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Future Prospects for Macro Rainwater Harvesting Technique at Northwest Iraq

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Abstract

Rainfall data is part of the main components in the hydrological cycle and firmly associated with almost all aspect of climate. Previous research indicated that Macro rainwater harvesting techniques (RWH) can be implemented successfully in Sinjar area northwest Iraq. Recently, prediction of rainfall trends in the Middle East and Iraq in particular suggest a decrease in rainfall due to climate change. This raises the question about the future validity of RWH in the area.

In this research, the validity of RWH was investigated using predicted rainfall data in Sinjar area. Eight seasons were selected representing different decades that start 2020 to 2099. The results showed that the maximum, minimum and average harvested future runoff volumes reached about 28.5, 7.61, and 13.9 million cubic meters, that may occurred during the seasons 2055-2056, 2046-2047, and 2065-2066 respectively. The resultant harvested runoff volumes produced by four selected basins at Eastern Sinjar as a catchment area with total area of 435.15 km^2.In the second part, an attempt had been made to provide the study area by a set of charts that can help in estimating daily runoff under dry, wet and normal conditions for rainfall depths that ranged between 15 to 55 mm.

Keywords: Macro rainwater harvesting; rainfall prediction; Sinjar; Iraq.

1 Introduction

The countries in the Middle East and North Africa (MENA Region), including Iraq, have an arid climate and are projected to become considerably hotter and drier as results of climatic change. According to the Intergovernmental Panel on Climate Change (IPCC) 4th assessment report, estimates an increase in temperature in MENA Region of about 4 degrees by 2100[1].

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The negative impacts associated with climate change are extensive, and in conjunction with global warming there is a crisis of water scarcity. Recently, water scarcity issue is becoming more serious due to several factors. In Iraq these factors can be classified as internal and external factors. The former include increasing water demand, high population rate, miss management and planning of the water resources. The external factors are more complicated which involves the effect of global warming in addition, to the water policies of neighboring countries enforced which add another burden where huge dams were built on the upper parts of the Tigris and Euphrates Rivers in Syria and Turkey that led to the reduction of the flow rate of both rivers inside of Iraq [2, 3, and 4]. However existing supplies simply cannot meet the growing demand for water; as a result, Iraq import most of its food. Iraq is expected to face more challenges in future, where the water shortages problem is becoming more serious with time [3,5, and 6] and Tigris and Euphrates River are expected to be dry in 2040 [5]. The expected discharge in the year 2025 of Tigris and Euphrates Rivers will be tremendously decreased [7].

Climatic change is the biggest challenge facing the world. To overcome this challenge requires understanding the processes that effect different components of the climate as well as the hydrological cycle. Understanding the physical processes plus the advances in modeling, make it increasingly reliable regional climate change projections available for many regions of the world. Atmosphere-Ocean General Circulation Models (AOGCMs) represents the foundation for projections while downscaling techniques now provide valuable additional details [8].

The increase in the concentration of greenhouse gases (GHGs) in the atmosphere is the main reason lead to the change in the climatic system as results of human activities (burning of fossil fuels like coal, oil, and natural gas as an energy source), in addition to aerosols, and land surface changes [9].

1.1 Impacts of Climatic Change

IPCC [1] observed that there are different impacts on the physical and biological systems due to climatic change including regional and local levels such as: ecosystem health, food production, species distributions and phonology, human health, sea levels, precipitation and river runoff, drought, average and extreme changes in temperature and wind patterns. The impacts are, however, associated with large uncertainties. Developing countries, such as Iraq for example, are more affected by climatic change. IPCC [1] highlighted that, the negative impacts associated with climate change are extensive and its effects on developing countries are relatively more than it is on other countries. World Bank [10] noted that, despite global initiatives to tackle climate change, the rate of climate change had increased during the twentieth century.

Dry-lands occupy over 40 % of the global terrestrial area that is inhabited by more than 2 billion of the most low-income populations in the world [11]. Climate change has large effects on the hydrological cycles in dry-lands with less total rainfall, drier soils but with increased risks of floods from increased frequency and intensity of storm events [1]. Furthermore, some studies indicated that, the negative impact of climatic change in MENA Region will include decrease of precipitation in high percentage terms than other regions, in addition to a water runoff reduction of 20-30 % by mid-century [12]. Sandstrom [13] noted that certain percentage reduction in rainfall amount in semi-arid areas showed a proportionately greater reduction on groundwater recharge. Mulholland [14] indicated that the rate at which water scarcity in the MENA region is becoming worse where per capita renewable fresh water in the region fell from 4000 m^3 per year (1950) to 1100 m^3 in 2010. There are several other impacts of climate change and climate variability on dry land agro-ecosystems which include reductions in crop yields and minimize pastures, difficulties in determining timings of sowing and harvesting, reduced availability of water, reduction of biodiversity of key crop species through habitat change and loss [15].

A number of studies had addressed the issue of climate change but the connections among climate change, land degradation and loss of biodiversity are viewed in high attention. The matter needs a complete framework and approaches to satisfy solving common problems [11]. These converging viewpoints lead to an increased focus on sustainable land, water management and development [8].

