



Assessment of Future Climate Change Impacts on Water Resources of Khabour River Catchment, North Of Iraq

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HIGHLIGHTS

- The implemented HEC-HMS model was superior in modeling the streamflow data.
- annual river runoff will likely decrease under all scenarios of RCPs and time stages of the future period.
- CFSR weather data has been successfully used to model the Khabour basin.

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ABSTRACT

In arid and semi-arid areas, assessing the potential impact of climate change on water availability is of critical importance for achieving better management of future water resources. Iraq as one example of those areas is expected to experience more stress on water due to the climatological characteristics and to the rapid population growth in addition to the policy of the riparian upstream countries. Therefore, the present study aims to quantify the impacts of climate change on the Khabour River catchment north of Iraq, which is one of the riparian catchments between Iraq and Turkey. The HEC-HMS model was firstly calibrated and validated against daily streamflow data measured for the period 01Jan2004-30Jun2009 near the catchment outlet at Zakho station. Thereafter, the future climate changes data from the HadGEM2_ES model was fed into the calibrated HEC-HMS model to quantify the future water resources availability. The impacts of climate change on the water under four possible scenarios of RCPs (RCP2.6, RCP4.5, RCP6, and RCP8.5) of atmospheric greenhouse gas (GHG) concentrations for three future slice periods (2021-2030), (2041-2050), and (2061-2070); was assessed in attribution to that from the period (2000-2009). Results show that the implemented HEC-HMS model was superior in modeling the streamflow data. NSE, R² and RMSE value was 0.871, 0.89 and 26.7, respectively, for calibration and 0.936, 0.9364 and 18.0, respectively for validation. The results also suggest that annual river runoff will likely decrease under all scenarios of RCPs and time stages of the future period.

1. Introduction

The increased rates of direct/natural or indirect anthropogenic greenhouse gasses in the atmosphere of the earth have changed the climate in various regions in the world. Greenhouse gases are the major driver of climate change since the beginning of the industrial revolution in the mid of 18th century [1]. Various experiments and studies of the general circulation model (GCM) indicate that as the concentration of carbon dioxide (CO₂) doubles, the global temperature is expected to rise significantly where the atmospheric concentration of carbon dioxide increased from 280 ppm in 1750 to 415 ppm in 2019 [1]. As a result, climate processes, including the severity of hydrologic events are likely to intensify owing to that change. These predicted impacts of possible future climate changes would have a significant impact on many hydrological systems, which in turn impact water availability and runoff, and river flow. Therefore, in the face of global warming, and evaluation of possible impacts of climate change on a basin's hydrology is necessary [1]. The water resources of any river basin are affected by several variables, such as precipitation, soil, land use, and natural disasters, and induced disasters [2] Climate changes have a major impact on the balance of supply and demand of global and regional water resources [3]. In the case of limited water resources, the water balance is often fragile, and climate change can exacerbate this situation [4] This may be unprecedented because the water system is vulnerable to climate changes outside the scope of historical events [5]. Climate changes may have a major effect on the hydrological cycle mainly by changes in evapotranspiration and precipitation [6,7]. This impact can be clearly manifested as a severe drought or flood. In turn, this could have a significant effect on the basin's water balance [8]. Iraq is classified as an arid or semi-arid region, with an annual rainfall of less than 150 mm and a high evaporation rate. Its water balance is relatively fragile and is threatened by water shortages. Due to climate change, water shortage will be severely

