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The Impact of Meteorological Drought on Rainwater Harvesting in Al-Khoser Basin, Iraq

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Abstract: The relationship between rainfall and runoff is complex and directly related to human life, plants, and animals and their whereabouts. Modeling this process requires a suitable hydrologic model to determine accurate results, such as volume and peak discharge of runoff, that can be adopted in the planning and management of water resources. Many factors affect the quantities of surface runoff that can be saved, including climate change and drought. In this study, HEC-HMS was used and calibrated to estimate the runoff volumes and peak discharge for (1986–2018). The initial and constant methods were considered and used to account for the precipitation loss. Snyder's unit hydrograph (UH) was the transform method. Drought characteristics can be analyzed by calculating the severity and duration of drought using the Modified Chinese Z Index (MCZI). The results showed the possibility of applying a rainwater harvesting system to achieve an abundance of water that compensates for the water scarcity in the study area. The seasonal surface runoff ranged from 1361.3-19706.8 ($\times 10^3$ m^3) during the study period (1986–2018). Regarding the drought intensity, the region experienced its most severe period in 2007–2008, with a rate of 4.63, followed by 1998–1999 at a rate of 2.48. Both are classified as extreme drought. The study revealed that certain years had a higher intensity of drought and resulted in better water collection than other years when the area was affected by drought.

تأثير الجفاف على حصاد مياه الأمطار في حوض الخوصر، العراق

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قسم هندسة السدود والموارد المائية / كلية الهندسة / جامعة الموصل / الموصل – العراق.

الخلاصة

تعتبر علاقة الامطار-الجريان السطحي عملية معقدة وترتبط ارتباطًا مباشرًا بحياة الإنسان والنباتات والحيوانات وأماكن وجودهم. تتطلب نمذجة هذه العملية نموذجًا هيدرولوجيًا مناسبًا من أجل تحديد نتائج دقيقة لحجم وذروة تصريف الجريان السطحي الممكن استخدامها في تخطيط وإدارة الموارد المائية. تؤثر العديد من العوامل على كميات الجريان السطحي التي يمكن حفظها، وفي مقدمتها تغير المناخ والجفاف. في هذه الدراسة تم استخدام HEC-HMS ومعايرته لتقدير أحجام الجريان السطحي وذروة التصريف للفترة من ١٩٨٦ الى ٢٠١٨. تم استخدام الطريقة الأولية والثابتة (Initial and Constant) لحساب فواقد الامطار. تم استخدام وحدة هيدروغراف سنايدر(Snyder's UH) كطريقة لتحويل المطر الزائد الى سيح مباشر. ومن ثم تم تحليل خصائص الجفاف بالاعتماد على مؤشر Z الصيني المعدل (MCZI). أظهرت النتائج إمكانية تطبيق نظام حصاد مياه الأمطار لتحقيق وفرة المياه التي يمكن استخدامها لتعويض ندرة المياه في منطقة الدراسة. تراوح الجريان السطحي الموسمي ١٣٦١,٣-١٩٧٠٦,٨ (* ١٠٣ م٣) خلال فترة الدراسة ١٩٨٦-٢٠١٨. ومن حيث شدة الجفاف، شهدت المنطقة أشد فتراتها في الفترة ٢٠٠٧-٢٠٠٨، بمعدل ٤,٦٣، تلتها الفترة ١٩٩٨-١٩٩٩ بمعدل ٢,٤٨، وكلاهما مصنف على أنه جفاف شديد. وكشفت الدراسة أن سنوات معينة شهدت كثافة جفاف أعلى وأدت إلى جمع أفضل للمياه مقارنة بالسنوات الأخرى التي تأثرت فيها المنطقة بالجفاف.

الكلمات الدالة: HEC-HMS، حصاد مياه الأمطار، مؤشر Z الصيني المعدل، الجفاف.