1.2 Strategy to be Adopted to Increase Water Productivity

Developing countries in MENA region possess large areas of dry lands. The water is the important factor that limits the crop yield in these lands, therefore the goal to be considered as a good strategy is to adopt increase water productivity in order to save enough water for different purposes (agricultural, industrial consumption and daily us[16, 17, and 18]. There are two important terms that are used to describe water productivity. The first is the physical productivity that is defined as the ratio of the amount of agricultural output to the amount of water used. The second is the economic productivity which is defined as the value derived per unit of water used [15]. However, in dry land, one of the important methods to reduce water demand is by improving the water productivity by increasing the ratio of net benefits from agriculture, forestry and fisheries to the amount of water needed to achieve those benefits [19]. Certainly this should be supported by several techniques and methods that can be used in order to improve water productivity including rainwater harvesting (RWH), drip and sprinkler irrigation using supplemental and/or deficit irrigation in addition to more efficient storage, delivery and application of water, soil water conservation and tillage practices and better synchrony of water and inorganic and organic nutrient supplies [15]. Moreover, FAO defined Conservation Agriculture (CA) as, agriculture that maintains and improves crop yields and resilience against drought while maintaining the biological functioning of the soil [20]. Dumanski et al. [21] defined CA as, the integration of natural resources management with sustainable and economic agricultural production. Indeed FAO focus on CA research can be considered as a base for sustainable production intensification which is appropriate to climate change adaptation and mitigation [2]. FAO [23] mentioned that daily and inter-annual variation in precipitation are most crucial for rain-fed and runoff for irrigated production. The variability in rainfall intensity and duration makes the performance of agricultural systems in relation to long-term climate trends very difficult to anticipate. It should be noted that the rain-fed sector occupies about 80% of the world’s cultivated land and produces about 60% of the world’s cereal grains [19].Richard et al. [15] noted that different sectors are to be embraced in the strategies for adaptation to climate change and this require collaboration amongst multiple stakeholders, ranging from resource managers to policy makers. RWH technique can provide a new source of water to the region which had been proven to be an effective technique in arid and semi-arid regions to achieve the most important goals of increasing crop yields and reducing cropping risk, in addition using harvested water to recharge groundwater aquifers, making best use of available water resources [24].

1.3 Climate Models and Emission Scenarios

IPCC [25] in Special Report on Emissions Scenarios (SRES) used climate models that include future scenarios of greenhouse gases and aerosols as input to make a suite of projected future climate changes that illustrates the possibilities that could lie ahead. Four different narrative storylines had been described as: A1, A2, B1 and B2. The A1 contain three groups A1FI, A1T, and A1B depending on their technological emphasis of fossil intensive, non-fossil energy sources and a balance across all sources respectively. These storylines describe the relationships between the forces driving emissions and their evolution and to add context for the scenario quantification. Each storylines described the cases of economic growth, global population, efficient technologies, and major underlying of the cases. The A2 storyline and scenario family describes a very heterogeneous world. This theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.

IPCC [25] describes each storyline and scenario family as follows:

"• **The A1 storyline and scenario family describes the following:**

1- A future world of very rapid economic growth.
2- Global population that peaks in mid-century and declines thereafter.
3- The rapid introduction of new and more efficient technologies.
4- Major underlying themes are convergence among regions.
5- Capacity building and increased cultural and social interactions.
6- A substantial reduction in regional differences in per capita income.
7- The three A1 groups are distinguished by their technological emphasis:
a- Fossil intensive (A1FI)
b- Non-fossil energy sources (A1T)
c- A balance across all sources (A1B).

where balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies.

• **The A2 storyline and scenario family describes the following:**

1- A very heterogeneous world.
2- The underlying theme is self-reliance and preservation of local identities.
3- Fertility patterns across regions converge very slowly, which results in continuously increasing global population.
4- Economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than in other storylines.

• **The B1 storyline and scenario family describes the following:**

1- A convergent world with the same global population that peaks in midcentury and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy.
2- Reductions in material intensity and the introduction of clean and resource-efficient technologies.
3- The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

• **The B2 storyline and scenario family describes the following:**

1- A world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2,
2- Intermediate levels of economic development are less rapid and more diverse technological change than in the B1 and A1 storylines.
3- While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels."

Al-Ansari, et al.[26] indicated that global Climate Models (GCMs) are important tools to predict large scale climate variations at seasonal and inter annual scales, but they are usually not successful in reproducing higher order statistics and extreme values. Furthermore, they cannot be adapted for impact-oriented applications at regional scale because of their relatively coarse resolution of typically several hundred kilometers [27].For bridging the gap between the scale of GCMs and required resolution for practical applications, downscaling provides climate change information at a suitable spatial scale from the GCM data.
Studies of future rainfall help in planning of the agricultural water management that may lead to the best use of water resources by giving an idea about expected rainfall for the coming seasons and provides some possible scenarios of future rainfall. It might give some indications about the intensity of rain-fed cultivation [28].

