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The Application of Watershed Delineation Technique and Water Harvesting Analysis to Select and Design Small Dams: A Case Study in Qara-Hanjeer Subbasin, Kirkuk-NE Iraq

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Abstract

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The rainwater harvesting technique is one of the solutions to overcome the effect of water shortage crises in arid and semi-arid regions. In this study, the feasibility of using small dams in water harvesting has been examined at Qara- Hanjeer sub-basin that lies east of Kirkuk, N-Iraq with a surface area of 503.88 Km². Watershed boundary for entire basin has been delineated comparatively by mask method, using hydrology toolset in ArcGIS (10) software. Direct surface runoff is calculated using Soil Conservation Service Curve Number method based on data from Kirkuk meteorological station for the period (1995-2020), information obtained from land use map, and soil type, the basin is divided into six zones with different CN values, Moreover, for average annual rainfall (334.33 mm/year), water surplus was 190.2 mm and surface runoff was 25.77 mm representing 7.708 % of the total rainfall. The runoff depth was 167.03 mm/year and the total annual harvested runoff is 12.99x10⁶ m³ Several temporary and semi-permanent check dams could be built across the valleys, with height (< 3m.). These dams are of low cost, reduce the loss of runoff water, improve agriculture, tourism and add impetus to the ecosystem programs in Qara-Hanjeer city.

Keywords: GIS; Watershed; Check dam; Kirkuk; Iraq

1. Introduction

Most Iraqi basins, in recent decades, is suffering from water shortage due to irregularity of rainfall as a result of global climate change, increasing groundwater use, land use abuse, and lack of a proper policy of management of water. Accordingly, there is a vast need for studies and researches that works on the effectual use of all water resources capability in the region to minimize the bad consequences of water shortage in drought seasons. In the study area, the climate is semi-arid to humid, following the general climate trend of Mediterranean regions (Soran and Refan, 2019). As rainfall is the essential source of water in the area a large amount of surface water runoff will be vanished due to either the evaporation processes or that the excess water will flow into the valleys and pour into the Tigris River without bringing any benefit to inhabitants and ecosystems. So, the basin was tested for the feasibility of Rainwater Harvesting (RWH) using small local dams. Their locations were suggested, depending on the drainage system and the geometry of the valley (Al-Ansari et al., 2013). The first use of such a

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technique was originated in Iraq over 5000 years ago by the Assyrian, Sumerian, and Babylonians in agriculture (Hardan, 1975). The RWH system deals with all the procedures which achieve the rainfall-runoff relation to retain water in the soil or underground for later beneficial use (Abdelaziz et al. 2017). However, GIS techniques were recently applied as a new approach to select dam sites (Kumar et al. 2008), where the ArcGIS hydrology tool is used to delineate watersheds directly from DEMs (Woodrow et al. 2016), and these DEMs based on the SRTM digital elevation model, which derives the area concerned to the current study by Mask Technique (Merwade, 2011). Application of the above techniques and the geological information of the studied basin provides valuable datasets to examine the kind of dam suitable for the particular site. In this paper, check dams (temporal or semi-permanent types) have been suggested to be built on some wades in a short time by natural available local materials, so they are of low cost and resists for several years. The policy to build such a dam is feasible, and great benefits are attached to the local society.

2. Materials and Methods

2.1. Study Area

The study area is located between coordinates 35°27' to 35°43'N and 44°22' to 44°50' E (UTM) coordinates (475300-505500 East) and (3915000-3936000 North) which lies in Zone 38N with an area of 504Km² (Fig.1). Situated thirty-five kilometers to the Northeast of Kirkuk city (265 kilometers north of the capital Baghdad); with a population of 51000 inhabitants live in about 49 villages. Located within the semi-arid zone of Iraq and according to Kirkuk meteorological station, it is characterized by a mean maximum temperature of 43.9 °C during July and a mean minimum temperature of 4.9 °C during January, where the annual rainfall is approximately 334mm.yr⁻¹ (IMOS, 2021). The study area is a part of the Butmah-Chamchamal sub-zone of the Foothill Zone, related to the unstable shelf units (Buday and Jassim, 1987). The main observed structure in the area is Qara-hanjeer syncline (asymmetrical, double plunging, long and broad syncline extends for 65 Km in NW-SE direction), bounded by Chamchamal anticline, and by Kirkuk anticline to the northeast and southwest respectively (Jassim and Goff, 2006).

Fig.1. Location map of the study area

The geology of the study area was studied by several authors (Buday and Jassim, 1987; Stevanovic and Markovic, 2003). Generally, all the rock units in the study area belong to the Tertiary age. The main exposed formations in the area are Fat'ha, Injana, Mukdadiya, Bai Hassan formations, and Quaternary deposits (Fig.2). Fatha formation (middle Miocene); is characterized by the prevalent evaporitic (sulphatic and halogeneous) facies.