1.INTRODUCTION

The ongoing lack of rainfall results in a general shortage of water resources over a period. On the other hand, the reduction in the surface flow rate of water significantly impacts the affected area's environmental, social, and economic systems. Sometimes, the negative impact of the above will be maximized when the local conditions are combined with drought in the region. In fact, what was stated above is a description of Iraq's suffering due to wrong planning and management of water resources (in Iraq) policies, besides the climate change and water policies effect of neighboring countries that significantly decreased the Tigris and Euphrates Rivers discharge inside Iraq. Iraq's current conditions need to develop a strict water policy and the adoption of new sources of water, such as relying on rainwater harvesting systems (RWH) in Al-Ansari [1]. Boers and Ben-Asher [2], RWH is an old-new technique defined as a method for collecting and storing surface runoff for irrigation purposes or Critchley and Siegert [3] for productive use. Al-Ansari et al. [4] It is believed that the RWH systems may represent a key solution to treat and mitigate the negative effects of drought and a lack of water resources in arid and semi-arid areas, where the potential of these systems is very effective for saving water. Zakaria et al. [5] Furthermore, RWH is an effective technique to collect excess rainwater (surface runoff) from a large catchment area, store it in a small earthen dam reservoir, and exploit the water for various purposes. [6, 7] encouraging results from several studies worldwide have proven that RWH measured on a large scale may alleviate water scarcity even during severe drought years. In Iraq, many studies have been conducted to investigate the significance of RWH in Iraqi watersheds. Abdullah and Al-Ansari [8] conducted an overview of water harvesting existence in Iraqi watersheds. The authors specified three main regions of RWH dams: Northern, Eastern, and Western regions of Iraq. They explained that RWH in Iraq is a limited project in exploiting the available capacity. Sediment problems will appear and face the RWH dams; however, there are not enough observed hydrograph measurements. They conclude that Iraq is suffering from water shortage problems. To overcome this problem or minimize its effect, water harvesting techniques can be used. Two other vital studies about Iraqi watersheds [9, 10] highlighted the importance of choosing optimal RWH dam sites on the borders of riparian countries. Al-Aqeeli et al. [9] studied an individual and multi-reservoir system along the Iraq-Turkey borders. Meanwhile, Rahi et al. [10] concentrated on the Iraq-Iran borders, utilizing individual reservoirs. The conclusions of both studies showed that saving harvested water significantly benefited Iraq and Turkey, as well as Iraq and Iran. Hamdan et al. [11] modeled rainfall-runoff events using the HEC-HMS model for the Al-Adhaim River catchment area in Northern Iraq. The researchers used the HEC-HMS model with historical rainfall data (2015–2018), i.e., Soil Conservation Service-Curve number (SCS-CN) for loss method of HEC-HMS, SCS Unit Hydrograph for transformation method, and Muskingum methods for routing. They calibrated and verified the model. Their results showed good agreement between observed and simulated hydrographs, and the model reliably estimated the runoff discharge of the study basin. Limited studies are available for studying RWH in the Al-Khoser watershed; however, Saadallah and Ezz-Aldeen [12] used the Soil and Water Assessment Tool (SWAT) to estimate the runoff depth at the Al-Khoser watershed. The calibration and verification of the model were based on observed data. To evaluate the model performance, they used determination coefficient, index of agreement, model efficiency, and t-test. They obtained daily and yearly formulas between runoff and rainfall depths that may estimate the runoff depth of the watershed directly. Younes [13] studied the runoff hydrograph of the Al-Khoser watershed using the Soil Conservation Services Curve Number (SCS-CN) method. The TR-55 model of the Watershed Modeling System (WMS) was used in this study. TR-55 was calibrated, and then the model performance was evaluated based on Nash-Sutcliffe efficiency and the index of agreement. The results showed a good agreement between observed and calculated hydrographs. The estimated normal condition curve number (CN) value was about 73.0. Ezz-Aldeen [14] developed a conceptual mathematical model to simulate runoff and soil erosion events for a single storm events at the Al-Khoser watershed. The model was calibrated using hydrograph data of five rainfall-runoff events the researcher measured during 2003-2004. Model output was compared with observed runoff and sediment concentration hydrograph based on four statistical criteria: t-test, determination coefficient (R^2), model efficiency (EFF%), and percent of error (E%). The calibration results indicated that the model reasonably estimated the runoff hydrograph and evaluated the transport capacity of sediment concentration for un-gauged watersheds. The common points of the above studies are that they used one of the appropriate hydrological models for each available data and the study area, where the historical data of rainfall was employed to estimate the expected runoff. Then, the model was calibrated based on the availability of observed hydrograph data. Certainly, when the rainfall decreased (without a change in the rainfall distribution), the amount of runoff decreased. However, the rainfall reduction may lead to a drought that the above studies have not dealt with. Therefore, a quick review of some studies that have dealt with drought inside and around Iraq will broaden our understanding of the factors affecting rainwater harvesting. Drought is a natural occurrence that affects vast areas of the earth's surface, particularly in arid and semi-arid regions. Drought impacts can be devastating, causing environmental, economic, and social disasters. The main causes of drought are a deficiency in rainfall and human activities (mining and deforestation), leading to an imbalance in the hydrological cycle system [15, 16]. Other studies [17, 18] attributed the reason to population expansion and climate change. Tannehill [19] the world is facing a set of climate changes. Different studies worldwide showed that frequent and severe droughts, heat waves, storms, floods, and other climate extremes are the most characterized climatic changes our world will face [20, 21]. IPCC [22] Climate change will increase the stress on the available water . Combating drought requires addressing the lack of water resources, which is not an easy issue to address. Short periods of severe drought can cause damage and economic losses to societies. Therefore, several drought indicators were used to examine various elements of drought, such as length, frequency, severity, and intensity. Key indicators include the Standardized Precipitation Index (SPI) [23, 24], the Standardized Precipitation Evapotranspiration Index [25], Palmer's Drought Severity Index [26], Wu et al.'s (2001) China Z Index [27], Van Rooy's Rainfall Anomaly Index [28]. The Z Index (ZI) has been widely used in various investigations [29, 30]. Shahabfar and Eitzinger [31] is a good example of using a group of meteorological drought indices, including percent of normal (PN), standardized precipitation index (SPI), China-Z index (CZI), modified CZI (MCZI), Z-Score (Z), and the aridity index of E. de Martonne (I). These indices were used to assess the drought in Iran. The results showed that the Z-Score, CZI, and MCZI are good meteorological drought predictors. Numerous studies have been conducted worldwide to monitor and analyze droughts, such as in Jordan [32], Turkey [33], Iran [34], and Iraq, for example but not limited to [35-40]. None of the above studies pay attention to the effect of drought on rainwater harvesting. The present study attempts to bridge the gap between rainwater harvesting and the effect of drought on it. The study investigates the features of drought using the MCZI index. Also, it assesses the meteorological drought impact on the rainwater harvesting volume estimated by the HEC-HMS model at Al-Khoser Basin. No prior research has explored the drought characteristics using the MCZI index in this region, nor has any study examined the effect of climatic drought on water harvesting in the Iraq region.

2. STUDY AREA AND DATA

2.1. Study Area, Topography, and Soil Types

Iraqi watersheds are distributed in various regions, including semi-arid areas. Most of the Iraqi watersheds are seasonal. The Al-Khosar watershed is an example of the seasonal Iraqi watersheds; also, it is linked to the history and civilization of Nineveh. The area of the AL-Khoser watershed (as shown in Fig. 1), about 654 km² and 50 km northeast of Nineveh Governorate in Iraq, was selected to test the drought and the response to the potential of rainwater harvesting. Al-Khoser watershed is bounded by 36° 50´ 00" north, 36° 27´ 23" south, 43° 25´ 00" east, and 43° 05 00" west.

