Geoscience Research
ISSN: 0976-9846 & E-ISSN: 0976-9854, Volume 3, Issue 2, 2012, pp.-100-108.
Available online at http://www.bioinfo.in/contents.php?id=90

RAIN WATER HARVESTING AT EASTERN SINJAR MOUNTAIN, IRAQ

SALEH ZAKARIA, NADHIR AL-ANSARI, MOHAMMAD EZZ-ALDEEN AND SVEN KNUTSSON

Lulea University of Technology, Lulea, Sweden.
*Corresponding Author: Email- saleh.zakaria@ltu.se

Received: June 28, 2012; Accepted: July 18, 2012

Abstract- Iraq is facing water shortages and the problem is becoming more serious with time. The main water resources of Iraq (Tigris and Euphrates Rivers) suffer from severe reduction in their discharges due to construction dams on the both banks of Rivers inside Turkey and Syria. Agricultural land had been reduced drastically due to water scarcity. Despite this fact, none of the Iraqi farmers had yet used non-conventional techniques to augment water resources to overcome water shortage problems such as Rainwater Harvesting (RWH) technique.

The main aim of this research is to contribute to solving the problem of water shortage of Iraq by finding effective results in terms of saving significant runoff water for irrigation purposes, and therefore provide an academic effort as a tool for encourage and decision support for RWH in Iraq.

Macro RWH (large catchment area), was applied at East Sinjar Mountain in Iraq. The estimating volume of harvested runoff ranged (0.11-28.11)×10^6 m^3 calculated using the Watershed Modeling System (WMS) for the four selected basins together with total area of 435.14 km^2 for the study period of (1990-2009).

The results of estimating runoff volume showed that the runoff volume can be considered for irrigation practices especially in supplementary irrigation.

A linear programming technique was adopted to maximize the irrigated area. Three scenarios of irrigation level were chosen: supplemental irrigation (SI) 100% Satisfy full irrigation requirements (S1), deficit irrigation (DI) 50% of full irrigation requirements (S2), and deficit irrigation (DI) 25% of full irrigation requirements (S3). The resultant irrigated area ranged between 18-2646 for SI 100%, 58-41303 for DI 50%, and 27 -9543for DI 25% hectares respectively for all four selected basins together. These results reflect useful value of RWH and its influence to increase the irrigated area in the studied region.

Key words- Macro Rainwater Harvesting, WMS, Supplemental Irrigation, Sinjar, Iraq.

Citation: Saleh Zakaria, et al. (2012) Rain Water Harvesting at Eastern Sinjar Mountain, Iraq. Geoscience Research, ISSN: 0976-9846 & E-ISSN: 0976-9854, Volume 3, Issue 2, pp.-100-108.

Introduction

Several factors can affect agricultural production, but water is the most important factor [28]. Iraq's water resources is facing a big problem of water shortages, due to shortage of water supply from the main two rivers [5]. In addition the geographic location of the country in a dry area which is characterized by water scarcity and low annual rainfall (154 mm/year) [5] with uneven distribution [13]. This rainfall depth is not enough for successful agriculture production [26].

In dry areas more rainwater will be available to the crops when water harvesting is used. It increases the volume of water per unit cropped area, reduces dry effect and increases the productivity of rainwater [27]. Water productivity is the yield per unit of water used [28].

The most influential factor for improving agricultural production in dry areas is the water. Consequently, the strategy that should be adopted is represented by maximizing the yield per unit of water used and not the yield per unit of land. This will lead to more production of the harvest using less amount of the water. It should be mentioned however, that this strategy will take place if all other factors of improving agricultural production are taken in consideration [28].

The productivity of the rainwater can be significantly improved by applying a specific technique such as Macro RWH (large catchment area), based on availability of a surface reservoir. This will increase the water productivity as well as the agricultural land especially when RWH is combined with most efficient-proven irrigation technologies, such as supplemental irrigation (SI) and deficit irrigation (DI).

Oweis and Hachum (2003) indicated that adding limited amount of irrigation water for the rainfed agricultural area during critical stages of crop growth can improve not just the yield but water productivity as well [27].

The potential of enhancing crop production by using rainwater harvesting and management of soil fertility is widely cited [21]. The selected criteria have important role for the prosperity of the water harvesting [25]. It was found that, the conjunctive use of rainfall and limited irrigation water will greatly enhances the yields and water productivity [26].

RWH system gives a prospect for integrating several aspects of soil and water movement. Starting with fall of the rain, part of its water is directed either to deep percolation into the ground, or starts the process of runoff. Surface runoff can be captured into reservoirs and may be spilled over or released to lower agricultural area [31]. This integration leads to other factors that impact the process of runoff generation in the watershed. The adoption of throughfall in the rainfall-runoff analysis within sub-watershed is also essential in the planning and management of rainwater harvesting [31].

The rainfall-runoff relationship of watershed have been studied with different approaches such as water balance, agricultural non-point source, kinematic wave storm runoff, and Soil Conservation Service Curve Number (SCS-CN). However, SCS-CN method having its advantages over other above mentioned methods [16].

Adekalu, et al (2009) tested the impacts of macro and micro catchments runoff harvesting [3]. They stated that using harvested runoff water with supplemental irrigation which provides twin benefits of minimizing the impacts of dry periods, increasing the yields and improving the yields of smallholder farming systems. Mzirai and Tumbo (2010) conducted a study using macro RWH systems [22]. Their results showed that in macro-catchment RWH systems, water use efficiency increased crop production up to more than 20 kg ha^{-1} mm^{-1} compared to rain-fed system where water use efficiency can hardly reach 3 kg ha^{-1} mm^{-1}.

Kadam, et al. (2012) investigated a watershed located in semi-arid area, in India, using Arc-CN runoff tool, to identify the potential locations to create rainwater harvesting components [16]. They conclude that the average accuracy of Soil Conservation Service Curve Number (SCS-CN) method is about 86.25 %, taking into consideration accuracy of rainwater harvesting components. In addition, SCS-CN method is effectively proven as a better technique, which consumes less time, higher accuracy and ability to handle extensive data set as well as larger geographical area to identify preliminarily rainwater harvesting potential sites.