1.4 Aim of the Study

The present work contains two parts; the first is an attempt to test the ability of the future rainfall (2020-2099) for the Macro rainwater harvesting (RWH) technique at eastern Sinjar district, Iraq. The future rainfall was estimated by Al-Ansari et al. [26] that was based on global climatic projections and their scenarios, using the HadCM3 Global Climate Model (GCM), Scenario A2.
In the second part, an attempt has made in order to provide the study area by a set of chart that help in estimating a daily runoff under dry, wet and normal conditions for rainfall depths that ranged between 15 to 55 mm.

2 Methodology

2.1 Study Area

Eastern Sinjar District was chosen in order to test the area ability for RWH technique [28, and 29]. The District is characterized by semi-arid climate located within Nineveh Governorate, northwest Iraq (Figure 1). Sinjar land is famous for the cultivation of rain-fed crops such as wheat and barley. The rainfall totals are relatively low with an uneven distribution that extends from November to May.

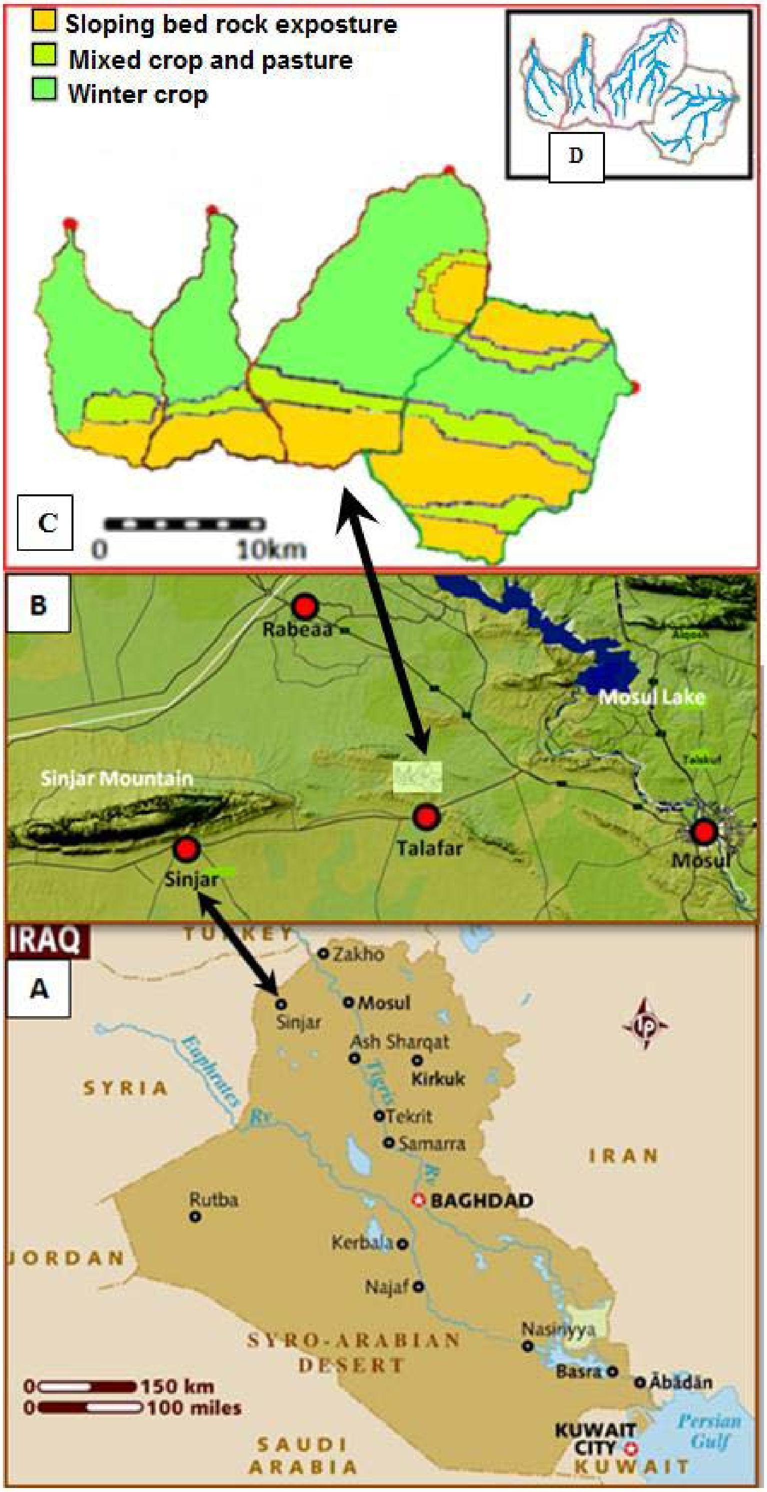

Figure 1: (A) Map of Iraq, (B) location of the study area, (C) Basins Land use map, (D) Selected four basins at east Sinjar, source: [29].

The average annual rainfall for the past twenty years is 320 mm [29]. The soil of study area is 2 m deep and contains 1-2% organic material of silt clay to silt clay loam [30]. Four basins with total area of 435.15 km^2 were chosen as a catchments area for the application of RWH technique. For more details please see previous work [28, and 29].