The length and slope of the AL-Khoser watershed are about 49.8 km and 0.16 m/m along the main channel from the outlet to the upstream boundary, respectively. The Global Digital Elevation Model (GDEM) with 30 m resolution was used to define the Al-Khoser watershed and its physical characteristics. The topography of the AL-Khoser watershed varies in elevation from a steep slope at the northern part (with a maximum elevation of 1233 m.a.s.l.) to a semi-flat area near the outlet. The major part of the area, i.e., 74.0%, is plain, with an elevation varying between 260 and 500 m.a.s.l. over about 39 km. Mainly, the land of the AL-Khoser watershed can be divided into two parts: (i) the bare soil throughout the year, i.e., not available for agricultural use due to a high infiltration rate, and represents about 27.0% of the total area of the watershed, (ii) agricultural and pasture, representing about 73% of the total area. These lands are usually used for wheat, barley, olive tree agriculture, and the natural plants for pastures. Some villages with a limited population are also available inside the Al-Khoser watershed. Three types of soil are available at the AL-Khoser watershed: silty clay loam, silty clay, and silty loam [14, 42].

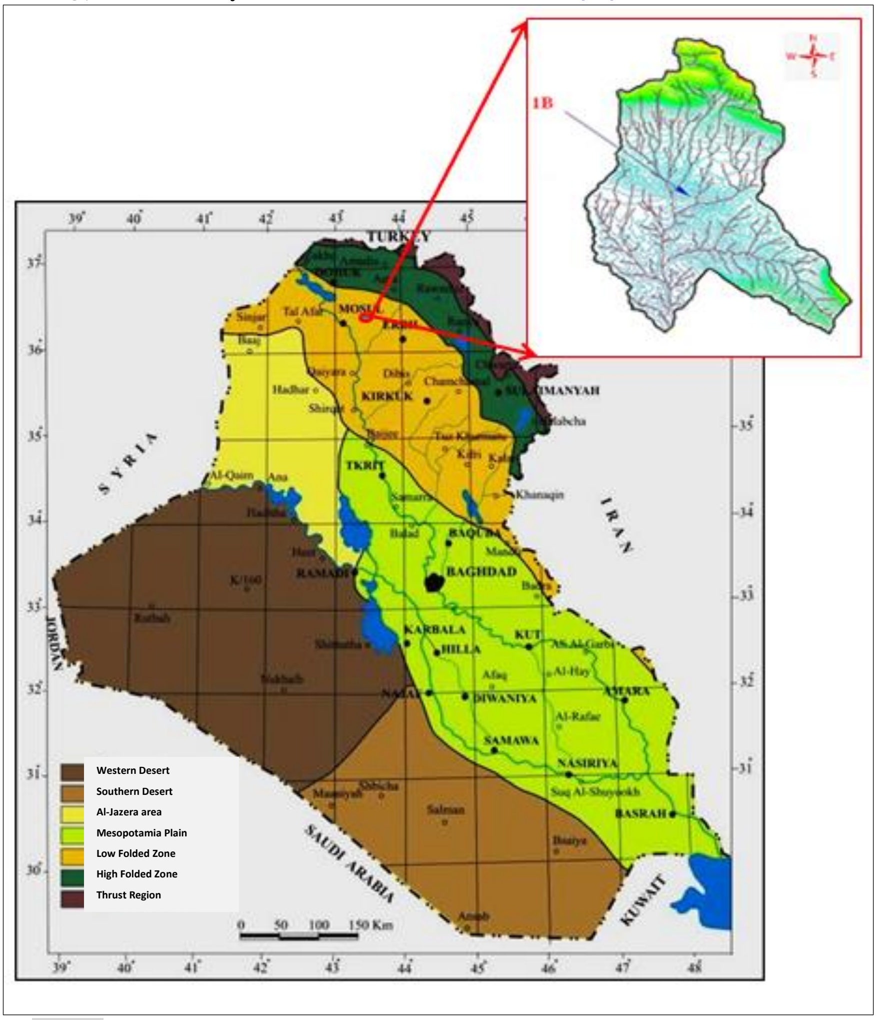

Fig. 1 AL-Khoser Watershed Location According to Iraq Map [8, 41].

2.2. Rainfall and Runoff Data

The meteorological Mosul station-Iraqi Department of Meteorology and Seismic Monitoring data was considered for 1985-2018 (Fig. 2). The data represents 33 rainy seasons. The maximum seasonal rainfall depth was achieved in the 2015–2016 season, reaching 475 mm. Meanwhile, the minimum seasonal rainfall depth was achieved during the 1999–2000 season, reaching 116 mm. The average rainy season may be represented by the rainy 2010–2011 season, with a total rainfall depth of 255 mm. For the AL-Khoser watershed, a data set of observed surface runoff hydrographs observed during 2003–2004 for individual rain events of different depths of 9, 17, 18, and 19 mm is available. The maximum discharges of the observed hydrographs were about 4.7, 54.0, 51.0, and 66.0 m3/sec, respectively. The homogeneity test of the monthly rainfall series was analyzed using Pettitt tests, as described by Pettitt [43]. The analysis was conducted using the XLstat program. The results for the monthly rainfall series indicated that the Mosul station exhibited homogeneity across all months at a significance level of 0.05. The p-values obtained from the Pettitt test ranged from 0.06 to 1.2.