Khidir (1999) presented a nonlinear model for runoff hydrograph for a single storm in northern Iraq [18]. The goal is to estimate the runoff based on Soil Conservation Service method and the routing flow in the overland flow and channel. His results indicate that the model is capable in estimating the runoff hydrograph for ungauged watersheds

A study conducted by Agricultural Research Center in Iraq (IPA) and International Center for Agricultural Research in Dry Areas (ICARDA) showed that both yield and water productivity increased using supplementary irrigation (SI) in conjunction with rainfall, by using only 68 mm of irrigation water for rain fed wheat. The yield increased in one season from 2.16 T/ha to 4.61 T/ha i.e. more than 100% [2].

Experiments carried by ICARDA, in northern Syria using SI water to rain-fed crops, showed that applying 212, 150 and 75 mm of additional water to rain-fed crops receiving an annual rainfall of 234, 316 and 504 mm respectively, increased the yields by 350, 140 and 30% respectively over that of rain-fed crops. The effect of SI was on both the yield as well as on water productivity. Using limited amounts of SI with rainwater conjunctively, leads to improved productivity of both irrigation water and rainwater. In the dry areas the average rainwater productivity of wheat grains is up to 0.35 kg/m^3 and may increase to 1.0 kg/m^3 i.e. about 300% by improved management and rainfall distribution. The results showed that 1 m^3 of water applied as SI at the suitable time might produce more than 2 kg of wheat grain over that irrigated by rainfall only [27].

In northern Iraq, 284 farms were used to study the impact of SI on the wheat yield. The results showed that SI increased wheat yield by 100% [32]. It also indicated that large, medium, and small farms have different potentials for improving their level of water-use efficiency by 28, 19 and 23 % respectively.

Haji (2010) had applied her model on watersheds in Northern Iraq for estimating excess rainfall based on two methods, the first is Phi index (Φ index) method and the second is Natural Resource Conservation Service (NRCS) method [15]. The results of her model indicated that the Natural Resources Conservation services method can be applied to estimate excess rainfall for ungauged watersheds based on watershed characteristics and rainfall data.

In Iraq, water harvesting techniques are not used yet. It is hoped that this study will lead to encourage farmers to use these techniques.

It is believed that rain water harvesting will be one of the solutions to overcome water shortages problem in Iraq.

Study Area

The study area (Eastern Sinjar District) (Fig. 1A) is located within Nineveh province in northwest Iraq about 84 km of Mosul center. It is surrounded from the north by Al-Jazeera Irrigation Project, at the south by some hills with average height up to 100 meters, at the west by Sinjar Mountain with its highest peak having an elevation of 1400 meters (a. s. l.) and the extension Province of Nineveh from the east.

The average annual rainfall obtained from (4) meteorological stations (Rabiaa, Sinjar, Tal Afar and Mosul) (Fig. 1B) is about 325mm for the study period 1990-2009 (Fig. 2).

The rainy season start in November and nearly ends in May. During this season, the excess rain water (runoff) flows in the valleys from the hills toward north and east. Maximum monthly evaporation is usually recorded in July and reaches 563.4 mm. The value drops to 57.4 mm in December. Water consumption for the wheat crop is ranging from 26.7 mm in December to the 197.6 mm in May [7].

The main crops in the study area are wheat, barley in additional some summer vegetables.

Buringh (1960) classified Iraq's soil into eight types, two of which represent the soil of the study area [9] (Fig. 3). The first is brown soil which covers most of the study area, known as type 35 according to the soil map of Iraq, and characterized by pH>7 and organic matter of 1-2 % the soil deep > 2 m and consists of silt clay and silt clay loam [2]. The second type of soil is lithosolic soils in sandstone and gypsum soil type 31 according to the soil map of Iraq, which cover the most Upland areas and hills southern study area.

Fields observation indicate that, the catchment area of selected basins, contains three basic zone cultivated land, pasture land with of poor to good condition, and land covered by exposures of hard rocks.

For the selected dams' locations, and to ensure minimum evaporation, the cross section of the valleys were carefully chosen to minimize surface area of their reservoirs.

The heights and lengths of the dams were taken into consideration to minimize the construction cost of dams.

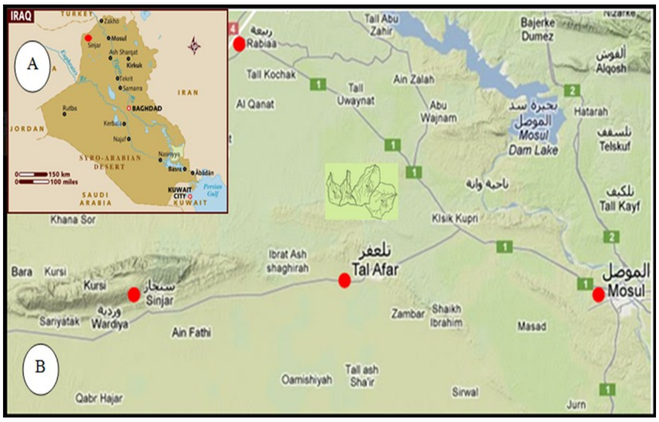

Fig. 1- (A) Map of Iraq shows the Sinjar District at North West of Iraq, the red spot (*Source : lonelyplanet.com*). (B) Enlarged Map of Sinjar District and the surrounding areas, show the four basins of the study area surrounded by four climatic stations Rabiaa, Sinjar, Tal Afar and Mosul (red spots) (*Source : Google map*)

