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Rainwater Harvesting Using Recorded and Hypothetical Rainfall Data Scenarios

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Abstract

Macro Rainwater Harvesting (RWH) under recorded and forecasting rainfall scenarios helps to overcome the water shortage problem.
Eastern Sinjar District-Iraq had been investigated for the potential of RWH with a catchment area of four basins. Three recorded rainfall scenarios (S1, S2, and S3) were diagnosed representing seasons of the maximum, minimum and average weekly rainfall events for the period 1990-2011. Forecasting the rainfall depths for the same catchment area were estimated depending on Box-Jenkins methodology to build Autoregressive Integrated Moving Average (ARIMA) models for weekly rainfall data for the period 2012-2016. Three forecasting rainfall scenarios (S4, S5, and S6) were diagnosed to represent the seasons of the maximum, minimum and average weekly forecasting rainfall events. The results of these scenarios were compared with an average area to be irrigated obtained from the results of 19 years record. The results indicated that in wet years RWH technique with supplemental irrigation help to give total irrigated area larger than a total specified average irrigated area. In average and dry years, the amounts of the additional needed water were estimated to irrigate the total areas that should be increase in order to satisfy the specified average irrigated area.

Keywords: Rainwater Harvesting, rainfall Forecasting, Sinjar District, Iraq.

1 Introduction

Rainwater harvesting (RWH) is defined as a method for inducing, collecting, storing, and conserving local surface runoff for an agricultural purpose in arid and semi-arid regions [1]. The most important factors that effect in practicing water harvesting are the distribution and intensity of the rainfall, the runoff properties of the catchment area, soil water storage, reservoir's capacity, the agricultural crops, available technologies and socio-economic conditions [2].

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The aim of the RWH system is supplying a new source of water to the region. The main components of RWH systems for agricultural purposes in dry areas consist of the catchment area in order to collect the resulting runoff from rainfall storms, an earth dam with reservoir to store the harvested runoff, and effective irrigation system like supplemental.

Water harvesting systems have proven to be an effective technique in an arid and semi-arid region to achieve the most important goals of increasing crop yields and reducing cropping risk, making best use of available water resources, as well as using harvested water to recharge groundwater aquifers [3].

Despite the urgent need for RWH in Iraq, it has not been used so far [4].

There are only few experiments implemented in the macro catchment RWH systems [5]. For example, the experiments of Bakari et al. [6] and Gowing et al. [7] implemented in macro catchment RWH systems using typical research station, where most conditions were been under control by the researchers.

Some researchers studied the performance of different kind of RWH systems, they concluded that they had good results to augment the crop yield [6, 7, 8, 9, and 10].

Nasri et al. [11] studied traditional macro-catchment water harvesting system of Tabias, in Tunisia. They conclude that: this system minimized flood risks by decreasing the local surface runoff that was collected from hill slope, which lead to reduce soil erosion hazards. The harvested water that was stored behind the Tabias requires not more than three days to supply (by infiltration) the soil water storage to allow planting vegetables during the following months. Even deep soil water storage will be utilized by the roots of fruit trees.

Adekalu et al. [12] studied both macro and micro catchment’s runoff harvesting. They stated that using supplemental irrigation with harvested runoff water give benefits of reducing the impacts of dry periods to the half, that lead to the increase the yield. Mzirai and Tumbo [5] concluded that the crop yield in semi-arid areas can be increased by using RWH systems; they noticed that water use efficiency can be increased up to more than 20 kg ha^{-1} mm^{-1} compared to a rain-fed system where water use-efficiency can hardly reach 3 kg ha^{-1} mm^{-1}.

A number of researchers have gone farther in the studying rainfall events where they studied forecasting rainfall to get some information that may help to be employed to service the society.

Number of researchers [e.g.13,14,15,16,17,18,19,20,21,22,23,24,25,26] studied the performance of Box-Jenkins (ARIMA) model methodology, and they developed ARIMA models in order to forecasting rainfall in their study areas. They conclude that Box-Jenkins methodology is an effective way for represent and forecast rainfall data.

It should be noted that, these forecasting rainfall data, are not guaranteed, but it significantly contributes to give an idea about the future rainfall that led to reduce the risk of adventure and avoid losing money in case of planted rain-fed farms during dry seasons, and the most important; it gives an early warning in the events of dry seasons that might take place in near future.

Iraq is part of West Asia and North Africa (WANA). Most of the agricultural area of WANA is rain-fed [27]. The rainfall in this region is characterized by a low amount with uneven distribution, the total quantity of rainfall is less than seasonal crop water requirements especially wheat and barley, which lead to some stages of soil-moisture shortages giving a very low result of crop yield [28].

Most of Iraqi agricultural lands are suffering from water shortage’s problems due to reduction the discharges of Tigris and Euphrates Rivers, effect of climatic changes, rising temperatures, rain retention, in addition to the bad planning and management of the water resources. Accordingly, huge farm's lands were converted to desert areas [29, 30].

Agriculture is the largest overwhelming consumer of water across the region [31] and therefore, the water shortages cannot be objectively analyzed nor adequately addressed without a thorough consideration of agriculture in the region [32]. RWH can save a good amount of water used for agricultural purposes, and the excess can even be used for artificial recharge of groundwater aquifers. This can minimize the water shortage problems in Iraq.

Research on water harvesting conducted by Al-Ansari et al. [33] and Zakaria et al. [4, 34], aimed to study a macro RWH to exploit harvested runoff for supplemental irrigation system in order to increase the wheat crop yield of the rain-fed farms by increasing the irrigated area.

These researches conducted on south; east and north Sinjar District respectively using (NRCS-CN) curve number method with Watershed Modeling System (WMS) to estimate direct harvested runoff from an individual rain storm which is stored in the reservoir. The harvested runoff volume was used in supplemental irrigation processes. The results indicated that there was a considerable amount of annual runoff. This reflects that the volume of harvested runoff can be used for supplemental irrigation process to increase the annual crop yield.

At east and north Sinjar District, three scenarios of supplemental irrigation were been used, one scenario of 100% of total irrigation requirement, and two scenarios of Deficit Irrigation (DI) (50% and 25% of total irrigation requirement) respectively, that lead to increase the irrigated area. The results showed that using the DI of 50% of total irrigation requirement can be more beneficial than other scenarios. All the reservoirs were operated as split units.

In southern Sinjar District, the topography of the area gives the possibility to use two scenarios of reservoir's operation. In the first, the reservoirs were operated as a split unit; while in the second, all reservoirs that located in one main basin were operated as one system.

The second scenario offers the possibility to move the water from the reservoir located upstream to a downstream reservoir in order to provide a space for storing new harvested runoff into the upstream reservoir, and to compensate for the reduced amount of water storage that may take place in downstream reservoir due to increasing water demand.

The results indicated that using the second scenario increased the irrigated area. The results are encouraging and in certain occasions, there was a surplus of water, which can be used for recharging the aquifers.

Most research mentioned throughout this study has relied on the historical recorded rainfall data, the mostly alone, in exploring the study of rain water harvest without considering future rainfall events.