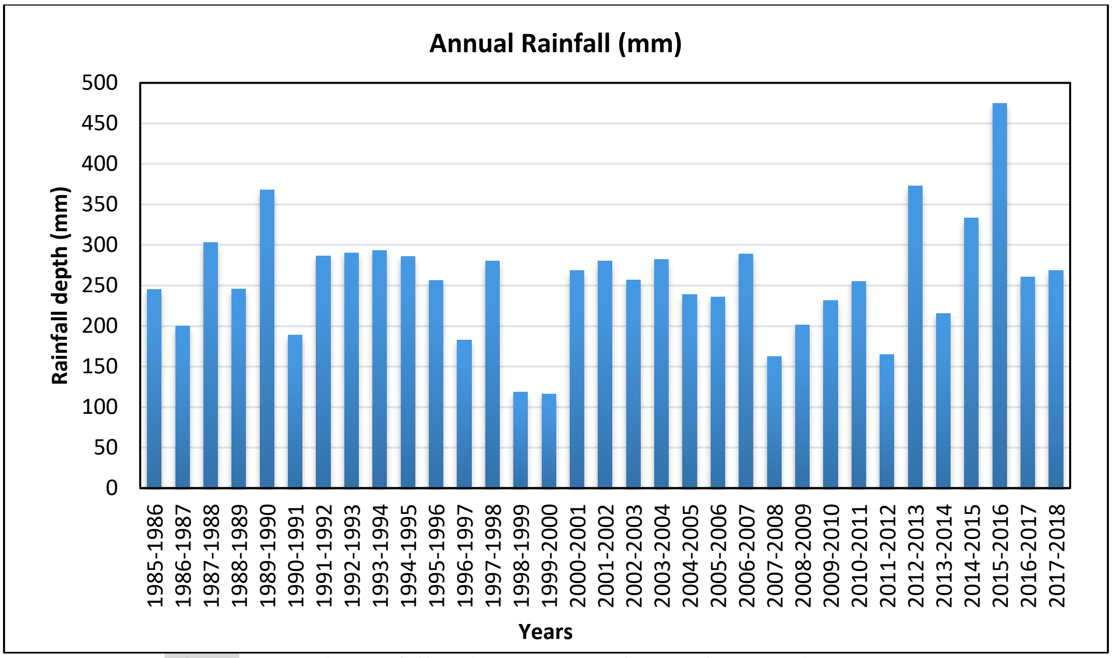

Fig. 2 Annual Rainfall Values During the Study Period 1985-2018.

3. METHODOLOGICAL

3.1. Modified Chinese Z Index (MCZI)

The National Climate Center of China developed this index based on the Pearson Type III distribution [44],[45]. The MCZI value is determined using the following equation.

$$\mathrm{MCZI} = \frac{6}{C_{v_i}}\left(\frac{C_{vij}}{2}\lambda_{ij} + 1\right)^{1/3} - \frac{6}{C_{vij}} + \frac{C_{vij}}{6} \qquad \textbf{(1)}$$

where MCZI value is the drought index, i is the time standard that equals 1, 2, 3, ..., 72 months, and j is the month. The current study ignored parameter i because Z values are only for one month. Cv is the deviation coefficient, and λ is the standard variable. Cv and λ can be calculated from:

$$\mathrm{Cv} = \frac{\sum_{j=1}^{n}(y_{ij}-\bar{y}_i)^3}{n\,\sigma_i^3} \qquad \textbf{(2)}$$

$$\lambda = \frac{y_{ij}-\bar{y}_i}{\sigma_i} \qquad \textbf{(3)}$$

Where n is the time series length, y_{ij} is the monthly rainfall amount, and $\bar{y}$ is the median of rainfall. Table 1 was used in this study to classify drought.

Table 1 Drought Classification Based on the Modified Chinese Z Index [52].

MCZI	Classification
≥2	Extreme wet
1.5 to 1.99	Severe wet
1 to 1.49	Moderate wet
-0.99 to 0.99	Normal
-1.49 to -1	Moderate drought
-1.99 to -1.5	Severe drought
2≥	Extreme drought

Positive MCZI values indicate humid years with above-average rainfall, while negative values indicate dry years with below-average rainfall. Drought characteristics can be analyzed by calculating the drought severity and duration. The dry period (D) is the number of consecutive months or years with an MCZI value less than zero. Drought severity (S) is measured by the absolute value of the cumulative sum of consecutive MCZI values during the drought period, and drought severity is determined using the following equation [16].

$$S = \left|\sum_{i=1}^{Di} \mathrm{MCZI}\right| \qquad \textbf{(4)}$$

3.2. Rainwater Harvesting (RWH)

A Digital Elevation Model (DEM) of the study area was used with the Watershed Modeling System (WMS) to characterize the watershed [47, 48]. The outlet of the Al-Khoser basin was selected as the location for building the rainwater harvesting dam considering the topography and the geology investigation of the area based on previous studies [14, 42, 49, 50]. Global Mapper Software (GM) was applied to test the cross section for the dam site and specified the available height of the site, which was used as the maximum height of the RWH dam. The dam site was selected on the higher degree stream flow order. Then, the HEC-HMS model was applied to investigate the potential of rainwater harvesting using the individual depth of rainfall storms for the entire study period. After information gathering, the HEC-HMS was run, and the calibration process was performed according to the objective functions of percent error in peaks and volumes, in addition to Mean Abs Error, Root Mean Squared Error, and Nash-Sutcliff Efficiency.

3.2.1 HEC-HMS Model

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is a physically-based, semi-distributed hydrologic model developed by the US Army Corps of Engineers to simulate the hydrologic response of a watershed subject to a given hydrometeorological input Scharffenberg et al.[51]. The HEC-HMS project consists of four components: (i) the basin model, which represents the watershed physical properties and includes hydrologic elements connected in a dendritic network (sub-basin, reach, junction, reservoir, diversion, source, and sink) for simulating the water movement of the watershed, (ii) the meteorological models, which prepared the meteorological boundary conditions for subbasins,(iii) the control specifications, used to control the time interval of simulation and include a starting date and time, an ending date and time, and a computation time step, and (iv) the time-series data that represent the time-series of precipitation data for estimating basin-average rainfall and observed discharge data, which are very useful for the calibration process. Time-series data was stored in a project as a gage Scharffenberg et al. [51]. The hypothetical storms of the Soil Conservation Service (Type I) were selected and used with the HEC-HMS model. Type I represents areas of climates with generally wet winters and dry summers in USDA [52]. The HEC-HMS uses separate models that compute the precipitation loss and runoff volume.