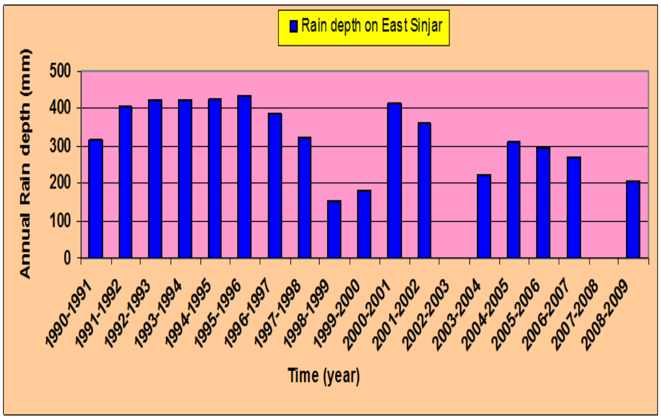

Fig. 2- Mean annual rainfall for the period 1990-2009 in Eastern Sinjar District

Watershed Modeling System (WMS)

The main purpose of the Watershed Modeling System (WMS) is to set up mathematical watershed hydrologic models for engineering purpose [23]. WMS has the ability to simulate the rainfall-runoff process for different conditions based on inside standard models.

Large group of researchers used WMS to simulate the rainfall-runoff process using one of the inside standard models [24,29,34]. They used standard computer models of HEC-1. Erturk, et al (2006) and Abu Sharkh (2009) used standard computer models of Rational Method [1,12]. While Clinton Country Board of Commissioners (CCBC) (1995), Al-Ansari, et al. (2012) and Zakaria, et al. (2012) used computer model TR-20 [4,11,35]. This model is widely used [19].

The land use map (Fig. 4), was obtained for the selected basin based on the map produced by Remote Sensing Center, University of Mosul [6].

Runoff was simulated using WMS with computer model TR-20 depending on the SCS runoff curve number (CN) method. Details of the selected basins with reservoirs properties are listed in Table 1. The input data were total area of individual selected basin (m^2) and its CN values and daily rainfall depth (mm). The output was daily runoff (m^3).Using the topographic features of the study area, four basins (Fig. 4) were selected to be used for calculating the runoff.

Table 1- Details of the selected basins with reservoirs properties

Details	basin No.1	basin No.2	basin No.3	basin No.4
Curve number (CN)	77	79	78	82
Basin area (km^2)	63.32	65.81	151.77	154.25
Average basin slope %	0.9	0.8	1.1	1.2
Mean basin elevation (m)	343	455	426	435
Max. reservoir capacity($10^6 m^3$)	0.756	0.265	0.872	0.846
Max. dam length (m)	850	636	904	763
Max. dam height (m)	2.5	3	4	6

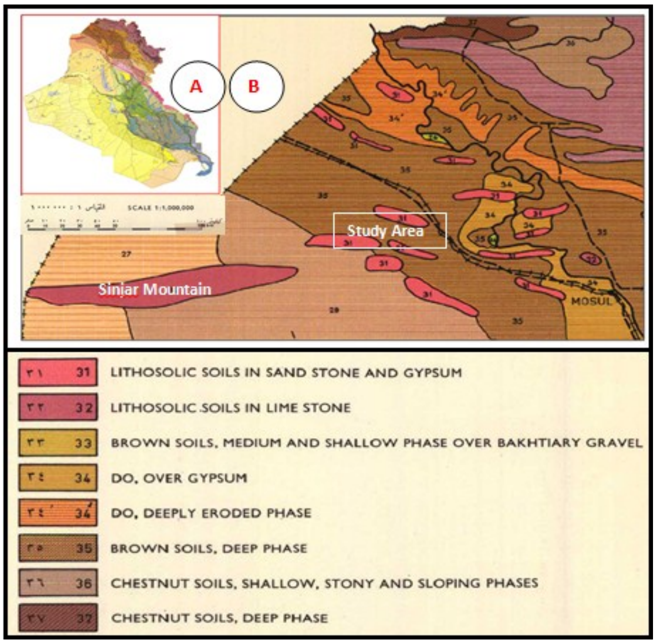

Fig. 3- (A) soil map of Iraq / directorate general of agricultural research and projects/ ministry of agricultural/ Baghdad. (B) Enlarge map shown soil type of the study area at northwest of Iraq.

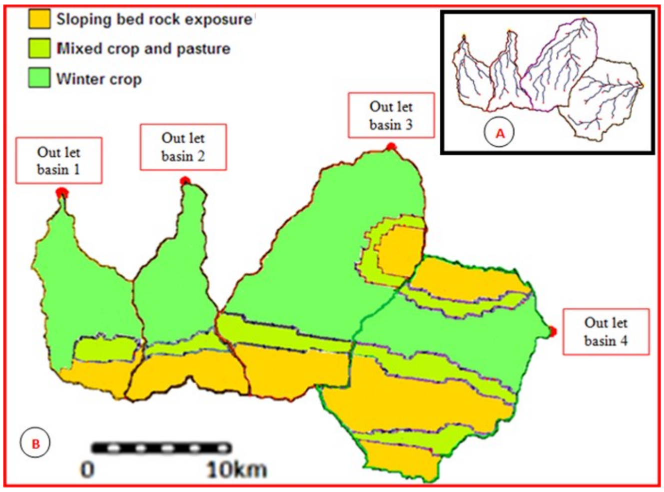

Fig. 4- (A) The four selected basin at east sinjar. (B) Land use map for the four selected basin at east sinjar

Runoff model

Daily rainfall data on Eastern Sinjar area had been used to estimate the runoff for each single storm by applying WMS software. The considered runoff was based on SCS Curve Number (CN) method. CN method is widely used by many researchers [30].

For the current research, four basins were selected to harvest the rainwater in the study area. The curve number values are estimated for each basin depending on the land use, land cover and soil type.

The weighted average CN values were estimated depending on area of specific land use as a percent of total basin area, as well as, calibrated for antecedent moisture condition (AMC) for dry, average, and wet conditions according the antecedent rainfall depth for the five days.