Fig.2. Geological map of the study area

The rocks composing the formation are Anhydrite, Gypsum, and salt, interbedded with limestone, marl, and relatively fine-grained clastic. The basal unit of the Injana formation (Late Miocene) comprises thin red and green mudstone with thin-bedded gypsum and purple sandstone horizon. The calcareous sandstones contain Miliolides oscillation ripple marks overlain by fining upward cycles, of sandstone, siltstone, and mudstone. While Al-Mukdadya (Pliocene) and Bai-Hassan (Pleistocene-Pliocene) formations, as well as Holocene-Pleistocene Quaternary deposits, are constituted by alteration of recent alluvial deposits, conglomerate, gravel, and sandstones. Hydrologically, the aquifer within the area is unconfined, composed of alluvial with sequences of sand, clay, and silt layers of various thicknesses. The movement of groundwater is in the direction of the topographic slope of the basin (from the north and northeast toward the southwest). The depth to the groundwater table varies from 45-90m to ground level. The chemical analysis of water indicates that the water quality is dominated by Ca-HCO₃ geochemical facies (Al-Saud, 2008). It plays a great role in the irrigation and drinking water supply of the inhabitants of this area.

2.2. Data Preparation

2.2.1. Watershed delineation

A Watershed is a natural hydrologic unit enclosed by a drainage divide lying upslope from a specified spillway outlet, or "Pour point." (Zhang et al. 2011), it is topographically separated from adjacent watersheds by ridges in the landscape. Therefore, an understanding of the geospatial dataset (geology, topography, geomorphology, soil, and land cover) determines the quality of ground and surface water, as well as the magnitude and timing of streamflow and groundwater outflow of the area. The watershed area of the Qara Hanjeer basin is about 503.8km², considered as a small watershed, and has been delineated using ArcGIS (10) software based on an SRTM digital elevation model of (30 x30

m EDM), and have been downloaded from the United States Geological Survey Earth Explorer (USGSEE). To Extract hydrologic information from a digital elevation model (DEM) in ArcGIS using Hydrology Toolset; Arc Catalogue10, and Spatial Analyst Tools which enclosed with Arc Map (10), has been used to extract the area concerned to the current study by Mask Technique (Merwade, 2011).

The first step is to prepare a DEM to represent the topography (terrain) of the area (Fig.3), which should have no depressions or sinks. Therefore, all sinks in the elevation grid are removed from the DEM layer using the Fill Sink function of the Hydrology toolbox (Figs.4 and 5). The flow direction raster is created from the DEM, Fig. 6 shows the direction of water flow of overland runoff. Then, to create a stream network, the flow accumulation tool is, used to compute the number of high flow cells flowing to a location. Flow accumulation defines a drainage Network, from where the stream grid is, calculated to extract Stream orders (Fig.7). Finally, delineate watersheds by converting the watershed layer from a raster to polygons before assigning their attributes (Figs.8 and 9). The point source of inlet and outlet of the flowing watershed was additionally chosen (Fig. 10).

Fig.3. Topography (3-D) map of the study area

Fig.4. Digital Elevation Model (DEM) of the study area

Fig.5. The filling of sinks of the studied watershed

Fig.6. Flow direction function of the study area

Fig.7. Stream order of the basin

Fig.8. Catchment grid delineation function of the study area

Fig.9. Automatically delineating watersheds, area of each Watershed in km²

Fig.10. Watersheds with pour point for each watershed

2.2.2. Rainwater harvesting

RWH is the collection and storage of runoff to mitigate the effect of temporal shortages of rain in areas of arid and semi-arid regions for purposes such as cultivation, livestock, and domestic water supply (Fentaw et al., 2002)). It depends on the quantity of water stored from an area under a given climate condition (rainfall intensity, evaporation, runoff, infiltration capacity) and the nature of the covered topsoil within the whole basin (Fink, 1984). The Macro RWH technique is the most suitable technique to be tested in this region where all the requirements and variables (semi-arid, rainfall, and runoff) that needed to apply such technique were available (Gupta et al. 1997). The foregoing Watershed modeling system was used to estimate the harvested runoff volume at the studied area, based on The NRCS Runoff Curve Number (CN) method. The details are described in NEH-4 (SCS, 2004). The curve numbers (CN) values are calculated from runoff volume using rainfall data (Fig.11) for the studied period (1995-2020), soil type and land use map (Hawkins, 2004).

Fig.11. Mean monthly Rainfall (mm.) for the year (1995-2020), (IMOS, 2021)

Runoff for each month and for each geological formation zone (Fig.2) is calculated according to the following equations (USDA, 2004, 1986):

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

Where:

Q = runoff in (mm) of depth

P = total precipitation (mm) (average monthly records used).