aggravated [9,10]. It can be said that climate change is one of the main challenges facing Iraq. Its adverse effects on water resources will affect the environment and the economy, especially the agricultural sector. Decision-makers have a strong need to predict the potential impact of climate change on precipitation intensity and frequency, which have consequences on sustaining and managing water resources appropriately and diminishing water scarcity problem, which has become noticeable [11]. The Khabour tributary is one of the tributaries of the Tigris River and is the main water resource of the Duhok City, which is one of the main cities in the Kurdistan region [12]. To model watersheds, The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) has been introduced as the most appropriate protocol modeling tool to conduct rainfall-runoff simulation because given that its free availability. The model has been proved to be reliable and usable for many hydrological simulations [13]. Many researchers have studied the impacts of climate change on water resources and flooding using hydrological models [14,15,16]. Kang et al., [17] used the HEC-HMS model for the assessment response of streamflow to weather variability and climate change in the South Platte River basin in the United States. The results showed the average modeled runoff in the future will be decreased. Yimer et al., [18] used HEC-HMS to assess the hydrological response of the Upper Blue Nile and Upper Beles River catchment area in Ethiopia to climate change. The future data obtained from the GCM model output (HadCM3) were used. The result of Streamflow change showed a decrease in the mean annual flow in the future. Van Ty et al., [19] used the HEC-HMS model to assess the potential impact of climate, land use/cover, and population changes in the future water availability and demand of the Vietnam-Cambodia Srepok River Basin. The data were obtained from ECHAM4, under two emission scenarios (A2, B2). The results revealed there will be an increased surface runoff. Meenu et al., [1] applied (HEC-HMS) model to assess the hydrologic impact of climate changes in Tunga-Bhadra river catchment under two emission scenarios (A2, B2). Scenarios obtained from the Hadley Centre Coupled Model were used. The results suggested increasing runoff and decreasing actual evapotranspiration. Al-mukhtar al.,(2014)[20] used the SWAT model to assess the possible impact of future climate changes on the hydrological response in the upper reach of the Spree River basin in Germany from two different downscaled climate models. The result showed the annual streamflow was predicted to decrease and annual evapotranspiration increased. Azmat et al., [21] applied the HECHMS model for the event and continuous simulation in high altitude scarcely-gauged catchment under a changing climate in the Jhelum River catchment. The hypothetical climate change scenarios showed a significant increase in annual streamflows. Bai et al., [22] used HEC-HMS and CMIP.5 climate changes model to assess the impact of climate changes on flood events in the Nippersink Creek watershed in the United States. The results showed that as the concentration of greenhouse gases increased, the amount of precipitation also increased. This had a greater impact on the flood event and further led to more serious flood stream flows. In Iraq, There are several attempts to model the impacts of climate change were reported in the literature. For instance. Adamo et al., [23] applied six (GCMs) onto the SWAT model to study the effect of climate changes on the water resources of the Tigris River. Under three scenarios, they represent the highest, medium, and low emissions A2 and A1B, and B1. They concluded that as temperature increases and precipitation decreases, surface water and groundwater will decrease in the overall five tributaries (Khabour, Greater Zab, Lesser Zab, Al-Adhaim, and Diyala) of the Tigris River Basin. Abbas et al., [24] studied climate changes impact on water resources of the Greater Zab River in Iraq by using SWAT. The model is tested for its suitability to capture characteristics of the watershed, then forecasts from six GCMs for two future periods 2046-2064 and 2080-2100 under scenarios (A1B, A2, and B1). The results showed that the future water resources situation will deteriorate. Abbas et al., [25] studied the assessment of climate change impact on water resources of the Lesser Zab in Iraq by using SWAT. The model has been used to assess the impact of climate change on its hydrological components for two future periods 2046-2064 and 2080-2100. The suitability of the model was first evaluated, and then, outputs from six GCMs were incorporated under scenarios (A1B, A2, and B1). The results showed the water resources situation has deteriorated.

The objective of this study was to assess the impacts of climate changes on the streamflow of the Khabour River using the most recent future emission scenarios (RCPs) which are RCP2.6, RCP, 4.5, and RCP8.5. The HEC-HMS model was firstly calibrated and validated to investigate its applicability before its application. Then, the future precipitation, and temperature data from the HadGEM2_ES were employed in the calibrated model to analyze the impacts of climate changes. The results of this study will contribute greatly to a deeper understanding of the interaction between climate changes and hydrological systems. In turn, this can help humans better be adapted to the impact of climate changes and variability on water resources in the Kharbor Basin.

2. Data and Methods

2.1 Study Area Description

Khabour River (Figure 1) rises from the Anatolian region in eastern Turkey, flows through the southern border between Turkey and Iraq, then flows west through the city of Zakhko, and finally merges with the Tigris River in the south. Khabour has an average annual flow of 58 m³/sec and a length of 181 km [26]. Khabour River basin covers an area of 5,737 km², of which 43% are located in Iraq and the remaining percentage (57%) is in Turkey. The basin is mountainous with an elevation of (300 to 3300 m) above sea level. Many springs gush out in the basin. The average annual temperature is 10°C, and the average annual total rainfall is 780 mm. About 60% and 25% of precipitation occur in winter and spring, respectively. In autumn and summer, the precipitation is 14% and 1%, respectively. The flow regime of the Khabour River indicates highly seasonal flow, peak flow in May, and low seasonal flow from July to December. In which winter precipitation and snowmelt in the spring is dominant. So far, no dams or regulators have been built on the Khabour River [26].

2.2 Data Used

In this research, topography, land use, soil data, climate data, and flow data were collected, processed, and used for this study as inputs data to the HEC-HMS model for successful simulation.

2.2.1 Satellite Data

2.2.1.1 Digital Elevation Model (Dem)

Topography is a necessary input and used in the delineation of the watershed and analysis of the land surface characteristics and drainage patterns. It affects the rate of movement and direction of flow over the land surface. DEM is now available as a product of several satellites with different vertical and horizontal accuracy. Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) DEM of 30 m spatial resolution [27] is a collaborative mission of the National Aeronautics and Space Administration (NASA) was used in this study to extract the watershed topography. The ASTER provides DEM data sets for all global surfaces with 30x30 m of spatial resolution. The data set was downloaded on 19 Dec. 2019 from (www.earthexplorer.usgs.gov/). The ASTER DEM raster data set was processed using ArcGIS 10.4 program. Figure 2 shows the elevation for the Khabour watershed that is used in the HEC-HMS model.