Dry condition will be achieved if the total five days rainfall depth was less than 35 for growing and 12.7 mm for dormant season. Wet condition will be achieved if the total five days rainfall depth is greater than 53 mm for growing and 28 mm for dormant season respectively [10].

CN value was modified for dry and wet conditions using the following equations:

$$CN_I = \frac{4.2 * CN_{II}}{10 - 0.058 * CN_{II}} \quad (1)$$

and

$$CN_{III} = \frac{23 * CN_{II}}{10 + 0.13 * CN_{II}} \quad (2)$$

In which:

CN_I : is the curve number for dry condition.

CN_{II} : is the tabulated curve number (Soil Conservation Service 1972, chapter 9, Chow Ven Te, 1988, chap 5).

CN_{III} : is the curve number for wet condition.

This method was chosen because it is suitable for application in the studied area and gave good results[15,18].

Curve Number method depends on one main coefficient (CN), which represent the characteristics of the catchment area, soil type and classification, land use and methods of treatment, the condition of the surface hydrological and soil moisture content at the fall of rain. It is reliable and easy to apply, and was applied in many countries of the world [30].

The disadvantages of CN method are that, it is initially developed for agricultural regions before extended to be applied on urban regions and runoff should be with negligible base flow when estimating excess rainfall. In addition the method is sensitive to curve number value for the areas having low curve number, and/or low rainfall depth [30].

Despite the fact that there are disadvantages on CN method but they are inapplicable on the studied area due to its nature (agricultural land), there is no base flow according to the runoff flow and the curve number is not low in its value (Table 1).

The runoff model was calibrated using actual rainfall and runoff measurements [18]. The details of the calibration process are discussed in details by Al-Ansari, et al. (2012) [4].

Supplemental Irrigation model

Using Matlab software, the irrigation water requirements for the wheat crop for supplemental irrigation (SI), can be estimated for each day of the growing season. The estimation is based on rainfall depth, soil water storage and crop water requirements using the following equation:

RID = *CONUSE* - *AVW,* when *CONUSE* > *AVW* (3)

In which:

RID = required irrigation depth (mm).

CONUSE = the consumptive use for the wheat crop (mm).

AVW = available depth of water in the root zone (mm).

If the consumptive use for the wheat crop was less than available depth of water in the root zone, then the required irrigation depth is equal to zero.

The available water in the root zone can be calculated from :

$$AVW = \frac{PAW * TAW}{100} \quad (4)$$

In which:

PAW = percentage of the available water or percentage of the depletion, consider= 50% [20].

TAW = total available depth of water in the root zoon (mm).

Total available depth of stored soil water depends on plant root depth. The available water capacity of the soil (AWCS) (mm/mm) was identified based on soil type. This is given by the Ministry of Agriculture, Food and Fisheries (2002). It can be calculated from the following formula:

$$TAW = AWCS * RZD \quad (5)$$

In which:

AWCS = available water capacity of the soil (mm/m).

RZD = root zone depth (mm).

The depth of the root zone *RZD* was calculated using equation (6) developed by Borg and Grimes (1986) [8] as quoted by Gregory, (2006) [14]:

$$RZD = RDm * (0.5 + 0.5 * Sin(3.03 * (DAP / DTM)) - 1.47) \quad (6)$$

In which:

DAP = current day after planting.

RDm= maximum rooting depth (mm).
DTM= number of days to maturity.
Sin = a trigonometric function.
In this research, deficit irrigation (DI) of 50% and 25% of full irrigation requirements is defined as the 50% and 75% of the total amount of water required for the crop consumptive use respectively.

The Optimization Model

A linear programming computer model technique (based on Matlab software) has been used to optimize crop area that could be irrigated by supplemental (100% crop water requirement satisfaction) and deficit irrigation (50% and 25%) of full irrigation requirements depending on total runoff volume that is collected in a reservoir for each basin.
The objective function is to maximize the total cropped area (Acrop), which could be irrigated using the harvested runoff water volume that was collected in the individual reservoir.

$$MAX(ObjFunc.) = (A) \tag{7}$$

In which:
ObjFunc. = value of objective function.
A = irrigated area.
The objective function is subjected to some constraints, such as the volume balance equation, for daily intervals which can be expressed as follows:

$$(S_v)_{j+1} = (S_v)_j + (I_n)_j - (O_t)_j \tag{8}$$

In which:
$(S_v)_{j+1}$ =storage volume at the end of time interval ($_j$) (m^3).
$(S_v)_j$ =volume of storage at the beginning of time interval ($_j$) (m^3).
$(I_n)_j$ =volume of inflow to the reservoir during the time interval ($_j$) (m^3).
$(O_t)_j$ =volume of outflow during the time interval ($_j$) (m^3), i.e, irrigation water, volume of evaporation, and spill water.

The outflow volume $(O_t)_j$ at the time interval ($_j$) can be expressed as follow:

$$(O_t)_j = (D_R)_j + (E_{Vres})_j + (S_p) \tag{9}$$

In which;
$(D_R)_j$ = volume of demand i.e. irrigation water at time interval($_j$) (m^3).;
$(E_{Vres})_j$ = volume of evaporation loss from the reservoir (m^3).
(S_p) = volume of spilled water through time interval ($_j$) (m^3).
The constraints of storage capacity are:

$$(S_V)_j \geq V_{Min} \quad _j= 1,2,3\dots n \tag{10}$$

And $$(S_V)_j \leq V_{Max} \quad _j= 1, 2, 3\dots n \tag{11}$$

In which:
V_{Min} = minimum storage capacity of the reservoir (m^3).
V_{Max} = maximum storage capacity of the reservoir (m^3).
n = number of time intervals.