Studies of rainfall forecasting help in planning agricultural water management that may lead to the best use of water resources by giving an idea expected for the coming seasons and provide some possible scenarios of future rainfall. It might give some indications about the intensity of rain-fed cultivation.

Box-Jenkins (ARIMA) methodology can be used as an appropriate tool to forecast weekly rainfall in a semi-arid region like eastern Sinjar District at Iraq for up-coming 5 years [35].

In this research, recorded and hypothetical rainfall data used to evaluate the quantity of water that can be harvested and used for agricultural purposes. The former highlights past events while the latter will give an idea about expected events. This work will contribute to solve water shortages in Iraq.

2 Methodology

2.1 Study Area

Eastern Sinjar District (Fig. 1-A) is located within Nineveh province in northwest Iraq about 84 km of Mosul center. The region is famous for the cultivation of rain-fed crops such as wheat and barley.

Sinjar district is characterized by semi-arid climate, where rainfall totals are low with an uneven distribution. The rainy season extends from November to May.

Table 1 shows annual rainfall depths for the period (1990-2011) as provided by Iraqi Meteorological and Seismology Organization, obtained from four meteorological stations (Rabeaa, Sinjar, Talafar and Mosul) (Fig. 1-B).

The maximum, minimum and average rainfall seasons occurred during 1994-1995, 1998-1999 and 2005-2006 and reach up to 426.4, 150.3 and 293.6 mm of rainfall depth respectively.

The soil is 2 m deep and contains 1-2% organic material, and it is of silt clay to silt clay loam type. In addition there are other layers of sandstone and gypsum soil that cover most of the upland areas and hills southern the studied area [36].

Four basins (Fig.1-D) have been selected to estimate the runoff during the rainy season for two periods. The first period extends from 1990 to 2011. The second (2012 to 2016) represent near future. The catchment area of the selected basins contains three basic zones as follows cultivated, pasture, and land covered by exposures of hard rocks. For each basin, the runoff is to be collected from the catchment area of the basin toward its outlet where a reservoir of an earth dam is located.

The methodology used for this research is well documented by Al-Ansari et al. [33] and Zakaria et al. [4 and 34], which can be summarized as discussed below.

2.2 Scenarios Using Actual Rainfall Records

Three recorded rainfall scenarios (S1, S2, and S3) for the period (1990-2011) were analyzed to select the maximum, minimum and average weekly rainfall seasons under the condition that the maximum weekly rainfall distribution is most of the season lead to maximize the irrigated area under the crops. The maximum total rainfall depth (scenario S1) reached 426.4 mm (1994-1995) while the minimum (scenario S2) reached 150.3 mm (1998-1999). The average total rainfall depth (scenario S3) reached 293.6 mm (2005-2006). Fig 2 shows the weekly rainfall events of the above scenarios along 24 weeks. This period represents the wheat season growth for Sinjar District-Iraq region.

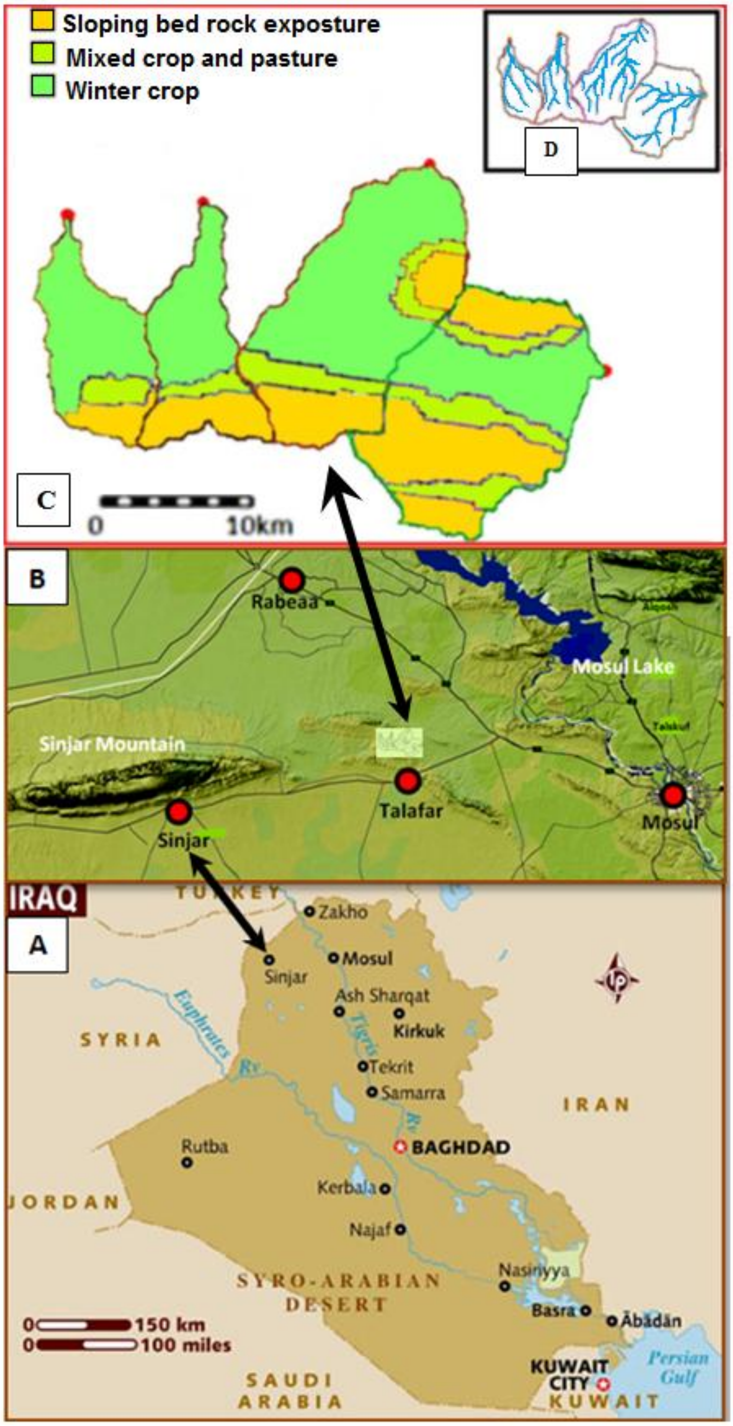

Figure 1: (A) Map of Iraq (source: lonelyplanet.com), (B) Meteorological stations in the study area (source: Google map), (C) Basins Land use map, (D) Selected basin at east Sinjar

Table 1: Annual rainfall depths on study area for the period (1990-2011)

Season	Rainfall depth (mm)
1990-1991	314.6
1991-1992	406.2
1992-1993	422.2
1993-1994	421.9
1994-1995	426.4
1995-1996	435.5
1996-1997	384.1
1997-1998	322.2
1998-1999	150.3
1999-2000	181.9
2000-2001	415.9
2001-2002	359.8
2003-2004	221.1
2004-2005	310.4
2005-2006	293.6
2006-2007	268.8
2008-2009	203.5
2009-2010	291.3
2010-2011	282.6