2.2 Hypothetical Rainfall Data

The rainfall data that was used in this work had been diverted by Al-Ansari et al.[26]. They used HadCM3 Global Climate Model (GCM) with grid resolution of 2.50x3.750 in order to provide future climate scenarios for the periods 2020-2099. Both the A2 and B2 emission scenarios were employed.Definitely the climate projections are related to emission uncertainty, therefore the Intergovernmental Panel on Climate Change used different climate scenarios that defined by Nakicenovic et al. (the IPCC Working Group III, 2000) [25] to account for the uncertainty of future anthropogenic carbon emissions.
In this work, only future rainfall of A2 scenario was used. The future average annual rainfall for A2 scenario was graphically represented (Figure 2).

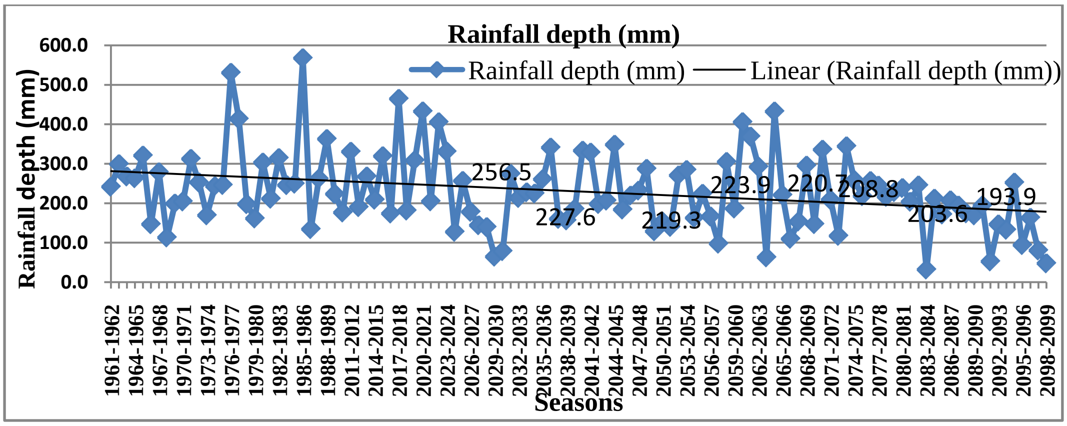

Figure 2: Average annual rainfall for A2 scenario. Linear trend indicate that there is a significant downward trend [26].

Figure 2 shows that the linear trend indicate that there is a significant downward trend reflecting decrease in total seasonal rainfall depth with time. The period of 2020-2099 was divided into eight sub periods each one of them representing ten seasons. Then in each sub-period, the nearest season to the general trend was chosen (Table 1) to study future expected harvested runoff.

2.3 Runoff Estimation

Macro RWH technique was implemented to estimate future runoff for individual daily future rainstorm that are based on Soil Conservation Service-curve number (SCS-CN) method using Watershed Modeling System (WMS) with Data Elevation Model (DEM) of Sinjar area. The curve number was estimated using land use map for the study area (Fig. 1-C) which was obtained for the four selected basins based on the map produced by Remote Sensing Center, University of Mosul [31].For more details please see previous work [28, and 29].

3 Results and Discussion

In spite of the impact of climatic change which is associated with large uncertainties, the future seasonal rainfall during the study period 2020-2099 showed a clear downward trend reflecting the reduction in total seasonal rainfall amount. Annual rainfall depth had been decreasing for all selected seasons except for the season 2055-2056, which witnessed an increase of several millimeters in the seasonal rainfall depth (Table 1).This is in agreement with the future rainfall estimation that is based on climatic change for Iraq. It should be noted that, for the rain-fed farms such values of rainfall (historical and future forecasted) are insufficient to grow economical crop [16]. However using Macro RWH technique can support the region where this technique will increase the water availability and consequently, the productivity of the rainwater for the rain-fed farm [29].

Rainfall data is part of the main components in the hydrological cycle and intimately linked with almost all aspect of climate. Therefore rainfall data even with uncertainty can support the area to give some idea about future prospects of the status of rainfall that can support estimating hydraulic events such as runoff.

The maximum, minimum and average rainfall depths for the selected rainfall seasons were: 256.51, 193.95, and 219.3mm that may occur during the seasons 2025-2026, 2091-2092, and 2046-2047 respectively. Definitely not all rain storms produce runoff. This is due to the effect of the rainfall amount and distribution i.e. the individual rain storm depth and span time between rain storms which produce the hydraulic condition of the catchment area. However, each of the above selected seasons contains just five rain storms that can produce runoff, their depths ranged between 12.5 to 56 mm. Moreover, Table 1 shows that the maximum rainfall season didn’t produce maximum runoff volume. Similarly, the minimum rainfall season didn’t produce minimum runoff volume. This is due to the effect of the rainfall distribution during the seasons. Figure 3 shows the maximum, minimum and average harvested runoff volumes that reached 28.5, 7.61, and 13.9 million cubic metersand might occur during the followingseasons : 2055 - 2056 ,

Table 1: Future and historical annual rainfall depth for the selected seasons with total harvested runoff from the four basins.