Model Application

WMS was applied for each single rainfall storm for the four selected basins to find out the runoff as a volume of water which can be collected and stored in the reservoirs.
The locations of the reservoirs were previously carefully chosen. Then, their water is to be used for irrigation process in the study area.
Three irrigation scenarios were used assuming supplementary irrigation 100% of crop water requirement (S1), and two Deficit Irrigation 50 % (S2) and 25 % (S3) of full irrigation requirement to estimate the daily irrigation water requirements based on rainfall, soil water depth and planting stage.
The growth season in the studied area is almost about six months (170 days). It starts November-December and ends May-June. The growing season for wheat varies from about 100 to over 250 days in the Mediterranean basin [33].
The start of wheat growing season begins when the rainfall on the basins reaches a proper depth 10±2 mm.
The optimization model was applied considering the three irrigation scenarios and the runoff volume that was stored in the reservoirs to find out the maximum cropped area (A) for each reservoir for a period of 17 agricultural seasons during the years 1990-2009. Two seasons were neglected (2002-2003 and 2007-2008) due to missing data.
The most important factors that influence the total cropped area (Acrop) is the availability of sufficient rainfall water with good spatial distribution over the season. In such a case, water can be stored in the reservoirs and used to irrigate the crop.

Results and Discussion

Fig. 2 shows the seasonal rainfall for the period of 1990-2009 at Eastern Sinjar district
The annual rainfall during the study period reached 435mm in 1995-1996 and drop to 150mm in 1998-1999 with mean of 325mm which reflect the characteristic of arid and semi-arid region. Such values are insufficient to grow economical crop according to Oweis, et al (1999) [26].
The total calculated volume of harvested runoff (Fig. 7) from all the basins was stored in the assumed reservoirs according to their capacity (Table 1).
It is very important to have good distribution of the rainfall events along the growing season rather than having high rainfall storms not well distributed Zakaria S. (2012) [35]. In spite of the fact that not all rainfall storms produce runoff, but even with that the weak rain storm is very important for estimating the SCS curve number where it effect the corresponding value of CN and increase its value from dry to wet and this is very important for runoff calculations.

Some season has high rainfall storm, in case of successive and sequential matter. In such circumstances the harvested runoff may fill the reservoirs, especially if they limited with their capacity, so the following runoff event will be of no use in such cases, where most of the water will be lost through spillway of the dams.

Other season has suitable to large volume of rainfall water, but not in the right suitable time for irrigation. Such events might take place during the second half of the growing season. This means that all the harvested runoff of these rainfall events will be of no use for irrigation process to the cop.

The results showed that the most influential factors on the harvested runoff volume are the size of the catchment area, the distribution and amount of rainfall, the size of the reservoirs and the important effect of CN values.

For the growing season 1999-2000, due to the rainfall conditions, the harvested runoff volume was at its minimum value. Accordingly, that storage in Dam's reservoir of basin No. 3 was 3.45 $\times 10^3$ m^3. While in the season 2000-2001, the rainfall conditions were so good that gave maximum harvested runoff volume in Dam No. 4 that reached up to 11411.0×10^3 m^3. This is also reflecting the fact that Dam no. 3 reservoir is the smallest while dam no. 4 is the largest in their catchment areas. Accordingly, the minimum and maximum harvested runoff for the entire four basins together reached up to 118.41×10^3 m^3 (season of 1999-2000) and 28187.61×10^3 m^3 (season of 2000-2001) respectively.

The huge volume of water harvested during 2000-2001 can be attributed to six interrelated and integrated reasons. The first is the heavy rainfall storm within short time intervals produced suitable amount of harvested runoff. Secondly, the weakly rainfall storms in between the heavy rainfall storms prevented ground surface to be dry. Thirdly the above two points help to maintain antecedent moisture conditions (AMC) at high value. Fourthly, that high value of (AMC) help to produce high value of CN during increasing its value from dry and normal values to its wet value when the accumulate rain water each 5 days exceeds 27.94, and 53.34mm for dormant, and growing seasons respectively according to Chow, et.al. (1988) [10]. Fifthly wet value of CN will strongly support rainfall especially weakly rainfall storms to produce more runoff amounts. Sixthly all above will work together to reduce the losses of rain water by infiltration process through the ground surface and lead to the accumulation of runoff volume on the ground surface of the basins then directed toward the reservoirs by gravity.

The results show that the maximum volume of harvested runoff had been produced during the season of 2000-2001 of annual rainfall of 415.5 mm. The volume of harvested runoff that can be reached and part of it stored in the reservoir No. 1 through No. 4 are 3532.3, 4023.7, 9220.6 and 11410.9(×10^3 m^3) respectively, where the summation volumes of theses harvested runoff reach up to 28187.6×10^3 m^3 representing the maximum annual runoff volume from the 4 basins together along the study period. The remaining runoff was lost through spillway of dams. These quantities of water even they are limited in their amount but, can be used for the purpose of recharging ground water. Fig. 5 reflects the explanation given above.

The minimum runoff volume had been achieved during the season 1999-2000, where the annual rainfall was 182 mm. For this value, the volume of stored water in the reservoirs was 5.67, 5.67, 3.45, and 103.61(×10^3 m^3) respectively as an individual reservoir. The total volume of all harvested runoff reach up to 118.41×10^3 m^3 representing the minimum annual runoff volume from the 4 basins together along the study period.

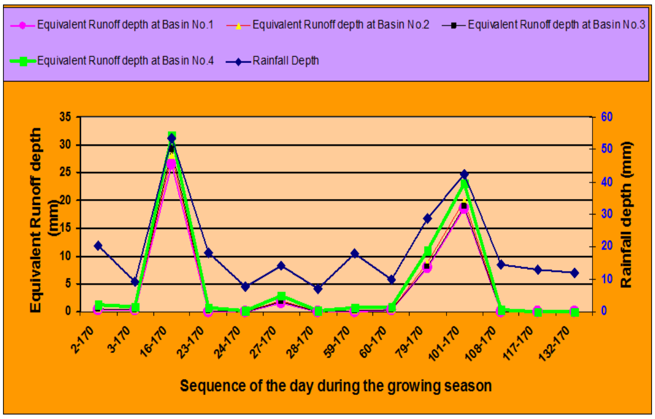

Fig. 5- Rain fall depth and Equivalent Runoff depth for the four Basins during the season 2000-2001

Fig. 6 shows the rainstorms during the season 1999-2000. The rainfall events produced only three runoff evidences, on the second, the twenty-third and on the thirty-ninth day of growing season of 170 days in its long.. It should be noted that due to weak rainfall depth during this season and according to the antecedent rainfall depth for the five days, the CN value did not reach its wet value which was reflected on the amount of runoff that had been produced.