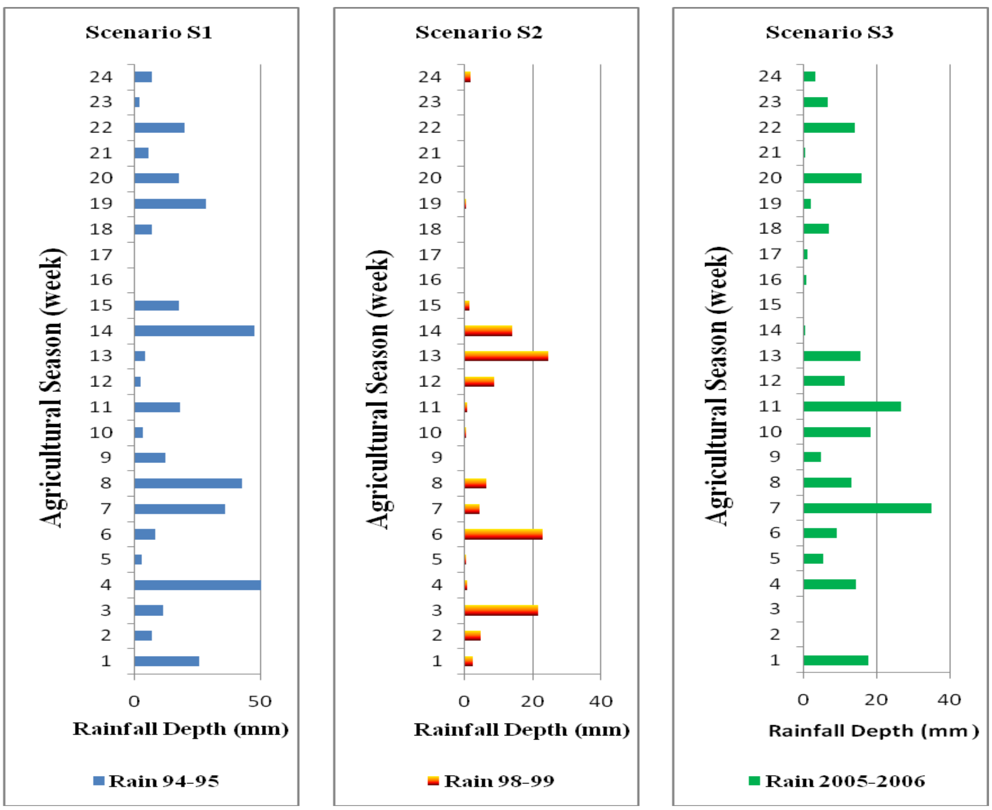

Figure 2: Rainfall Events through three selected weekly recorded rainfall Scenarios (S1, S2 and S3)

2.3 Watershed Modeling System and Runoff Estimation

Watershed Modeling System (WMS) is an efficient tool to estimate runoff for a specific catchment area. In this work the land use map for the study area (Fig. 1-C) it was obtained for the four selected basins based on the map produced by Remote Sensing Center, University of Mosul [37]. For each single rainfall storm the runoff volume was estimated using TR-20 of WMS model based upon the runoff curve number method (NRCS-CN).

2.4 Supplemental Irrigation Model

Using MATLAB software (R 2008 a), the irrigation water requirements of supplemental irrigation (SI) of 100% crop water requirement satisfaction for the wheat crop can be estimated. The estimation is based on rainfall depth, soil water storage and crop water requirements.

2.5 Optimization Model

A linear programming computer model technique had been used with MATLAB software to optimize crop area that could be irrigated by SI of 100% crop water requirement satisfaction. For a given rainfall scenario, the objective function is to maximize the total cropped area, which could be irrigated using the harvested runoff water that has been collected and stored in the individual reservoir for each basin.

2.6 Scenarios Using Hypothetical Data

Box-Jenkins methodology used to build Autoregressive Integrated Moving Average (ARIMA) models for weekly rainfall data from four rainfall stations: Sinjar, Mosul, Rabeaa and Talafar located around Sinjar District-Iraq for the period 1990-2011. ARIMA model was developed for each of the above stations in order to forecast rainfall during the period 2012-2016 then averaged over the study area. Future rainfall depths were forecasted with adoption of a confidence level of 95%. The results of forecasting rainfall data showed that the maximum (S4), minimum (S5) and average (S6) annual rainfall was 233.9 mm (2015-2016), 198.4 mm (2013-2014) and 210.2 mm (2011-2012) respectively.

2.7 Water Release

For the four selected basins, the total volume of harvested runoff through any rainfall scenarios could be stored in the individual reservoirs that are available at the outlet of each basin.

Emphasis will be placed on these amounts of excess water that can be released for the purpose of employing them to recharge ground water.

The volume of the water release will be equal to zero if the reservoir is not filled completely with water during the rainfall season. While those filled to its maximum capacity, the water release can be estimated for the recorded and forecasted rainfall scenarios by the following formula:

$$VWR_{i+1} = VS_i - SEVAP_i - VIRR_i - VRES + VRUN_i \quad (1)$$

Where:

VWR_{i+1} = the volume of water release (m^3).

VS_i = the current water storage in the reservoir (m^3).

$SEVAP_i$ = the volume of evaporated water from the reservoir surface (m^3).

$VIRR_i$ = the volume of irrigation water by SI (m^3).

$VRES$ = the maximum reservoir capacity (m^3).

$VRUN_i$ = the volume of current runoff (m^3).

3 Model Application

The study area had been investigated, and four basins were selected as a specific catchment area to harvest the runoff that was produced from rainfall and could be stored in the reservoir. Studying the recorded rainfall during the period 1990-2011 helps to analyze rainfall seasons to diagnose three rainfall scenarios, represent the maximum (S1), minimum (S2) and the average (S3) of total falling depth of rainfall during this period.
The WMS was applied in the first phase of the work to estimate runoff volume for each selected basin for each single rainfall storm for the study period.
The average rainfall data in the study area were obtained from Rabeaa, Sinjar, Talafar and Mosul stations that are located within the vicinity of Sinjar District.
The second phase of work is to apply SI model to estimate the irrigation water requirements of the wheat crop for the considered period. The growth season of the wheat crop in the study area is almost about six months (170 days). Finally the optimization model was applied to maximize the irrigated area using the storage of harvesting runoff for each reservoir with full irrigation requirements. The amount of water released from these reservoirs was estimated also.

4 Results and Discussion

4.1 Scenarios Using Actual Rainfall Records

The total volumes of harvested runoff through scenarios S1 (94-95), S2 (98-99) and S3 (2005-2006) from the four selected basins were stored in individual reservoirs. When the volume of harvested runoff exceeded the maximum capacity of any reservoir, the water will be released through the spillway. Figure 3 shows the volume of harvested runoff in the reservoirs.1 through 4 from the four selected basins during the scenarios (S1, S2 and S3). Thus the total harvested water in all the reservoirs during scenarios S1, S2, and S3 reach up to 16.06, 0.18, and 2.30 million cubic meters respectively. The main factors that affect the harvested runoff volume are the size of the catchment area, its type of soil, the distribution and amount of rainfall, The time period between the rain storms, curve number (CN) values, the antecedent moisture condition (AMC), the size of the reservoirs [4].