No.	Season	Annual Rainfall (mm)	harvested Runoff $*10^6$ (m^3)	Notes
		Future period 2020-2099		
1	2025-2026	256.5	25.08	
2	2033-2034	227.5	08.45	
3	2046-2047	219.3	07.61	Min. Runoff
4	2055-2056	223.9	28.50	Max. Runoff
5	2065-2066	220.7	13.90	Aver. Runoff
6	2071-2072	208.8	08.16	
7	2081-2082	203.6	17.99	
8	2090-2091	193.9	07.85	
		Historical recorded period 1990-2009		
1	1999-2000	182.0	0.12	Min. Runoff
2	2000-2001	415.9	28.19	Max. Runoff
3	1990-2009	325.0	12.52	Aver. Runoff

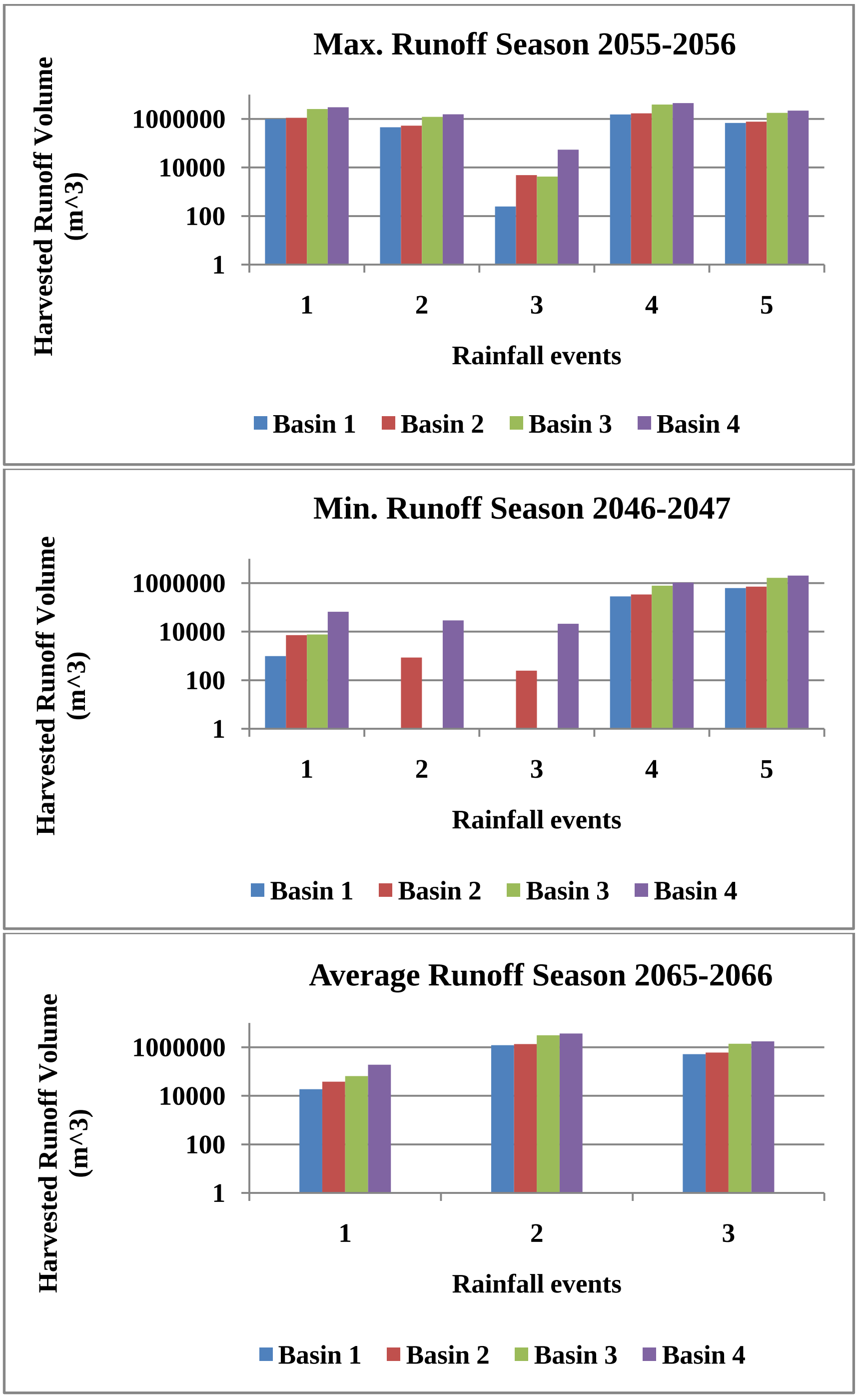

Figure 3: The maximum minimum and average annual harvested runoff volume for the selected basins.

2046-2047and 2065-2066 respectively. The first two seasons contains five rain storms that produce runoff while the season 2065-2066 contains three rainfall storms. High rainfall depth for the individual rain storm (some of them exceeded 50 mm) proceeded by weak rainfall storms. This will enhanced the hydraulic condition of the catchment area and support that the curve number to be in wet value, all that leads to contribute to produce the maximum runoff during the season 2055-2056, while such events were less during other seasons.