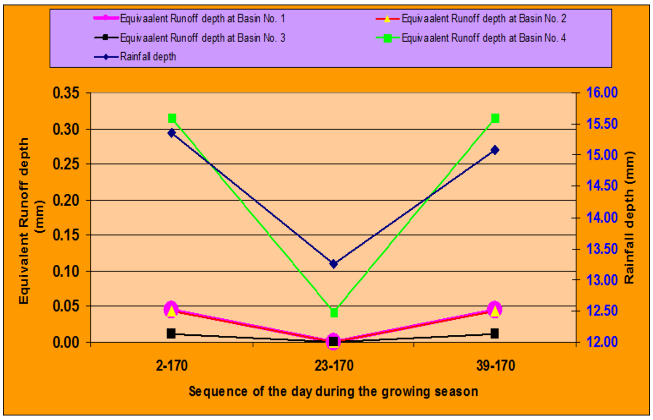

Fig. 6- Rainfall depth and Equivalent Runoff depth for the four Basins during the season 1999-2000

The average annual rainfall as a value may not reflect the reality of the harvested runoff events that would result from these averages annual rainfall, the most important factor that effects the situation is the distribution of rainfall and its impact on the value of the curve number (CN), in addition to changing its values among dry, normal and wet conditions. For example this can be noticed during the season of 1995-1996 of maximum annual rainfall depth (435.6 mm) along the study period, but this season did not achieve the maximum volume of harvested runoff. The same is true during the dry season of 1998-1999 of minimum annual rainfall depth of 150 mm where did not achieve the minimum volume of harvested runoff.

The results showed that using the technique of deficit irrigation lead to increase the irrigated area.

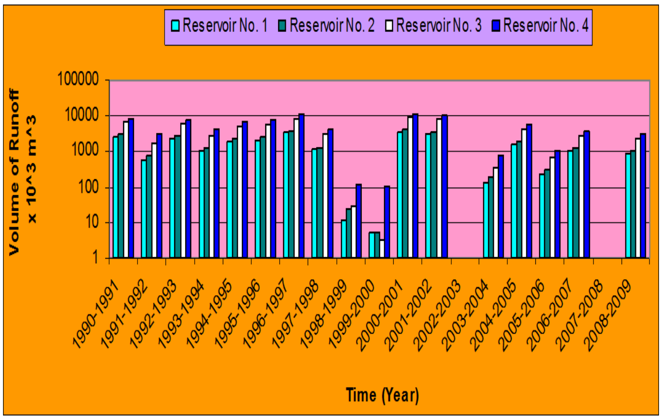

Fig. 7- The annual runoff volume for reservoirs, 1, 2, 3 and 4 for studied period

For the scenario of supplemental irrigation (SI) 100% of full irrigation requirements (S1), the maximum irrigated area was 852 hectares during the season (1994-1995) by using the harvested runoff water that had been stored in reservoir No. 3. While the minimum irrigated area was 1.1 hectares during the season (1998-1999) by using the harvested runoff water that had been stored in reservoir No. 2 (Fig. 8A).

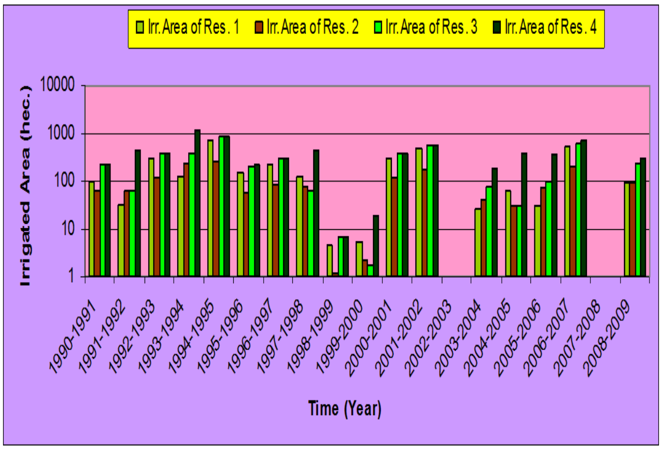

Fig. 8A- Resultant irrigation area for reservoirs 1, 2, 3, and 4 for studied period (scenario 1)

For the scenario of deficit irrigation (DI) 50% of full irrigation requirements (S2), the maximum irrigated area was 15633.91 hectares during the season (1994-1995) using the harvested runoff water that had been stored in reservoir No. 3. While the minimum irrigated area was 1.52 hectares during the season (1999-2000) using the harvested runoff water that had been stored in reservoir No. 3 (Fig. 8B).

In the case of the scenario of deficit irrigation (DI) 25% of full irrigation requirements (S3), the results showed that the maximum irrigated area was 3080.44 hectares during the season (1994-1995) using the harvested runoff water that had been stored in reservoir No. 4. While the minimum irrigated area was 1.27 hectares during the season (1999-2000) by using the harvested runoff water that had been stored in reservoir No. 3 (Fig. 8C).