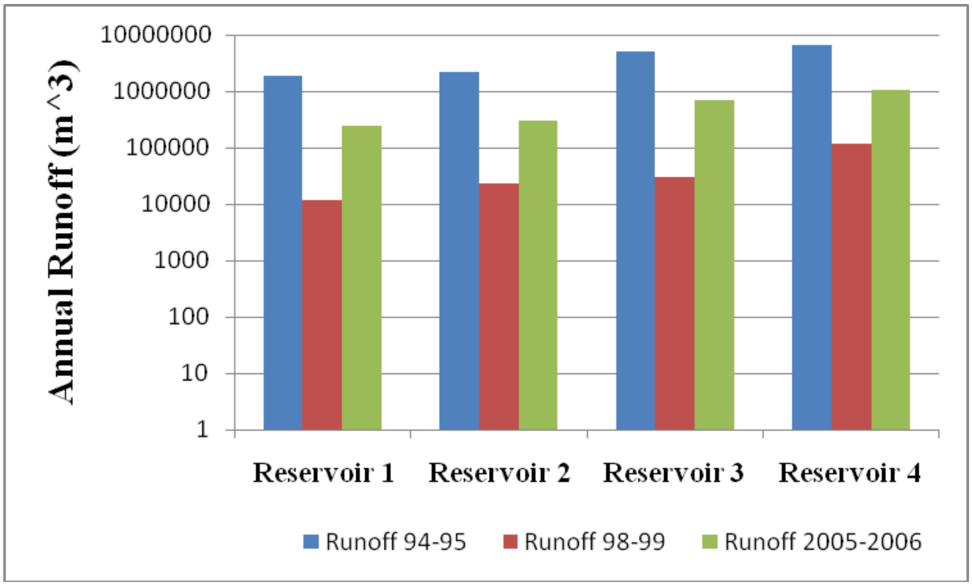

Figure 3: Annual runoff of the recorded rainfall scenarios (S1, S2 and S3)

Despite that Sinjar District is famous with rain-fed crop, especially wheat and has the most suitable agricultural conditions, but it lacks a water resource. Therefore, the rain water harvesting is an important part of its agricultural water management. Harvested rainfall can solve part of the problem in that area and if groundwater is used in periods of no rain then the crops can be maintained for the whole season.

Irrespective to the water resource there should be a good strategy for agricultural water management by using an efficient and reliable irrigation system, such as SI in order to supplement the limited rainfall to the equivalent value of the crop water requirements to maximize the irrigated area and then the crop yield.

Figure 4 shows that the resultant irrigated area by combination of SI (full irrigation requirement) and each of the rainfall scenarios S1, S2, and S3. Where the harvested runoff that stored in the individual reservoirs was used by irrigation process.

For scenarios S1, S2, and S3 the summation maximum, minimum, and averaged irrigated area from the four reservoirs reached up to 2646.27, 18.66, and 554.75 hectares respectively.

Certainly water availability is the main factor affecting the increase or decrease of the irrigated area when other factors are stable.

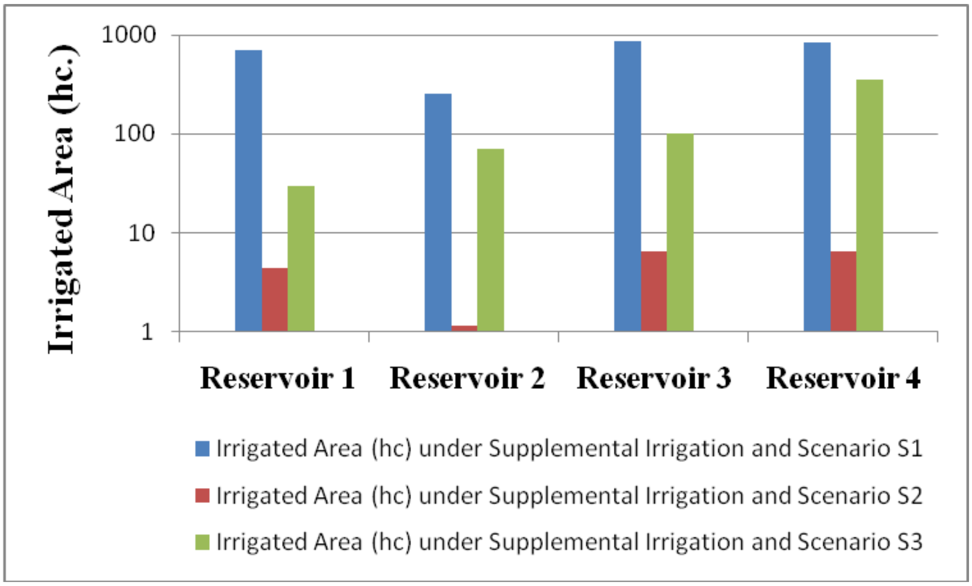

Figure 4: Resultant Irrigated Area by combination of Supplemental Irrigation and each of rainfall scenarios S1, S2, and S3

Table 2 shows the results of previous study at eastern Sinjar [4]. This table gives the calculated areas during the period 1990- 2009.

The irrigated area of the seasons 1996-1997, 2008-2009 and 1992-1993 are selected to represent the average irrigated area for reservoir 1, both reservoirs 2 and 3, and reservoir 4 respectively, as the closest average irrigated area to the calculated one. The irrigated area reached up to 229.51, 91.24, 243.14 and 391.41 ha for the reservoirs 1, 2, 3 and 4 for the above season respectively.

In order to explore the wheat crop yield at eastern Sinjar, these average areas will be used to evaluate the results of irrigated area at Sinjar rain-fed with a combination of SI (full irrigation requirements) with different rainfall scenarios.

Table 2: Irrigated area by the water of the four reservoirs for the period 1990-2009 with satisfaction of 100% of irrigation water requirement

Irrigated Area by the four reservoirs (hectares)				
Season	**reservoir1**	**reservoir2**	**reservoir3**	**reservoir4**
90-91	98.40	59.81	213.66	215.96
91-92	34.10	64.46	63.90	443.73
92-93	313.19	114.17	390.58	391.41
93-94	130.65	231.54	380.90	1205.40
94-95	706.28	252.31	852.05	835.63
95-96	148.33	57.34	203.20	220.33
96-97	229.51	85.00	294.90	297.59
97-98	126.02	76.29	64.54	449.59
98-99	4.49	1.15	6.53	6.50
99-2000	5.46	2.17	0.18	18.61
2000-2001	314.90	114.34	391.53	393.12

2001-2002	470.37	170.63	582.88	590.02
2003-2004	26.96	40.81	78.62	184.12
2004-2005	61.94	31.10	30.22	380.53
2005-2006	30.02	70.77	102.38	351.58
2006-2007	513.85	197.86	641.28	729.29
2008-2009	88.90	91.24	243.14	315.79
Summation	3303.39	1661.01	4540.49	7029.21
Average	194.32	97.71	267.09	413.48

It should be noted that scenario S1 always gives an irrigated area larger than specified average irrigated area for all reservoirs. The irrigated areas under both of scenarios S2 and S3 are always less than the average of the irrigated area for all reservoirs. The main cause of a bove results is a direct reflection of the important effect of the water availability by both of rain and irrigation water under scenario S1 and the limited availability of the water with both scenarios S2 and S3.