It should be noted that, the some rain storms (between 13-15 mm) may not produce runoff for all selected basins due to the hydraulic condition of some basins. This is true for the seasons 2046-2047 (Figure 3), where the rain storms of 14.3 and 14.0 mm for the 2nd and 3rd rainfall events produced runoff at basin no. 2 and 4 while they didn't in basins 1 and 3. This is because the curve number values at basins 2 and 4 were higher than their values at basin 1 and 3. Figure 4 shows the total annual harvested runoff volume that is expected to be produced by the four selected basins during the eight selected seasons.

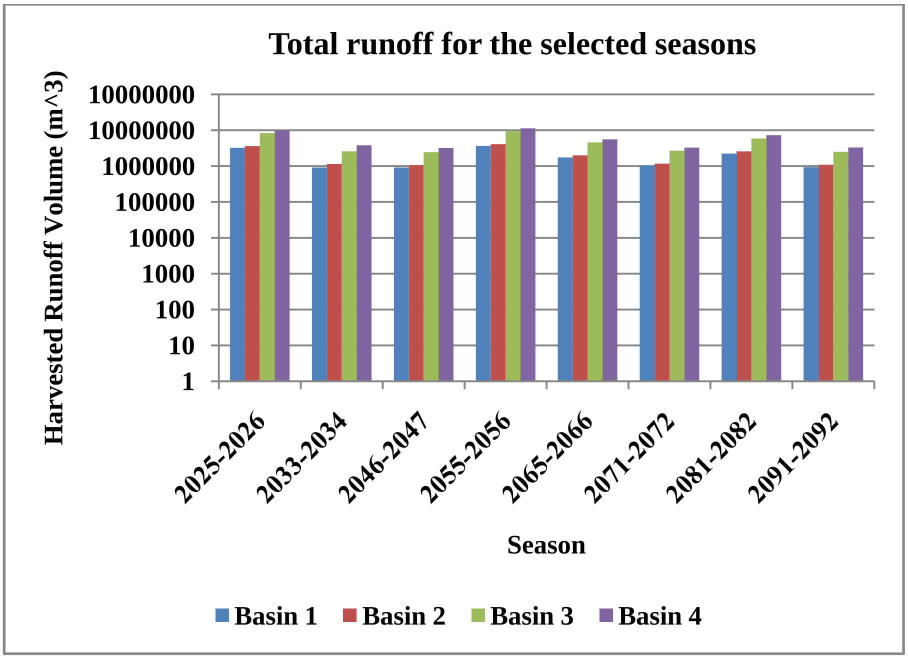

Figure 4: Total annual harvested runoff volume for the selected seasons.

Comparing the results of historical rainfall data (1990-2009) with those expected showed that the annual runoff volume for all catchments area of the four basins (1990-2009), were ranging from 0.12 to 28.19 million cubic meters (Table 1). These values occurred during the seasons 1999-2000, and 2000-2001 respectively, and the average annual runoff volume was about 12.52 million cubic meters for that period. While for future rainfall, the resultant runoff for all the catchments area of the four basins ranged from 7.61 to 28.5 million cubic meters for the future selected seasons (Table 1). These values may occur during the rainfall seasons 2046-2047 and 2055-2056 respectively, and the average annual runoff volume may reach about 14.6 million cubic meters for the future selected seasons, and the nearest amount for this value is that satisfied in 2065-2066 of 13.9 million cubic meters. however its seems there is no dramatic change in maximum runoff values between historical recorded rainfall and future rainfall which indicates that the rain may has the same ability to produce the maximum runoff due to type of equilibrium between the decrease of the total amount of seasonal rainfall and the increase the depth of individual rain storms. In general, the individual future rain storms that produces runoff has increased its rainfall depth and decreased in number of occurrence. Minimum runoff amount for the two periods (historical and future expected rainfall) cannot be compared due to not select minimum seasons of future rainfall.

3.1 Runoff Charts

To get an idea about the amount of runoff that can be harvested from a given catchment area at eastern Sinjar, an attempted was made to provide a set of charts that is easy to be used (Figures 5-A, 5-B and 5-C). These charts include the selected rainfall depth (x-axis) that ranged 15-55 (mm) and several values of the selected curve number (CN) that ranged 76-82, 86-92, and 60-68 for normal, wet and dry condition respectively. The y-axis represents the resultant equivalent harvested runoff depth (mm). However, the chosen values of the selected rainfall