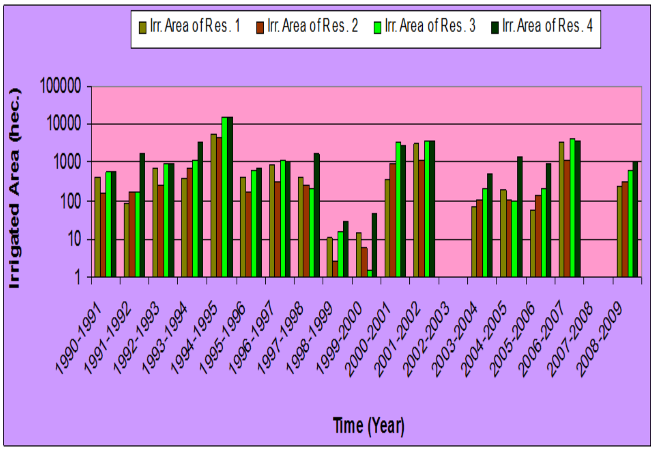

Fig. 8B- Resultant irrigation area for reservoirs 1, 2, 3, and 4 for studied period (scenario 2)

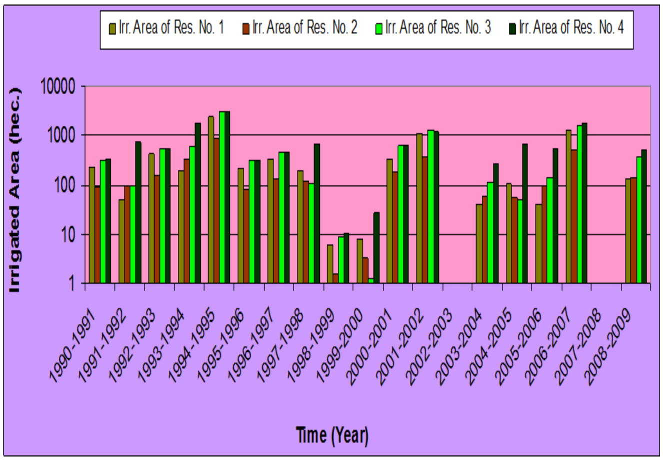

Fig. 8C- Resultant irrigation area for reservoirs 1, 2, 3, and 4 for studied period (scenario 3)

The application of RWH for the four selected basins east Sinjar indicates that the total volume of harvested runoff for all basins for the study period that ranged from 118.41×10^3 m^3 (1999-2000) to 28187.61×10^3 m^3 (2000-2001) (Fig. 9). Using the above harvested runoff water for supplemental irrigation scenarios for all basins, gave irrigated areas for SI as 18.66-2646.27 (hectares), for the scenario S2 the results were 58.86-41303.13 (hectares) and 27.80-9543.98 (hectares) for the scenario of S3, where the minimum value of irrigated area was achieved during the season 1998-1999 while the maximum was during the season 1994-1995 (Fig. 9).

It should be noted that, maximum rainfall season is not necessarily to produce the maximum runoff season. For east Sinjar District the maximum rainfall was during 1995-1996, while the maximum runoff was during 1995-1996. The reason for the incompatibility of the maximum rainfall season with the maximum runoff season is the distribution of rainfall events.

Generally, The resultant irrigated area (Fig. 8A, 8B and 8C) show that using deficit irrigation scenarios of S2 and S3 lead to increased cropped area compared with that when using supplemental irrigation scenario of S1 of 100% crop water requirement satisfaction.

The average percent of increasing in irrigated area using scenario S3, instead of scenario S1 reached up to 74%, while for using scenario S2 reached up to 334%. The results of the three scenarios which were used indicate that scenario S2 can be more beneficial than scenario S1 and S3.It should be mentioned however that, the increase of the irrigation areas by using deficit irrigation is coupled with reduction of wheat grain yield per unit area due to the water reduction of irrigation. Despite this fact that, reduction of wheat grain yield per unit area will be compensated by increasing the total irrigated area.

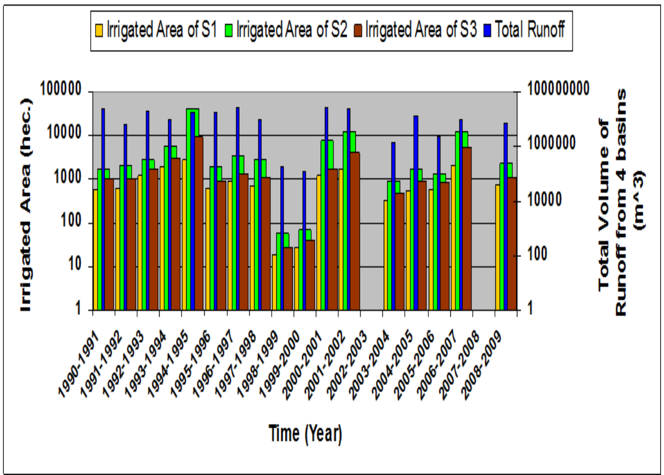

Fig. 9- Total irrigation area resulting from the 4 selected basins together for scenarios S1, S2, and S3 and the total volume of harvested runoff for all basins together for the studied period

Conclusion

Iraq is facing a big problem due to the shortages in its water resources. This problem had greatly affected the agricultural activities and huge areas were converted to desertic areas.

Iraqi farmers are not using the new techniques such as rainwater harvesting that can be suitable for the climate of Iraq to save amount of water for irrigation practices which maximize the irrigated area.

Application of RWH will provide a new source for water. Therefore the technique of Macro RWH has been tested in east of Sinjar, Northwest Iraq, to discover the capability of the area for rainwater harvesting.

Daily rainfall data for the period 1990-2009 on East Sinjar area had been used in application of WMS. The results show that considerable amount of yearly runoff can be harvested. The volume of water that can be harvested for all selected basins east Sinjar, ranged 118-28187($\times 10^3$ m^3), during minimum season (1999-2000) and maximum season (2000-2001). This indicates that the runoff volume can be considered for supplemental irrigation practices.

To maximize irrigated crop area, linear programming optimization technique was used depending on three different irrigation scenarios of crop water requirement satisfaction i.e. supplemental irrigation of 100%, deficit irrigation of 50% and 25% of full irrigation requirement respectively. The results indicated that the total minimum irrigated crop area for all basins is about 18, 58 and 27 (hectares) for the three irrigation scenarios respectively for the considered period. While the total maximum irrigated crop area for all basins is about 2646, 41303 and, 9543 (hectares) for the three irrigation scenarios that had been used respectively for the considered period.

