducing the time and cost of the survey.

The described approach is confirmed that the visual interpretation of satellite data and the analysis of large-scale availability cartography are precious instruments for an effective preliminary territorial analysis for the feasibility study of water resource projects in developing countries. It is important to observe that the analysis presented here determines the choice of suitable construction sites from prevalent engineering. A conclusive evaluation about the feasibility and advantage of such projects should consider further perspectives.

References

[1] Jia, Z. and W. Luo (2006). "Modeling net water requirements for wetlands in semi-arid regions." Agricultural Water Management 81(3): 282-294.

[2] Shangguan, Z., M. Shao, et al. (2002). "A model for regional optimal allocation of irrigation water resources under deficit irrigation and its applications." Agricultural Water Management 52(2): 139-154.

[3] Cai, X., M. W. Rosegrant, and C. Ringler (2003). "Physical and economic efficiency of water use in the river basin: Implications for efficient water management." Water Resources. Res. 39(1).

[4] Liniger, H., Mekdaschi Studer, R., Hauert, C. and M. Gurtner. 2011. Sustainable Land Management in Practice. Guidelines and Best Practices for Sub-Saharan Africa. TerrAfrica, World Overview of Conservation Approaches and Technologies (WOCAT) and Food and Agriculture Organization of the United Nations (FAO).

[5] De Winnaar, G., Jewitt, G.P.W. and Horan, M. (2007) A GIS-based approach for identifying potential runoff harvesting sites in the Thukela River basin, South Africa. Physics and Chemistry of the Earth, Parts A/B/C 32

[6] Forzieri, G., Gardenti, M., Caparrini, F. and 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. Physics and Chemistry of the Earth, Parts A/B/C 33(1-2), 74-85.

[7] Jamali, I.A., Mörtberg, U., Olofsson, B. and Shafique, M. (2014) A Spatial Multi-Criteria Analysis Approach for Locating Suitable Sites for Construction of Subsurface Dams in Northern Pakistan. Water Resources Management 28(14), 5157-5174.

[8] Jasrotia, A.S., Majhi, A. and Singh, S. (2009) Water Balance Approach for Rainwater Harvesting using Remote Sensing and GIS Techniques, Jammu Himalaya, India. Water Resources Management 23(14), 3035-3055.

[9] Kadam, A.K., Kale, S.S., Pande, N.N., Pawar, N.J. and Sankhua, R.N. (2012) Identifying Potential Rainwater Harvesting Sites of a Semi-arid, Basaltic Region of Western India, Using SCS-CN Method. Water Resources Management 26(9), 2537-2554.

[10] Krois, J. and Schulte, A. (2014) GIS-based multi-criteria evaluation to identify potential sites for soil and water conservation techniques in the Ronquillo watershed, northern Peru. Applied Geography 51, 131-142.

[11] Pandey, A., Chowdary, V.M., Mal, B.C. and Dabral, P.P. (2011) Remote sensing and GIS for identification of suitable sites for soil and water conservation structures. Land Degradation & Development 22(3), 359-372.

[12] Sekar, I. and Randhir, T.O. (2007) Spatial assessment of conjunctive water harvesting potential in watershed systems. Journal of Hydrology 334.

[13]Bulcock, L.M. and Jewitt, G.P.W. (2013) Key physical characteristics used to assess water harvesting suitability. Physics and Chemistry of the Earth, Parts A/B/C 66, 89-100.

[14] Kahinda, J.M., Lillie, E.S.B., Taigbenu, A.E., Taute, M. and Boroto, R.J. (2008) Developing suitability maps for rainwater harvesting in South Africa. Physics and Chemistry of the Earth, Parts A/B/C 33(8-13), 788-799.

[15] Ziadat, F., Bruggeman, A., Oweis, T., Haddad, N., Mazahreh, S., Sartawi, W. and Syuof, M. (2012) A Participatory GIS Approach for Assessing Land Suitability for Rainwater Harvesting in an Arid Rangeland Environment. Arid Land Research and Management 26(4), 297-311.

[16] Daniel, R. (2002) Concepts in Space Science, Universities Press.

[17] Malczewski, J. (2004) GIS-based land-use suitability analysis: a critical overview. Progress in planning 62(1), 3-65.

[18] Kamel, Ammar H., evaluation runoff volume in Iraqi western desert by synthetic unit hydrograph, Baghdad, 1999.

[19] Nilsson, A., 1985. Siting of groundwater dams for rural water supply in developing countries, hydrogeologiacal and planning aspects. In: Proceedings of the Fifth World Congress on Water Resources, vol. 3, pp. 1287–1296.

[20] Stephens, T. (2010) Manual on small earth dams. Food and Agriculture Organization of the United Nations, Rome.

[21] AL-Furat center for studies and designs of irrigation projects 1994, western desert dams design report of horan dam H-2.

[22] Gupta, K.K, Deelstra, J. and K.D, Remote Sensing and Geographic Information Systems for Design and Operation of Water Resources Systems, April 1997, IAHS Publ. no. 242).

[23] Maidment, David R, HandBook of Hydrology, University of Texas at Astin, Texas USA 1993.

[24] Melesse, Assefa M, Shih, S.F, Spatially distributed storm runoff depth estimation using Landsat images and GIS, University of Florida, Gainesville.