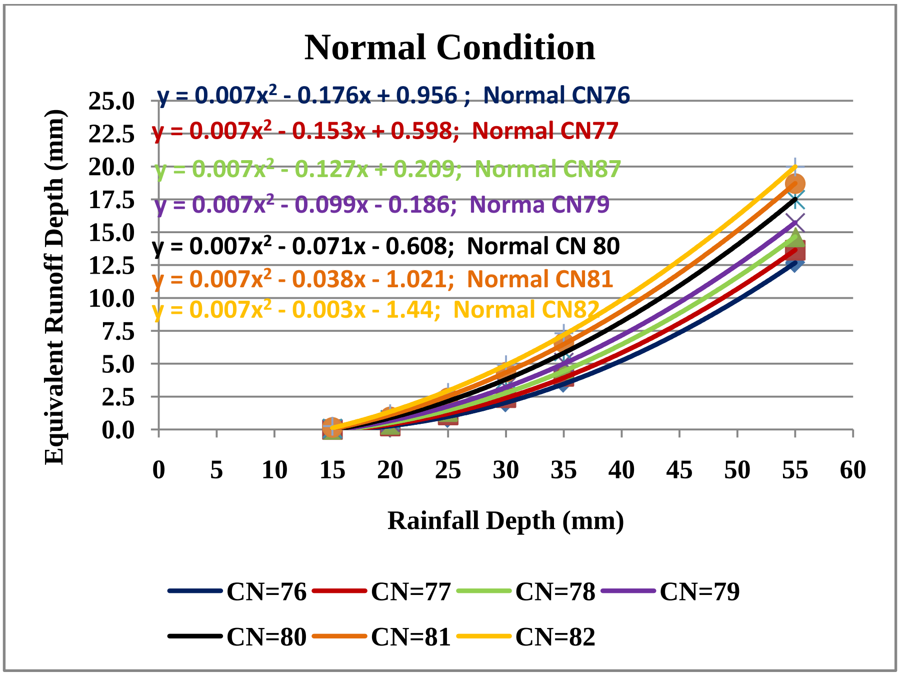

Figure 5-A: Equivalent Runoff Depth- Rainfall Depth relationship for normal condition.

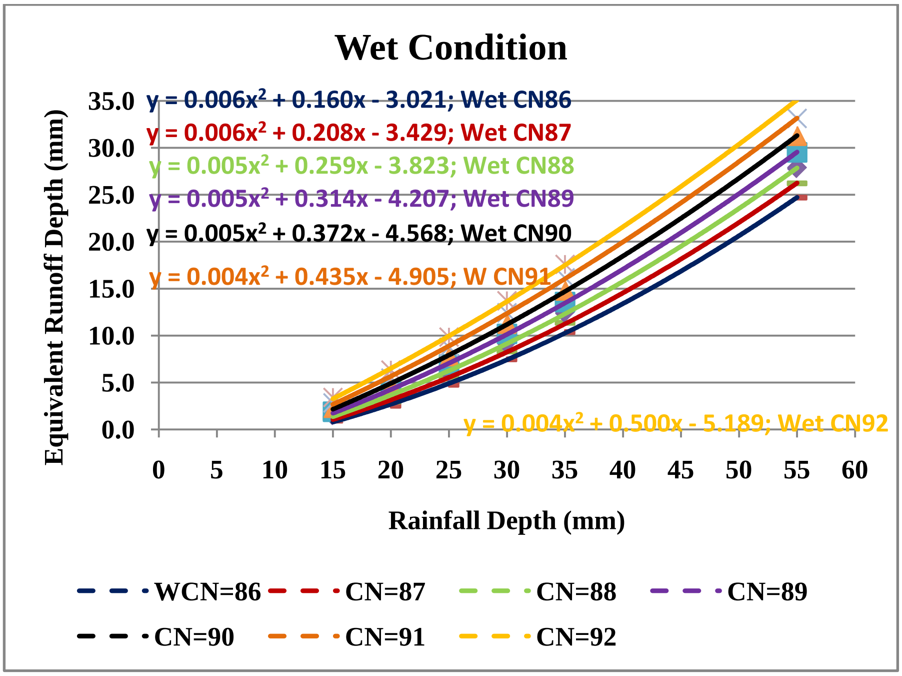

Figure 5-B: Equivalent Runoff Depth- Rainfall Depth relationship for wet condition.

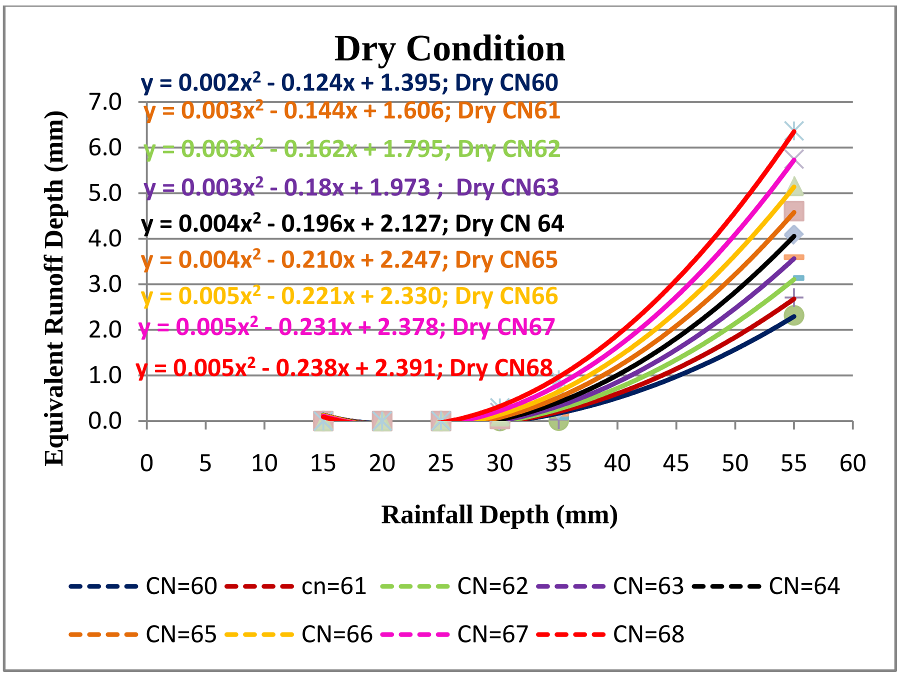

Figure 5-C: Equivalent Runoff Depth- Rainfall Depth relationship for dry condition.

depths and curve numbers were based on the studied and extrapolated results of previous research of rain water harvesting that had been carried out at east of Sinjar area.