3.2.2 Loss Method

In this study, the constant methods were considered and used to account for the precipitation loss. The method includes two parameters, constant rate and initial loss (Ia), which represent the physical characteristics of the soil, land use, and antecedent conditions of the study area. The initial loss (Ia) tends to be zero for saturated soil conditions. In contrast, for dry soil conditions, it increases and reaches the maximum rainfall depth of the watershed with no runoff, which will depend on the watershed terrain, land use, soil types, and soil treatment. Ia value varies for forest areas. It is between 10 and 20 percent of the rainfall, while for urban areas, it is between 0.1 and 0.2 inches. On the other hand, the constant loss rate can be used to represent the soil's final infiltration capacity. Soil conservation services classified soils considering their infiltration capacity. Skaggs and Khaleel [53] estimate the values of these infiltration rates, as shown in Table 2. The model parameter is not a measured parameter; therefore, the model parameter and the initial condition are best determined by calibration [54].

Table 2 Soil Groups and Infiltration Loss Rates.

Hydrological Soil Groups	Soil Texture	Infiltration (mm/Hr)
A	Sand, Loamy Sand or Sandy Loam	7.62-11.43
B	Silt Loam or Loam	3.81-7.62
C	Sandy Clay Loam	1.25-3.81
D	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay or Clay	0-1.25

3.2.3 Transform Method of Snyder-Unit Hydrograph (UH)

The HEC-HMS model requires the Transform Method that specifies converting the excess rainfall to point runoff. In this study, Snyder's Unite hydrograph (UH), which requires specifying the standard lag time (tp) and the peaking coefficient (Cp), was used. Snyder related basin lag time with the basin characteristic as follows:

$$tp = C\,Ct(L\,Lca)^{0.3} \quad \textbf{(5)}$$

where tp= basin lag time (hr), C= 0.75 for SI system, Ct= timing coefficient (range from1.35 to1.65), L= length of mainstream from the outlet to the divided (km) (L = 41929.14 m), and Lca= length along mainstream to a point nearest the watershed centroid (km) (Lca= 25116.93 m).

For the standard case, Snyder discovered that UH lag and peak per unit of excess precipitation per unit area of the watershed were related by:

$$\mathrm{Up} = \mathrm{C\,Cp}\,\frac{\mathrm{A}}{\mathrm{tp}} \qquad \textbf{(6)}$$

where Up = peak of standard UH, A = watershed drainage area, Cp = UH peaking coefficient (ranges from 0.56 to 0.69), which depends on the watershed storage and retention characteristics, and C = conversion constant (2.75 for SI or 640 for foot-pound system) [54].

3.2.4 Model Calibration

After the development of HEC-HMS, the initial values of parameters (constant rate, initial loss, basin lag time, peaking coefficient) were entered into the HEC-HMS model to compute the runoff hydrograph. The calibration process was used with the observed runoff discharge data of the Khoser basin (recorded on February $22^{nd}22^{nd}$, 2003, with the maximum discharge of the observed hydrograph of 51 m3/sec produced by an individual rainfall storm of 18 mm depth). The parameters were adjusted until the observed and simulated hydrographs were fitted and well matched, i.e., the difference between the observed and simulated hydrographs was decreased. The results of calibration are explained in Table 3 and Fig. 3.

Table 3 Results of Calibrated Parameter.

Values	Constant Rate (mm/hr)	Initial Loss (mm)	Basin Time (hr)	Lag Peaking Coefficient
Calibrated Values	3.0	5.5	3.78	1.0

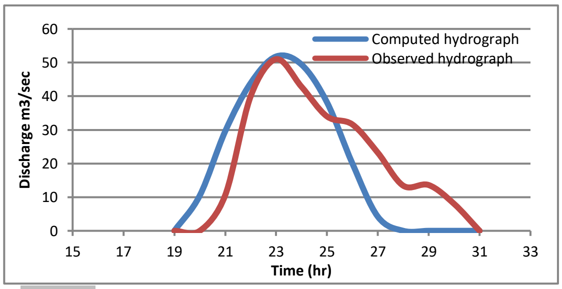

Fig. 3 Results of Calibration, Observed, and Computed Hydrograph.

3.2.5 Model Evaluation

Different criteria may be used to evaluate the performance of a hydrological model to reach a good agreement between the predicted (simulated) and observed (measured) variables, such as peak runoff discharges and runoff volume. The following statistical criteria identified the performance accuracy of the HEC-HMS model for the simulation process and assessed the match between model and observation: Mean Absolute Error (MAE), i.e., the average error; RMSE (Root Mean Square Error), i.e., the difference between the predicted and observed values; Percent Error in Peak Flow (PEPF); Percent Error in Volume (PEV); and Nash-Sutcliff Efficiency (NSE) [55]. These criteria are given by:

$$\text{MAE} = \frac{\sum_{i=1}^{n}|Pi-Oi|}{n} \quad \textbf{(7)}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Oi-Pi)^2}{n}} \quad \textbf{(8)}$$

$$\text{PEPF} = 100 * \frac{(Qo - Qs,)}{Qo} \quad \textbf{(9)}$$

$$\text{PEV} = 100 * \frac{(Vo-Vs)}{Vo} \quad \textbf{(10)}$$

$$\text{NSE} = 1 - \frac{\sum_{i=1}^{n}(Oi-Pi)^2}{\sum_{i=1}^{n}(Oi-ý)^2} \quad \textbf{(11)}$$

$$ý = \frac{\sum_{i=1}^{n} Oi}{n} \quad \textbf{(12)}$$

Where PEPF = Percent Error in Peak flow; PEV = Percent Error in Volume; Qo is observed peak flow; (Qs) is the simulated peak flow; Vo is the volume of the observed (simulated) hydrograph; (Vs) is the volume of the simulated hydrograph. NSE = Nash-Sutcliff Efficiency, Oi = observed values of the hydrograph, Pi = simulated values of the hydrograph, and ý = arithmetic mean of the observed values. The statistics results are tabulated in Table 4.

Table 4 Statistical Criteria with Computed and Observed Values of Peak Discharge and Volume of Runoff.