S = potential maximum retention which is assumed to be 0.2S.

CN is curve number, it has a range of 0 to 100, and S is related to CN by

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

Based on the land morphological features and the lithology of expected rock units (Fig.2), soil cover and land use /land cover (Fig.12).

The study area could be divided into 6 zones (Table 1), so it has more than one CN value, where the total CN value was calculated using the following equation:

$$CN_{\text{total}} = \frac{A_1CN_1 + A_2CN_2 + \dots + A_nCN_n}{A_1 + A_2 + \dots + A_n} \quad (3)$$

Where:

A₁, A₂... A_n is the areas of various zones.

CN₁, CN₂ ...CN_n is the curve members.

Fig.12. Land use map for the studied area

Table 1. Hydrologic groups and weighted curve numbers for the study area

C.N * Area	Formation	Area (Km ²)	Area (%)	CN
11241.25	Fatha	132.25	26.25	85
2193.75	Injana	29.25	5.80	75
945.00	Mukdadiya	27.00	5.36	35
8912.05	Bai Hassan	254.63	50.54	35
506.40	Recent	16.88	3.34	30
3416.40	Urban	43.80	8.71	78
27214.85	Total	503.81	100	
54.02	Weighted CN			

The water balance condition of the study area is conducted by using the mean monthly water balance method, depending upon the meteorological data from Kirkuk meteorological station for the period (1995-2020), used to determine the climatological characteristics of the study area and its effect on the water balance condition. The monthly average rainfall (P) and potential evapotranspiration (PE) values calculated by Thornthwaite method (Thornthwaite, 1948) used for calculating of monthly averages of Actual water losses (AE), and water surplus (WS) values as shown in Table 2.

Table 2. Expected amount of runoff for each month and for each geological formation zone based on SCS Method

Factors run off	Fatha	Injana	Mukdadiya	Bai Hassan	Recent	Urban	T
30*10 ⁶ m ³	78	85	75	35			35
Oct.	2.878	0.508	0		0		0
1.321	0.341	4.707					
Nov.	16.23	7.242	0		0		0
19.284	3.098	42.758					
Dec.	21.684	10.301	0		0		0
29.559	4.462	61.584					
Jan.	30.208	16.641	0		0		0
55.536	7.417	102.385					
Feb.	22.484	10.68	0		0		0
30.691	4.626	63.855					
Mar.	17.164	7.658	0		0		0
20.391	3.275	45.213					
Apr.	10.028	3.343	0		0		0
8.424	1.579	21.795					
May	0	0.399	0		0		0
1.038	0.104	1.437					
Jun	0	0	0		0		0
0	0	0					
July	0	0	0		0		0
0	0	0					
Aug.	0	0	0		0		0
0	0	0					
Sep.	0	0	0		0		0
0	0	0					
Runoff	120.67	56.772	0				0
166.284			24.90				343.734
Total							
Runoff%	35.108	16.516	0		0		0
48.376							
Area	132.25	29.25	27.00		254.63		16.88
43.8 km ²	503.81						Enclosed
Volume	15.96	1.66					
7.283(x 10 ⁶ m ³)		24.90					

$$WS\% = \frac{WS}{P} \times 100 \quad (4)$$

$$WS\% = \frac{190.2}{334.33} \times 100 = 56.91 \quad \text{of rain falls.}$$

2.2.3. Dam site selection

The selection of harvested dam locations is to be carefully considered (Stephens, 2010). Therefore, the position of the dams was selected depending on the drainage area and valley characteristics and built on bedrock or highly compacted soil in selected parts of the valleys, especially in the transitional zone between the hills and plains. Check dams at the studied basin are suggested to be constructed although they aren't, proposed for perennial streams, they can serve for few years. Temporary check dams are usually built at first-order stream, using local natural materials of stone, lumber (timber or wood), and sandbag (Piyapit & Cheng, 2011) (Fig.13-a), so as to reduce stream water flow and create water pools behind them to store water for several days or months. Position on streams of (order three), was proposed to be suitable places to construct semi-permanent check dams (Fig.13-b). The stream branching drainage patterns are parallel to a semi-dendritic.