Thus, the scenario S1 is guaranteed to achieve more than the specified average of the irrigated area while both scenarios S2 and S3 are not. Therefore, in such cases of scenarios S2 and S3, the farmer has to provide an additional source of water to the rain-fed farm in order to increase the irrigated area to achieve the same revenue of the average of the irrigated area to maintain a constant level of crop yield. Farmers can use sprinkler irrigation to save water and if some more water is required then the only option they have at such a rain-fed farm is the use of groundwater. Table 3 shows the details of actual demand of irrigation water for the above three scenarios for all reservoirs.

Table 3: Actual demand for the irrigated area by reservoirs 1, 2, 3 and 4 during the rainfall scenarios S1, S2, and S3

Actual demand for the irrigated area by the four reservoirs (mm)				
Scenario	**reservoir 1**	**reservoir 2**	**reservoir 3**	**reservoir 4**
S1	103.65	112.27	112.27	113.91
S2	558.65	563.39	563.39	563.39
S3	252.66	250.94	252.66	252.70

The volume of groundwater (additional amounts of water) to be used to increased an irrigated area can be estimated by multiplying the actual water demand of SI during a certain scenario by the increased irrigated area.

The results of SI model that had been used for this research showed that the actual demand of irrigation water, for example, for reservoir 1 during rainfall scenarios S1, S2 and S3 are 103.6, 558.6 and 252.6 mm respectively.

Table 4 shows the results of the Optimization Model to maximize an irrigated area for the three selected rainfall scenarios (S1, S2 and S3) and the average irrigated area during the study period 1990-2009 with area that has to be increased (for scenarios S2 and S3) to reach the average irrigated area in order to ensure the same level of crop yield of the average irrigated area for the study period.

Thus for all reservoirs, the total increases in the areas reached up to 936.63 and 400.55 ha for the scenario S2 and S3 respectively.

Table 4: Irrigated area for scenarios S1, S2, and S3, the average irrigated area, and the area to be increased for scenarios S2, and S3

Irrigated Area by the four reservoirs (hectares)				
details	**reservoir 1**	**reservoir 2**	**reservoir 3**	**reservoir 4**
Scenario S1	706.28	252.31	852.05	835.63
Scenario S2	004.49	001.15	006.53	006.5
Scenario S3	030.02	070.77	102.38	351.58
Average irrigated area	229.51	91.24	243.14	391.41
Increased Area for S2	225.02	90.09	236.61	384.91
Increased Area for S3	199.49	20.47	140.76	39.83

Depending on the above results (SI model and Optimization model), the total volumes of SI water (Table 5) that is required to irrigate the area for all scenarios as well as for the additional areas during scenarios S2 and S3 can be obtained by multiply the actual water demand of SI during a certain scenario by its irrigated area. For example, the water volumes of SI will be 732059.22, 25083.38, and 75848.53 to satisfy an irrigated area of 706.28, 4.49 and 30.02 ha respectively.

Thus, the total ground water needed to irrigate the increased areas during scenarios S2 and S3, reaches up to 5.26 and 1.01 million cubic meters that represent the summation of the volume of irrigation water from all reservoirs to overcome the area shortage during scenarios S2 and S3 respectively.

It should be noted that not all the amount of harvested runoff water had been stored in the reservoirs. In fact, parts of harvested runoff water were lost by the spillway as a water release. Table 6 shows the annual volume of water release from the four spillways of the reservoirs during rainfall scenarios S1, S2, and S3.

Table 5: Volumes of irrigation water from the four reservoirs and the volume of irrigation water for area to be increased for S2 and S3

Volumes of irrigation water from the four reservoirs (m^3)				
details	**reservoir 1**	**reservoir 2**	**reservoir 3**	**reservoir4**
Scenario S1	732059.22	283268.43	956596.53	951866.13
Scenario S2	25083.38	6478.98	36789.36	36620.35
Scenario S3	75848.53	177590.23	258673.30	888442.66
V for S2	1257074.2	507558.0	1333037.0	2168544.4
V for S3	504031.4	51367.4	355644.2	100650.4

V for S2 =Volume of irrigation water for area to be increased for S2

V for S3 =Volume of irrigation water for area to be increased for S3

Table 6: The annual volume of water release from the four spillways of the reservoirs during the rainfall scenarios S1, S2, and S3

The annual volume of water release from four reservoirs (m^3)				
Scenario	**reservoir 1**	**reservoir 2**	**reservoir 3**	**reservoir 4**
S1	960765	1793234	4092970	5387645
S2	0.0	0.0	0.0	0.0
S3	0.0	20523	0.0	124556

The total annual amount of water release that escaped from the four reservoirs during the wet season 1994-1995 (scenario S1) reached up to 12234614 m^3 while it reached up to 145079 m^3 for the season 2005-2006 (scenario S3). No water was released in scenario S2 due to the low amount of rainfall. These quantities of water release could be employed to recharge groundwater's aquifer.

4.2 Scenarios Using Hypothetical Rainfall Data

Future rainfall forecasting plays an important role as an indicator that reflects what might happen in the future, regarding to rain and runoff. Farmers at dry regions such as Sinjar District will never go to risk with their money by cultivating their rain-fed farms if they know in advance that they might face extremely dry season where the total rainfall depths are not enough to produce an economic crop yield. Financial losses can be avoided during dry seasons in case of the presence of an irrigation system to compensate for the deficit of rainwater. Most of the local farmers at Sinjar district depend on their expertise of extrapolating the rainfall of coming seasons by evaluating previous seasons, which is not enough to give them a good indicator about future rainfall events.

An attempt was been made to study rainfall forecasting at Sinjar district in order to provide an alert in advance about future rainfall and runoff events for contributing to minimize possible losses that occur for rain-fed agriculture. There should be an integrated agriculture water management system, in order to put these techniques into practice. Decision makers and farmers should have an idea about future rainfall events in the area so that they can take other measures (e.g. using groundwater) to overcome the water shortage caused by low rainfall.

In previous work [35], using the Box-Jenkins methodology, four Autoregressive Integrated Moving Average (ARIMA) models were achieved for forecasting near future weekly rainfall for upcoming 5 years (2012-2016) at the Sinjar district rainfall stations, depending on weekly rainfall data (Fig. 5).

The future average rainfall depths (Fig. 6) could be harnessed for agricultural water management, by estimating future amounts of harvested runoff into reservoirs. Then, it is possible to estimate the amount of water available and required water that could be applied for the rain-fed farms of wheat crop in the Sinjar District to overcome the problem of water scarcity during dry seasons. Using the forecasted data, three rainfall scenarios can be obtained that represent the maximum rainfall season (S4) with total rainfall of 233.9 mm that may occur during 2015-2016, minimum rainfall season (S5) of 198.4 mm, that may occur during 2013-2014, and the average rainfall season (S6) of 210.0 mm, that may occur during 2011-2012. Fig. 7 shows the weekly events of these scenarios.