	Computed	Observed on 22th Feb.2003	Mean Abs Error (m^3/sec)	RMS Error (m^3/sec)	PEPF %	PEV %	Nash-Sutcliff Efficiency
Peak discharge (m^3/sec)	51.8	51.0	5.4	3.7	1.56	13.8	0.783
Volume*10^3 m^3	891.1	1034.6					

4. RESULTS AND DISCUSSIONS

4.1 Rain Water Harvesting

The results (Fig. 4) showed that the Al-Khoser Basin responded to the potential of the RWH system; each volume of the individual rainy storm that exceeded the total water amount that intercepted, infiltrated, stored, evaporated, and transpired will enter and stored in the rainwater harvesting reservoir as a direct runoff volume. The amounts of seasonal volume of direct runoff varied throughout the study seasons and ranged (31.4 - 19706.8) ×10^3 m^3 with an average of 4251.4 ×10^3 m^3 during the seasons 2007-2008, 2001-2002, and 2006-2007. The main reasons for the different volumes of harvested water for the same study basin along the study period can be summarized in two points. The first is the individual depth of the rainstorm and the rainy season pattern. The second is the hydrological condition that covers the study basin, represented by the dry or wet (saturated) condition resulting from important, influential factors of watershed terrain, land use, soil types, and soil treatment. For an understanding of the relationship between rainfall-runoff events, four seasons were selected and summarized in Tables 5 and 6. These tables include the maximum, average, and minimum rainfall seasons that occurred during 2015-2016, 2010-2011, and 1999-2000 with total rainfall depths of 475, 255, and 116 mm, respectively, in addition to a fourth season (2001-2002) of total rainfall depth of 280 mm that produced maximum runoff volume of 19706.8×10^3 m^3. Table 5 shows the number of rainy days with the rainfall depth range. The maximum number of days without rainfall was (206) during the minimum rainy season (1999-2000), while there were (28) rainy days that did not exceed the rainfall depth of (5) mm, which could not produce any surface runoff storm because it did not exceed the initial loss of 5.5 mm. There were (7) rainy days with a rainfall depth range of (5-15) mm, which refined the hydrological condition and kept it away from the dry description. In other words, the total number of rainy days that exceeded a depth of (15) mm was about (3) days, producing surface runoff storms, and so on for the rest of the seasons. Table 6 shows the rainfall-runoff events for the selected four seasons. During the maximum rainy season (2015-2016), its maximum rainfall depth was about (32.7 mm) with a total rainfall depth of (475 mm). These rainfall events produced (11) runoff storms that entered and accumulated in the rainwater-harvesting reservoir with a total volume of (14818.6 ×10^3 m^3). Furthermore, Table 6 shows several rainstorms that direct runoff (DR) storms that entered and accumulated in the rainwater harvesting reservoir. The season with a maximum rainfall depth may not produce a maximum volume of DR due to the overlap of the influence of the factors mentioned earlier. The number of shallow rainstorms did not increase the volume of the DR due to losses of abstraction and infiltration process. For further clarification, the four seasons were drawn (Figs. 5- 8), showing the numbers and distribution of the rainfall and DR storms.

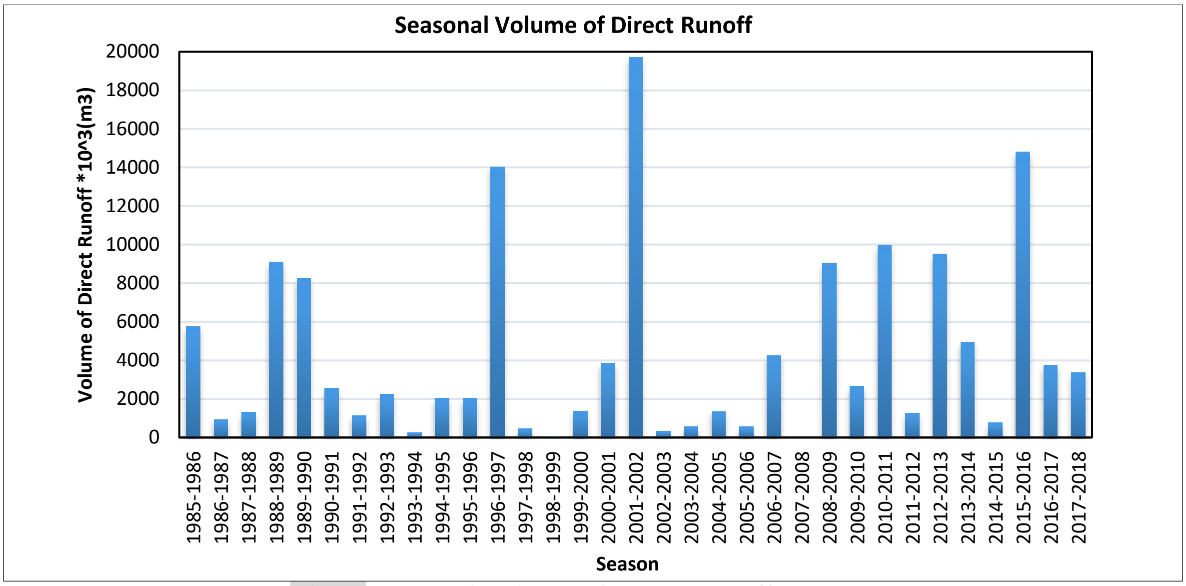

Fig. 4 Seasonal Volume of Direct Runoff (×10³ m³).

Table 5 Day's Events of Rainfall Patterns for the Selected Four Seasons.

Storms events	2015-2016	2010-2011	1999-2000	2001-2002
no rainfall	134	127	206	189
0.1-5.0 (mm)	82	105	28	38
5.0-15 (mm)	21	9	7	13
> 15.0 (mm)	7	3	3	4

Table 6 Rainfall-Runoff Events for the Selected Four Seasons.