Table 3. Climatological parameters of water balance, Kirkuk Meteorological Station (1995 – 2020)

	Factors	P (mm)	PE (mm)	AE (mm)	WS (mm)
0.00	Oct.	16.93		84.0	16.93
19.85	Nov.	44.95		25.1	25.1
44.71	Dec.	54.21		9.5	9.5
57.99	Jan.	64		6.01	6.01
	Feb.	56.21	10.61	10.61	45.6
22.11	Mar.	47.53		25.42	25.42
0.0	Apr.	36.0		62.36	36.0
0.0	May	13.31	139.1	13.31	0.0
0.0	Jun.	0.13		233.5	0.13
0.00	Jul.	0.19		279.5	0.19
0.00	Aug.	0.04		255.96	0.04
0.00	Sep.	0.84		158.2	0.84
0.00	Sum	334.33	1289.26	144.07	190.26

Fig.13. Examples local check dam (Piyapit & Cheng, 2011), a) Temporary check Dam; b) Semi-permanent check dam

3. Results and Discussion

In light of the foregoing, Fig.3 shows that the elevation of the North and East parts is high (> 800m.a.s.l.) and decreasing towards the Southwest part (300-250 m.a.s.l.), so the topographical gradient is also decreasing in the same direction. Fig.6 declares that the flow direction coincides with the topographical slope trend. The stream network shows two large streams in the study area, the first one, figured at the upper part of the area along the main highway between Kirkuk city and Qara-Hangeer, has a length of 43.744km with a stream slope of about (11.9 m/km). The second is located at the southeastern part of the area and has a length of 31.688 km with a gradient of 18.3 m/ km (Fig.7). Both streams are assigned to order four. Watersheds are delineated automatically to 24 catchment watersheds, and the area of each watershed was estimated (Fig.9). The Pour points of the inlet and outlet of the flowing watershed were selected (Fig. 10).

Applying the equation based on the annual rainfall average, which is equal to 334.33 mm, the amount of runoff is calculated by compensating the CN total value and the annual rainfall average in the equation 2. The result shows that the CN value of the basin is high; indicating the potentiality of a high rate of surface runoff (Manhi and Alkubaisi, 2021). The total value of water surplus is 190.2 mm forming 26.88% of the total annual rainfall, such value can be used to determine the recharge volume for groundwater after subtracting about 100mm from the total water surplus (Thorntwaite and Mather,1957), and surface runoff values.

The surface runoff (SR) was calculated of this basin using an equation based on experimental work by Sogreah (1983) as follows:

$$SR \text{ (mm)} = 0.167 \times [P \text{ (mm)} - 180] \quad (5)$$

Where:

SR = Surface runoff (mm),

P = Total annual rainfall (mm).

$$SR = 0.167 \times [334.33 - 180] = 25.77 \text{ mm}$$

$$SR\% = (25.77/334.33) \times 100 = 7.708 \% \text{ of the total rainfall}$$

Hence, the total runoff depth from the annual rainfall is equal to 167.03 mm/year. So the annual volume of water that can be harvested from the studied area is about $12.99 \times 10^6 \text{ m}^3$ for the studied period (1995-2020). Several temporary check dams, could be built on the first-order streams where the gradient is about 11-18m/Km. Table4: list some of the suggested suitable places for the building of temporary dams with a height of (1-1.5) meters on the cross- section of the valley while construction of one or two semi-permanent check dams was suggested to be built, at the head of second or third- order stream, with a maximum width, of such dams of about 3-5 meters.

Table 4. The suggested places for temporary and semi-permanent check dams at the studied area

Location / type of check dam elevation	Site Coordinates		Depth of the valley	Width of the valley
	East	North		
(m)				(m)
Qara-hanjir/temporary check dam 810	44° 38' 30"	35°28' 50"	16	9.6
Shekh jikri /temporary check dam 838	44° 41' 31"	35°28' 30"	11	7.4
Qara Hassan/temporary check dam 816	44° 37' 50"	35°24' 45"	6.5	11.8
Mamle (semi-permanent dam) 640	44° 34' 45"	35°24' 50"	3.8	6.4
Qazan bulaq (semi-permanent dam) 438	44° 30' 10"	35°22' 40"	2.8	9.5

4. Conclusions

The study area is a part of a semi-arid region, suffering as the majority of Iraqi water basins from water shortage problems, especially in drought seasons. In this study, hybrid techniques use the combination of Remote sensing data and ArcGIS hydrological tools to delineate a watershed so as to select the promising areas of surface water harvesting in Qara-Hanjeer sub-basin (East Kirkuk), using monthly rainfall data and land use map. Results based on The NRCS Runoff Curve Number (CN) method reveal that 49.96 % of the total annual rainfall goes as Surface Runoff, contributing about $84.13 \times 10^6 \text{ m}^3$ of water to be harvested, but unfortunately, they are lost and unused. So, to manage that quantity of water, local check dams (temporary or semi-permanent) were suggested to be built across the valleys. The location was selected upon drainage system map and field survey. These dams are of low cost, reduces the loss of runoff water, improve agriculture via tourism and add impetus to the ecosystem programs in the city of Qara-Hanjeer.

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