There was an average increase in irrigated area reach up to 74% in the using scenario S3 instead of scenario S1. While for using scenario S2, the average increase in irrigated area reach up to 334%. The results of the three scenarios used indicated that scenario S2 can be more beneficial than scenario S1 and S3. This also indicates that rainwater harvesting can reduce the effect of water shortage on the country.

References

[1] Abu Sharkh M.S. (2009) *Thirteenth International Water Technology Conference*, IWTC, Hurghada, Egypt.

[2] Adary A., Hachum A., Oweis T. and Pala M. (2002) *International Center for Agricultural Research in the Dry Areas*.

[3] Adekalu K.O., Balogun J.A., Aluko O.B., Okunade D.A., Gowing J.W. and Faborode M.O. (2009) *Agricultural Water Management.*, 96, 1502-1508.

[4] Al-Ansari N.A., Ezz-Aldeen M., Knutsson S. and Zakaria S. (2012) *J. Hydrologic Engineering*.

[5] Al-Ansari, N.A. and Knutsson S. (2011) *J. Advanced Science and Engineering Research*, 1, 53-67.

[6] Al-Daghastani H.S. (2008) *Remote Sensing Center*, Mosul University, Iraq.

[7] Al Khalidy Kh. A. (2004) *Preparation of Geographical Information System for the South Jazira Irrigation Project with the aid of Remote Sensing Data, M.Sc. thesis*, Mosul University.

[8] Borg H. and Grimes D.W. (1986) *An empirical description*. Trans ASAE 29, 194-197.

[9] Buringh P. (1960) *Ministry of Agriculture, Agricultural Research and Projects*.

[10] Chow Ven Te, Maidment, David R., Mays, Larry W. (1988) *Applied Hydrology*, McGraw Hill, NY., 277, ISBN 0-07-100174 -3,147-151.

[11] Clinton country Board of Commissioners (1995) *Storm water management plan*, Pennsylvania, USA.

[12] Erturk A., Gurel M., Baloch M., Dikerler T., Varol E., Akbulut N. and Tanik A. (2006) *J. Environ. Sci. Health A Tox. Hazard. Subst. Environ. Eng.*, 41(9), 2045-56.

[13] FAO (1987) *Improving Productivity of Dry land Areas.*

[14] Gregory P. (2006) *Plant Root, Growth, Activity and Interaction with Soil*, 9600.

[15] Haji Ali E. (2010) *Application of Different Models for Development of Instantaneous Unit Hydrograph for Solag Watershed. M.Sc. Thesis, University of Duhok, Iraq*.

[16] Kadam A.K., Kale S.S., Pawar N.J., Sankhua R.N., Pawar N.J. (2012) *Water Resource Management*.

[17] Kassam A.H. (1981) *Soil Water and Nitrogen*, 1-29.

[18] Khidir K. (1999) *Determination of a Mathematical Model for Estimating Surface Runoff for Some Watershed Northern Iraq. PhD. Thesis*, University of Mosul, Iraq.

[19] Kumar D. and Bahattacharjya R.K. (2011) *Distributed rainfall runoff modeling using WMS and HEC-HMS.*, 56.

[20] Ministry of Agricultural, Food and Fisheries (2002) *Water Conservation Factsheet*, British Colombia, Canada.

[21] Miriti J.M., Esilaba A.O., Bationo A., Cheruiyot H.K., Kathuku A.N. and Wakaba P. (2011) *J. of Biomedical and Life Scienc-*

es, 2, 473-480.
[22]Mzirai O. and Tumbo S. (2010) *J. Animal & Plant Sciences*, 7 (2), 789- 800.
[23]Nelson E. J., Jones N.L. and Miller A.W. (1994) *J. Hydraulic Engineering*, 20, 298-312.
[24]Nelson E.J, Christopher M.S. and Zhao B. (1999) *Water Resources Planning and Management Conference*.
[25]Ouessar M., Sghaier M., Mahdhi N., Abdelli F., De Graaff J., Chaieb H., Yahyaoui H. and Gabriels D. (2004) *J. of Environmental Monitoring and Assessment,* 99, 127-140.
[26]Oweis T., Hachum A. and Kijne J. (1999) *International Water Management Institute*, SWIM 7, Colombo, Sri Lanka.
[27]Oweis T. and Hachum A. (2003) *Improving water productivity in the dry areas of West Asia and North Africa, Water Productivity in Agriculture: Limits and Opportunities for Improvement*, Wallingford, UK, 179-197.
[28]Oweis T. and Hachum A. (2006) *J. Agricultural Water Management,* 80, 57-73.
[29]Owens B. (1998) *http://www.owenswatershedplanning.com/Malibu/malibu.html*.
[30]Ponce V.M. and Hawkins R.H. (1996) *ASCE J. Hydrologic Engineering*, 1(1), 11-19.
[31]Rogelio N. Concepcion, Samuel M. Contreras, Wilfredo B. Sanidad, Arnulfo B. Gesite, Gina P. Nilo, Karen A. Salandanan, Katherine M. Manalang, Sharon V. de Vera (2006) *Enhancing multi-functionality of agriculture through rainwater harvesting system*, Paddy Water Environ, 4, 235-243.
[32]Shideed K., Oweis T. and Mohammad E. (2003) *An empirical Case study of wheat production in Iraq*, United Nations New York.
[33]Smith R. and Harris H. (1981) *J. Plant and Soil,* 58, 31-57.
[34]Sonbol M.A., Mtalo F., EL-Bihery M. and Abdel-Motteleb M. (2001) *Watershed model of wadi sudr and wadi al-arbain in sinai, egypt. UNESCO, Office in Cairo, Natural Sciences, Hydrology Programme*.
[35]Zakaria S., Al-Ansari N.A., Knutsson S. and Ezz-Aldeen M. (2012) *J. Purity, utility reaction and environment,* 1(3), 121-141.