Storms Events	2015-2016	2010-2011	1999-2000	2001-2002
Max. Daily Rainfall Depth (mm)	32.7	44.7	17.3	48.0
Total Season Rainfall Depth (mm)	475	255	116	280
No. of Runoff Storm	11	6	2	5
Total Runoff Volume *10³ m³	14818.6	9989.7	1361.3	19706.8

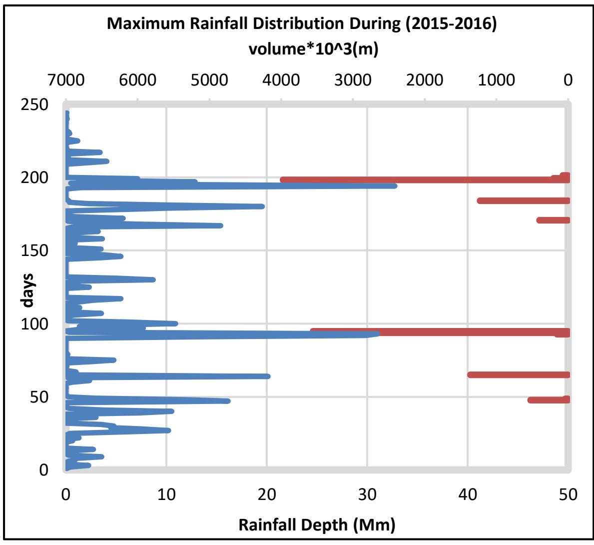

Fig. 5 Maximum Rainfall Distribution During (2015-2016).

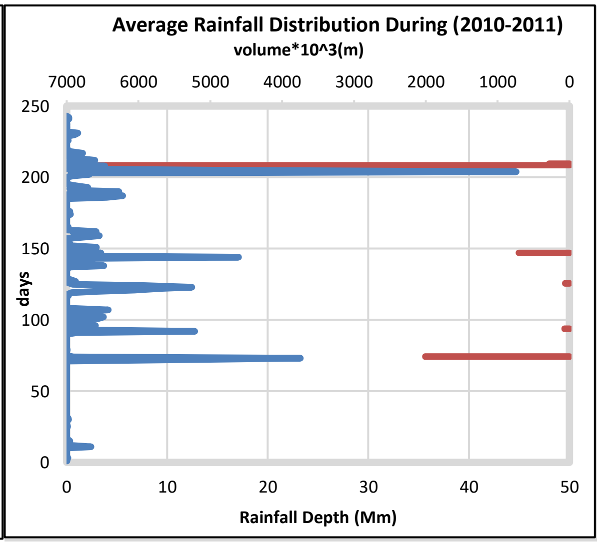

Fig. 6 Average Rainfall Distribution During (2010-2011).

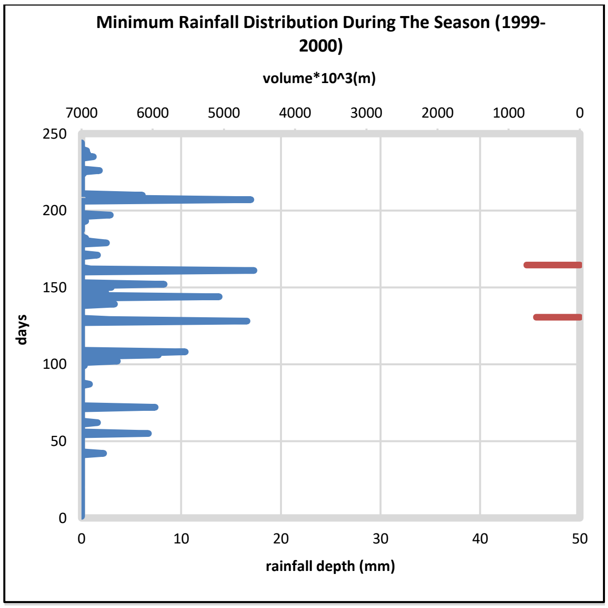

Fig. 7 Minimum Rainfall Distribution During the Season (1999-2000).

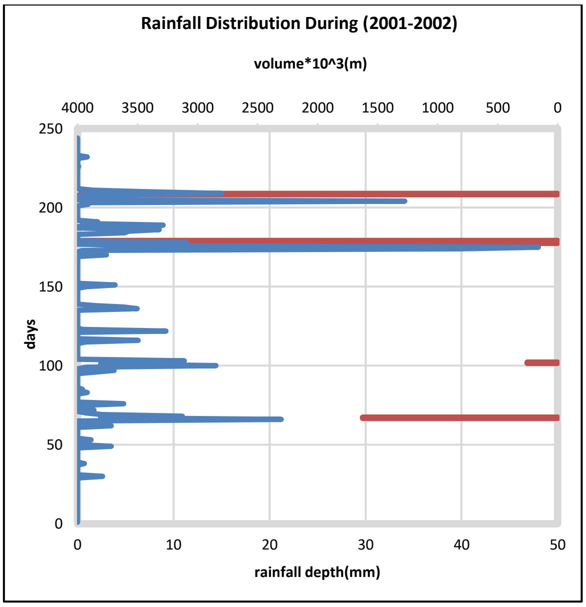

Fig.8 Rainfall Distribution During (2001-2002).