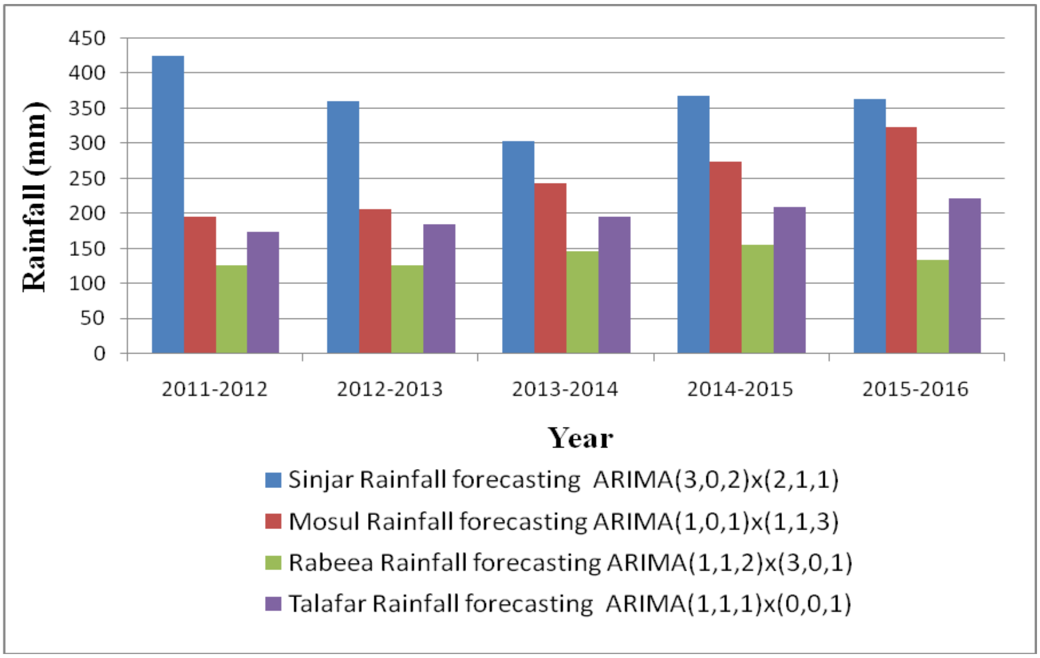

Figure 5 : Annual forecasting Rainfall for the four selected stations

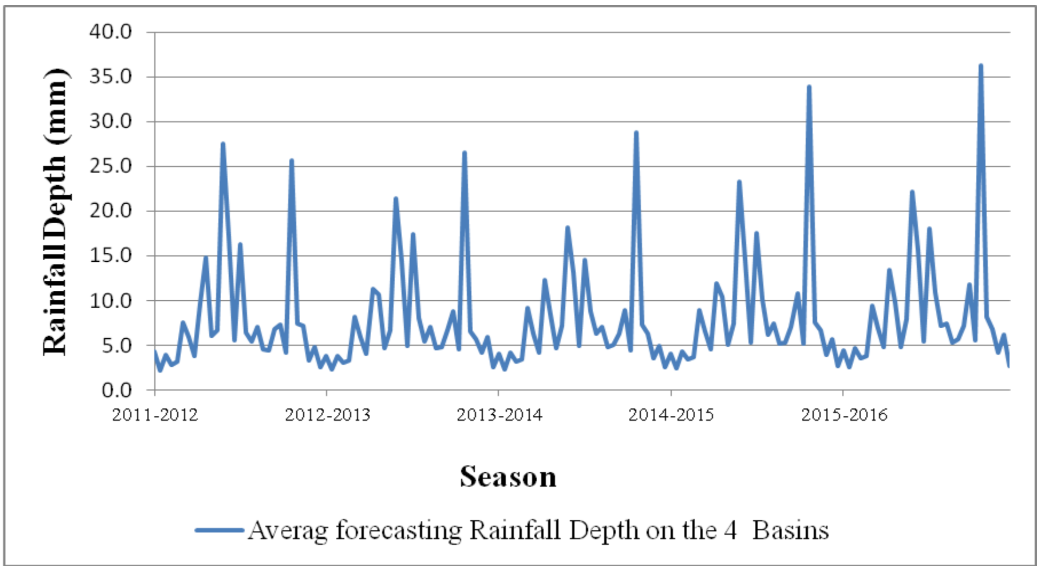

Figure 6: Average rainfall forecasting on the 4 basins for the up-coming 5 years (2012-2016)

Quick study and comparison between scenarios using actual rainfall records (S1 through S3) with scenarios using forecasted rainfall data (S4 through S6) may summarize the following important points:

The total depths of the future rainfall are relatively low compared to the total depths recorded rainfall. Considering the change with rainfall depths, the behavior of rainfall acts to distribute its depth with some pattern were rarely repeated its maximum values along the season. For example, if the maximum depth is 35 mm for a certain rainfall season, then it's rarely to find this depth more than once in the certain season. Considering the minimum amount of rainfall recommended for the NRCS-CN method that is not less than 12.75 mm [38]. Some rainfall depths of both recorded and forecasted scenarios exceed the minimum rainfall depth that produces runoff by a number of times, while it is less taking place during forecasted rainfall scenarios. It should be noted that the weekly rainfall depths of the scenarios S1 through S3 are based on accumulated daily rainfall depths, and all results are calculated daily and viewed on a weekly. While the rainfall depths of the forecasting scenarios S4 through S6 represents direct forecasting as weekly events. The maximum period of the rainfall depths for the weekly forecasting scenarios (in order to take place) is along seven days and this will produce a minimum harvested runoff and/or no runoff will be produced if the rainfall depth is less than 12.75mm. Maximum runoff volume will be achieved when their rainfall depths occur in one day, and this was been adopted in this study.

Fig. 8 shows the future runoff volumes that could be harvested for the up-coming 5 years (2012-2016).

The harvested runoff reached a maximum value of 2.1 million cubic meters at the reservoir 4 which is achieved through scenario S4 during the year 2015-2016. This scenario also satisfies the maximum total harvested runoff volume that has been collected from the four reservoirs that reached up to 4.43 million cubic meters.