Once the size of the catchment area, rainfall depth and the curve numbers for the catchment area are known, then a certain chart of the specific case can be used (Normal, Wet and Dry condition). The intersection values of rainfall depth (on x-axis) with suitable curve number will provide the corresponding value for the equivalent harvested runoff depth on y-axis. In order to find the runoff volume, the equivalent runoff depth should be multiplied by the size of the catchment area taking into consideration the system units. It should be noted that, not all rainfall depths will produce runoff. Nevertheless, low rainfall depth will not produce runoff unless high value of curve number is available for this particular case especially with dry condition; even with some cases of normal condition of low carve number. However Tables (2, 3, and 4) explain the equivalent runoff limitation for the rainfall depth.

Table 2: Equivalent Normal Runoff Depth (mm).

Rain depth (mm)	**CN 76**	**CN 77**	**CN 78**	**CN 79**	**CN 80**	**CN 81**	**CN 82**
15	0.00	0.00	0.01	0.03	0.08	0.16	0.26
20	0.17	0.27	0.39	0.54	0.74	0.96	1.21
25	0.88	1.10	1.36	1.64	2.04	2.41	2.82
30	2.06	2.42	2.80	3.23	3.84	4.36	4.94
35	3.56	4.03	4.55	5.11	5.93	6.60	7.32
55	12.66	13.63	14.65	15.71	17.49	18.70	19.97

Table 3: Equivalent Wet Runoff Depth (mm).

Rain depth (mm)	**CN 86**	**CN 87**	**CN 88**	**CN 89**	**CN 90**	**CN 91**	**CN 92**
15	0.94	1.21	1.52	1.89	2.32	2.83	3.42
20	2.52	2.98	3.49	4.08	4.74	5.48	6.32
25	4.77	5.42	6.14	6.93	7.80	8.77	9.85
30	7.47	8.30	9.21	10.19	11.26	12.43	13.71
35	10.37	11.36	12.43	13.58	14.81	16.15	17.59
55	24.69	26.22	27.83	29.51	31.28	33.14	35.09

Table 4: Equivalent Dry Runoff Depth (mm).

Rain depth (mm)	**CN 60**	**CN 61**	**CN 62**	**CN 63**	**CN 64**	**CN 65**	**CN 66**	**CN 67**	**CN 68**
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
30	0.00	0.00	0.00	0.00	0.01	0.05	0.11	0.19	0.29
35	0.01	0.03	0.08	0.16	0.26	0.38	0.53	0.71	0.91
55	2.32	2.71	3.14	3.60	4.08	4.61	5.16	5.75	6.37

4 Conclusion

Rainfall data is part of the main components in the hydrological cycle and intimately linked with almost all aspect of climate. The future seasonal rainfall during the study period 2020-2099 showed a clear negative trend reflecting the reduction in total seasonal rainfall amount.

For the future rainfall (2020-2099), the maximum, minimum and average harvested runoff volumes reached about 28.5, 7.61, and 13.9 million cubic meters which are supposed to occur during the seasons 2055-2056, 2046-2047, and 2065-2066 respectively.

The comparison of the runoff results between future and historical recorded rainfall for the same study area showed that, the average annual rainfall depth for the study period 1990-2009 was about 325mm, while for the future period 2020-2099 was about 212.3 mm and this is in agreement with the impact of climatic change that predicts reduction in rainfall within the MENA region countries such as Iraq.

The total annual runoff volume for all the catchment area (1990-2009), ranged from 0.12 to 28.19 million cubic meters, and the average annual runoff volume was about 12.52 million cubic meters. Runoff results for the future rainfall, by all catchment areas for the future selected seasons ranged from 7.61 to 28.5 million cubic meters. The calculate average annual runoff volume may reach about 14.6 million cubic meters and the nearest amount for this value is that satisfied in 2065-2066 of 13.9 million cubic meters. It seems that there is not that much change in maximum runoff amounts between historical recorded rainfall and future rainfall. This might be due to a kind of equilibrium between the decrease in the total amount of the seasonal rainfall depths and increase in individual rain storms depths. In general, the individual future rain storm that produces runoff has increased in its rainfall depth and decreased in number of occurrence.

An attempted was made to provide people who are interested with runoff of the study area with a set of charts that are easy to use in order to estimate the equivalent harvested runoff depth (mm) for different selected rainfall depths under different hydraulic conditions for the catchment area at eastern Sinjar district.

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