4-2. The Meteorological Drought Impact on Rainwater Harvesting

Drought periods and severity, derived based on the Modified Chinese Z Index (MCZI), were combined with the runoff volume estimated by the HEC-HMS model. The details are included in Tables 7 and 8. The rainy months start from October to May, presenting the water year in Iraq. The characteristics of the study period that extended from 1985 to 2018 were calculated. Each occurrence of a drought period was diagnosed. The accumulative values of MCZI were calculated. The daily runoff volumes of the drought periods were estimated and presented as monthly accumulated. The first drought period was found during May 1985-Jan 1986, in which the accumulative MCZI reached (2.36) during the only five rainy months (May, Oct., Nov., Dec., and Jan.). The total volume and monthly average of harvested water reached about (836.3 $\times 10^3$ m^3) and (167.26$\times 10^3$ m^3), respectively. The results showed (Table 7) that the drought periods of Dec. 1986- Feb 1987, Feb. 2000 - Apr. 2000, and Oct. 2001- Dec. 2001 had the highest amount of harvested water compared with other drought periods. In the study area, their values reached 515.28, 1361.2, and 1620.51 ($\times 10^3$ m^3). Conversely, no harvested water was available during Apr. 1989 - Oct. 1989, Apr. 1991 - Oct. 1991, May 1995 -Dec. 1995, and Dec. 2006 - Feb 2007 because the study area was exposed to drought intensities of (2.01, 2.13, 3.04, and 2.77), respectively, based on the MCZI index. The results indicated significant drought periods with the highest intensity in the study area. The high value of accumulated drought (Nov.2007- Oct. 2008) was (7.96). During this period, the total amount of harvested water was (722,080 m^3), and the average monthly volume of harvested water was (92,600 m^3). From November 1998 to May 1999, there also was an intensity drought with a rating of (5.17); the total amount and average monthly volume of harvested water reached about (38500) and (5500) m^3, respectively. The drought intensity in the period (2007-2008) was more significant than (1998-1999), while the average monthly volume of harvested water was more significant than (1998-1999). This result may be due to one or more rainfall characteristics (distribution, depth, and intensity). The above result repeated during the periods of May 1988 - Nov. 1988 and Feb. 2000 - Apr. 2000, where the drought intensities were 1.29 and 2.5, and the total amount and average monthly volume of harvested water reached about 362880, 120960, 1361200, and 340300, respectively. The result may be summarized as follows: with high drought intensities, more water harvesting can be produced at good conditions of rainfall characteristics (distribution, depth, and intensity) are available. Table 8 shows drought based on the seasonal period, where the drought intensity in the study area was determined using the MCZI index and calculated for the water year from October to May. The highest drought intensity occurred in 2007-2008, with a rate of 4.63, followed by 1998-1999, with a rate of 2.48, classified as extreme drought. Moderate drought was experienced in 1999–2000, 2008–2009, and 2011–2012, with intensities of 1.66, 1.04, and 1.55, respectively. The severity of the drought ranged from (0.01 to 0.92) for the remaining years. The volume of harvested water during the drought periods significantly varied. The maximum volume reached 10,050,900 m^3 harvested during the season of (2010–2011) at a drought intensity rate of 0.07, while the minimum volume of harvested water (31,400 m³) was during the extreme drought that occurred during the season (2007–2008) at a rate of 4.63. Despite some seasons having high drought intensity, their volume of harvested water was larger than other seasons with a low drought intensity. For example, the moderate drought in (2008–2009) resulted in collecting more water (9,056,500 m³) than other light drought years. It can be concluded that the rainfall distribution, depth, and intensity impacted the water harvested during a climatic drought more than the severity of the drought itself. Therefore, rainwater harvesting can collect water in the study area even during climatic drought periods.

Table 7 The Monthly Drought Intensity by MCZI and the Volume of Water Collected.

Duration of Drought	Accumulative MCZI	No. of Months	Volume ×10³ m³	Avg. monthly Volume ×10³ m³
May 1985-Jan.1986	2.36	5	836.3	167.26
Dec. 1986- Feb 1987	2.59	3	515.28	171.76
May 1988 – Nov. 1988	1.29	3	362.88	120.96
Apr. 1989 – Oct. 1989	2.01	3	0.0	0.0
May 1990 – Feb. 1991	3.55	6	134.58	22.43
Apr. 1991 – Oct 1991	2.13	3	0	0
May 1995 –Dec. 1995	3.0	4	0	0
Nov 1998 – May 1999	5.17	7	38.50	5.5
Feb. 2000 – Apr. 2000	2.5	4	1361.20	340.3
Oct. 2001- Dec 2001	1.56	3	1620.51	540.17
Nov. 2005 – Jan 2006	1.44	3	272.40	90.8
Dec. 2006 – Feb 2007	2.77	3	0	0
Nov. 2007- Oct. 2008	7.96	8	722.08	90.26
Jan. 2015- May 2015	3.08	5	745.0	149.0
Jan 2017 – Mar. 2017	4.54	3	30.0	10.0
Dec. 2017– Oct. 2018	2.27	3	0	0

Table 8 Seasonal Drought Severity Depending on the MCZI and the Volume of Water Collected.

Years	MCZI	Volume *(10³) m³
1985-1986	-0.06	6029.2
1986-1987	-0.6	1016.5
1988-1989	-0.33	9113.9
1998-1999	-2.48	38.4
1999-2000	-1.66	1361.3
2002-2003	-0.22	329.4
2006-2007	-0.11	4251.4
2007-2008	-4.63	31.4
2008-2009	-1.04	9056.5
2010-2011	-0.07	9989.7
2011-2012	-1.55	2512.6
2013-2014	-0.08	6193
2014-2015	-0.01	979.1
2016-2017	-0.92	3790.2
2017-2018	-0.21	3357.6

5. CONCLUSIONS

Several factors influence the surface runoff amount in the catchment area during climate change and drought. In this study, the impact of meteorological drought on rainwater harvesting was studied for the Al-Khoser basin of Mosul, Iraq, as a selected catchment area. The period (1986-2018) was selected for estimating runoff volumes and peak discharge for the study area using HEC-HMS. The drought characteristics were analyzed by calculating severity and duration using the Modified Chinese Z Index (MCZI). The results suggested that a rainwater harvesting system could alleviate water scarcity in the study area by providing abundant water. During the study period, seasonal surface runoff ranged from 1361.3-19706.8 (×10³ m³) during seasons (1999-2000) and (2000-2001), respectively.
According to the findings, the period of (2008-2009) experienced a moderate drought; however, it still managed to collect 9,056,500 m³ of water, i.e., a higher amount than the other years that only experienced light drought, suggesting that the drought severity had a minimal impact on water collection compared to other factors, such as rainfall distribution, depth, and intensity. Therefore, it can be concluded that the study area might collect water even during periods of climatic drought.

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