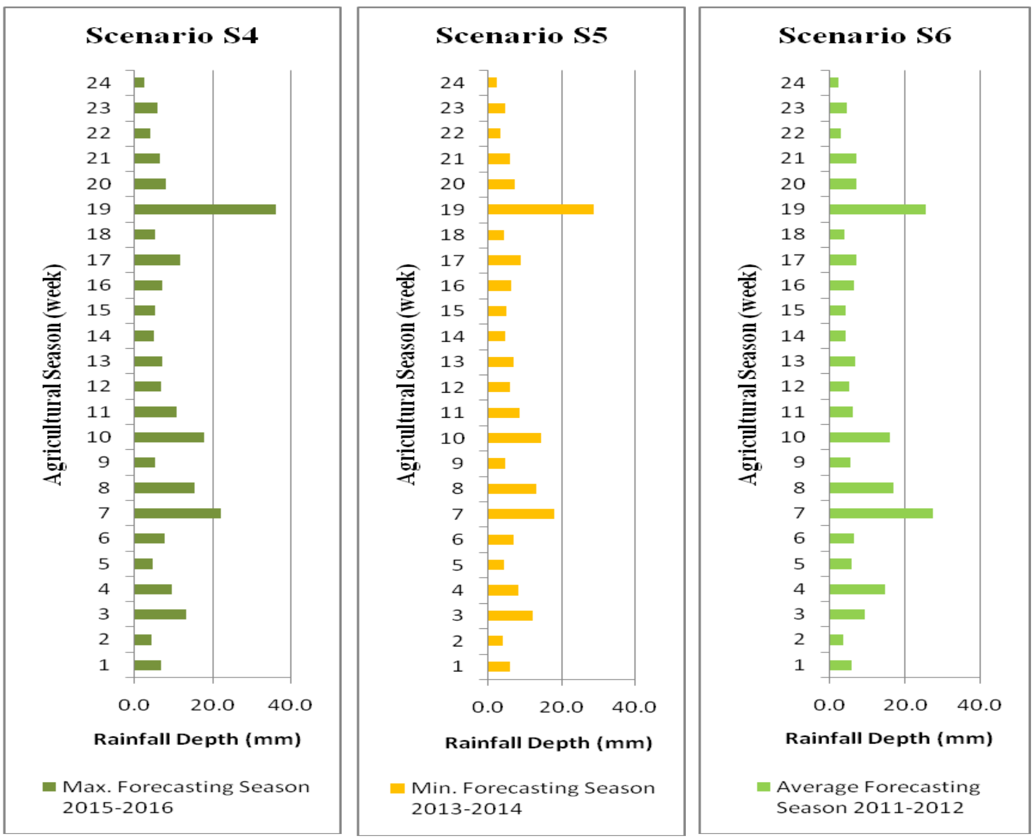

Figure 7: Rainfall events through three diagnosed weekly forecasting rainfall Scenarios (S4, S5 and S6).

On other hand, the harvested runoff reached a minimum value of 0.2 million cubic meters at the reservoir 1 which is achieved through scenario S5 (2013-2014), this scenario also produces the minimum total harvested runoff volume and reached up to 2.18 million cubic meters. The average scenario (S6) produced total harvested runoff of 3.49 million cubic meters.

Same main factors (that were discussed with a scenario S1 through S3) play the same role and effect to maximize or minimize the harvested runoff volume.

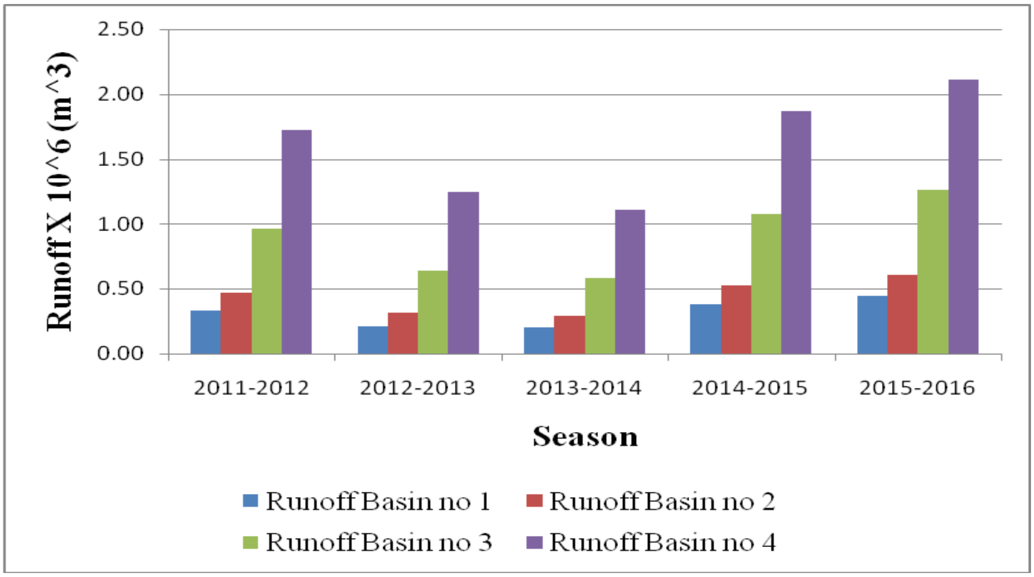

Figure 8: Runoff volumes for the up-coming 5 years (2012-2016).

These runoff volumes give new water resource for the dry region that can be achieved using RWH technique. In order to maximize the benefit of these limited amounts of harvested runoff water for agricultural purpose, SI should be used to provide the irrigation water to the rain-fed.

The results of Optimization Model (Fig. 9) show that the resultant irrigated area by a combination of SI and each of the rainfall scenarios S4 through S6.

For the forecasting scenarios, the results showed that the maximum irrigated area reached 446.09 hectares achieved by using water of reservoir 3 during the forecasting rainfall scenario (S4). The summation of the irrigated area of this scenario reached up to 1179.66 hectares, which are the maximum irrigated area between the forecasting scenarios. Scenario S5 produces total minimum irrigated area reach up to 600.29 hectares. While the average irrigated area achieved during scenario S6 and reached up to 910.37 hectares.

In order to assess the total irrigated area to satisfy a constant level of producing wheat crop yield, the same criteria that were been used with scenarios S1 through S3 of average irrigated area (229.51, 91.24, 243.14 and 391.41 hectares for the reservoirs 1, 2, 3 and 4 respectively) will be used with scenarios S4 through S6.

Thus, table 7 shows the results of the Optimization Model for the future study period which explains the values of irrigated areas that could be estimated by the individual water of the four reservoirs. Same table also shows the area that should be increased to ensure the same level of crop yield according to the criteria of the average irrigated area.

The required total water volumes of SI can be estimated as a result of multiplying the irrigated areas by the actual water demand of SI (the results of SI Model).

As it is expected, the depth of the actual water demand of SI increased in dry seasons while it is less in amount during wet season.
Thus in dry season, the water volume of SI for crop such as wheat in rain-fed farm will be larger than its amount during wet seasons.
This is due to the fact that the amount of limited rainwater that reaches the crop in the dry season is always less than the crop water requirements and supplemental irrigation would complete the water shortage to the limit of crop water requirement. However, in the rain-fed farms, must complete the depth of rainfall to the equivalent value of crop water requirement by SI process in order to achieve successful economic agricultural for a crop yield.

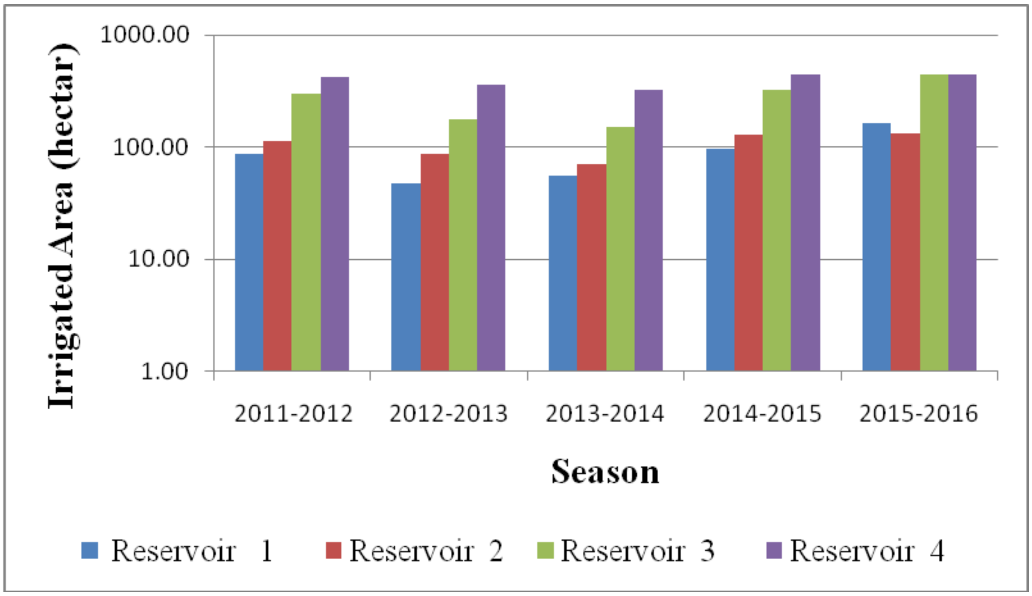

Figure 9: Irrigated area under combination both of supplemental irrigation and individual rainfall scenario of (S4, S5 and S6).

Table 7: Irrigated areas and the areas to be increased for the future study period.

The details	2011-2012	2012-2013	2013-2014	2014-2015	2015-2016
Irrigated Area (ha.)					
reservoir 1	85.2	47.4	55.2	96.8	160.7
reservoir 2	113.2	85.6	69.7	128.8	130.5
reservoir 3	294.6	177.6	151.6	320.3	446.1
reservoir 4	417.3	360.6	323.8	438.5	442.5
Area to be increased (ha.)					
reservoir 1	144.3	182.1	174.3	132.7	68.9
reservoir 2	not need	5.7	21.5	not need	not need
reservoir 3	not need	65.5	91.6	not need	not need
reservoir 4	not need	30.9	67.6	not need	not need

This is should be applied as the depth of rainfall is less than crop water requirement. Table 8 explains the required total water volumes for the irrigated area and the area to be increased.

Table 8: The volumes of irrigation water (m^3) by the four reservoirs for the future study period.

Volumes of irrigation water (m^3)					
The details	**2011-2012**	**2012-2013**	**2013-2014**	**2014-2015**	**2015-2016**
reservoir 1	250181	155059	180428	302687	366683
reservoir 2	333030	280531	228229	404082	299282
reservoir 3	865624	581530	495662	1002850	1020684
reservoir 4	1232084	1187917	1065389	1385794	1024161
s of irrigation water for area to be increased					
reservoir 1	423514	595576	569348	414679	157173
reservoir 2	not need	18588	70531	not need	not need
reservoir 3	not need	214558	299503	not need	not need
reservoir 4	not need	101675	222455	not need	not need

Table 9 shows the annual volume of water release from the four spillways of the reservoirs during forecasting rainfall scenarios for the period 2012-2016.

The volume of a water release from the reservoir is the result of water balance process between the maximum storage capacity of the reservoir, the availability of the harvested runoff volume, the evaporated water amount from the surface of the reservoir, and the amount of irrigation water requirements for SI. These releases can be used to recharge ground water aquifers in the area.

The volume of water release from the reservoir 1 equal zero for all the period of 2012-2016 since the produced volume of runoff is less than the maximum capacity of the reservoir 1 as well as the catchment area of the basin 1 is small when compared to the catchment area of basins 3 or 4, thus all the amount of harvested runoff from the catchment area of the basin 1 is stored in reservoir 1.

For reservoirs 2 and 3 the individual water release is more available over the wet seasons. With the exception of the dry season, the water release from reservoir 4 is always available due to the effects of the large catchment area of basin 4 that can collect enough amount of runoff in addition the big value of its curve number comparing with other basins. The annual summations of water release ranged from zero during the season 2012-2013 and 2013-2014 and reached its maximum value (1,280,908.62) m^3 through the scenario S4 (2015-2016). The best function for these amounts of water release is to recharge the ground water aquifer, although, they are not of high quantity.

Table 9: Annual water release that excess the reservoirs capacity during forecasting rainfall scenarios for the period 2012-2016.

	The annual volume of water release from four reservoirs (m^3)			
Season	**reservoir 1**	**reservoir 2**	**reservoir 3**	**reservoir 4**
2011-2012	0.0	71994	0.0	406461
2012-2013	0.0	0.0	0.0	0.0
2013-2014	0.0	0.0	0.0	0.0
2014-2015	0.0	50030	0.0	362361
2015-2016	0.0	235772	108789	936346

5 Conclusion

In this research, an average irrigated area (955.3 ha) was calculated using RWH technique for the period 1990-2011 for east Sinjar district. This area was used as a benchmark to find out water requirements to grow wheat in wet (S1) average (S2), and dry (S3) years. To achieve this goal, rainfall records for the period above was used to find out the wettest, average and driest years. Furthermore, rain forecasted data for the period 2012-2016 were also used in the same manner (S4 wet, S5 average and S6 dry).

The results show that the annual runoff reach up to 16.06, 0.18, and 2.30 million cubic meters using actual rainfall records during maximum, minimum, and average rainfall seasons of the period 1990-2011. Using scenarios of hypothetical rainfall data for the period 2012-2016 the above values reach up to 4.43, 0.20, and 3.49 million cubic meters. The runoff volume represent considerable water amount for supplemental irrigation.

Each of scenarios S1 and S4 give total irrigated area larger than a total specified average irrigated area that reached up to 2646.27 and 1179.8 ha respectively. During the above scenarios, the surplus water from (rain + irrigation) have been used to achieve a significant increase in irrigated areas, the percent of the increase in an irrigated area reached up to 177% and 23.5% for scenarios S1 and S4 respectively. The total irrigated areas under each of scenarios S2 and S5 are always less than the total average of an irrigated area that reached up to 18.67 and 600.3 ha respectively. The total irrigated areas for the above scenarios should be increase by 936.63 and 355 ha respectively, and they will need an additional amount of water, which had been estimated that reached up to 5.26 and 1.16 million cubic meters for scenario S2 and S5 respectively in order to satisfy the specified average irrigated area. The total irrigated areas under both of scenarios S3 and S6 are less than the total average of an irrigated area that reached up to 554.75 and 910.3 ha respectively. The total irrigated areas should be increased by 400.55 and 45.0 ha, and they will need additional amount of water, which had been estimated that it reached up to 1.01 and 0.13 million cubic meters for scenario S3 and S6 respectively in order to satisfy the specified average irrigated area. Farmers can use sprinkler irrigation to save water and if some more water is required then the only option they have is the use of groundwater.

The amount of water releases from the four reservoirs was been estimated to check their amounts for recharging ground water aquifers during both scenarios using actual rainfall records and hypothetical rainfall data. The annual volume of water release for scenarios S1 and S4 reached up to 12.23 and 2.56 million cubic meters respectively. Due to lack of rainwater during dry scenarios S2 and S5 all harvested runoff were stored in the reservoirs and have no water release. While for both scenarios, S3 and S6 there were limited amount of water release reached up to 0.14 and 0.95 million cubic meters respectively.

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