2.2.1.2 Land Use Map

There are many institutions and research centers that produce and publish digital images of land use with several spatial resolutions. Some of these images are acceptable for hydrological research and are available for free. In this study, the land use map was obtained from (www.weblakes.com/support/modeling-data.html) for the year 2010. The dataset was processed using ArcGIS 10.4 program. Figure 3 shows the land use map of the Khabour watershed.

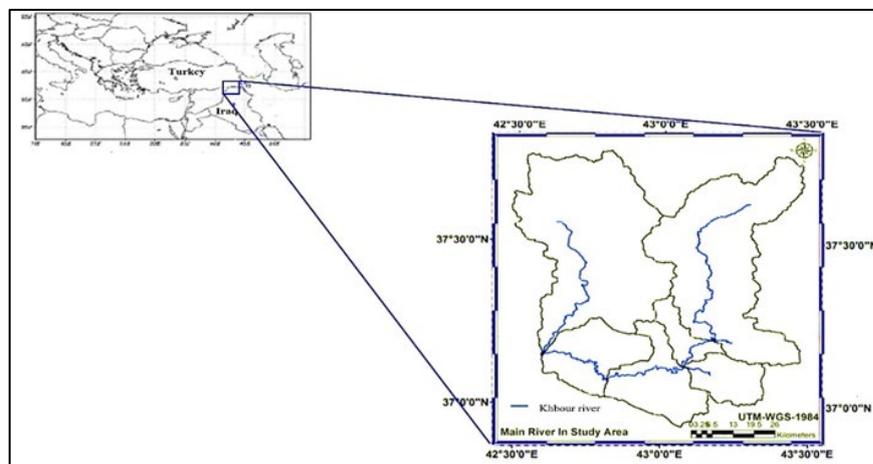


Figure 1: Location map for Khabour River Basin

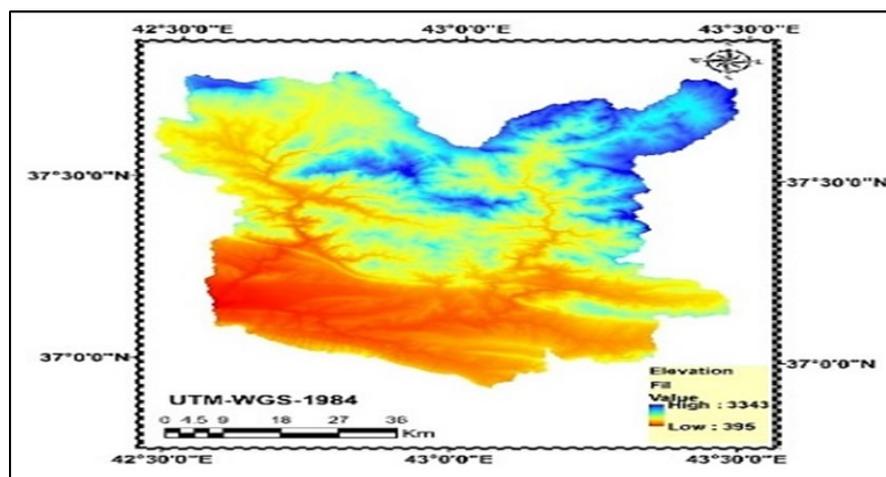


Figure 2: ASTER Digital Elevation Model (DEM) of Khabour watershed

2.2.1.3 Soil Map

The soil map was obtained from the Food and Agriculture Organization (FAO) global soil map (Figure 4). The data were downloaded on 19 Dec. 2019 from (<http://www.fao.org/home/en/>). FAO provides a soil database of 5000 soil types. This data comprises two layers (0 to 30 cm and 30 to 100 cm depth) at a spatial scale of 1:5000000. The basin's response to rainfall events depends on the nature and conditions of the underlying soil [28]. The dataset was processed using ArcGIS 10.4 program.

2.2.2 Climate Data

Climate data were obtained from the Climate Forecast System Reanalysis (CFSR). CFSR is global weather data provided by the National Weather Service's NCEP of Global Forecast System. CFSR provides data (precipitation, temperatures, solar radiation, wind speed, and relative humidity data) around the globe. The forecast model uses the weather observation data extracted from the international ground station network and satellites to re-analyze the data every six hours. It reproduces the global weather station grid with a spatial resolution of 38×38 km [29]. There are many research papers involved in using and evaluating the CFSR data in many watersheds in the northern region of Iraq. Most of these papers showed the efficiency of using this data. Such as Al-Khafaji and Al-Chalabi [30]. The relevant weather stations in the Khabour River Basin were downloaded in daily time step from (<https://globalweather.tamu.edu/>) for 35 years started from 1/1/1979 to 31/12/2013 for the watershed. Precipitation and temperatures were validated against monthly observed precipitation data available for the period (1979-2009) prior to its use in HEC-HMS which were collected from the Ministry of Water Resources (MoWR). Figure 5 shows the CFSR weather station distribution that applied in HEC-HMS for the Khabour River watershed.

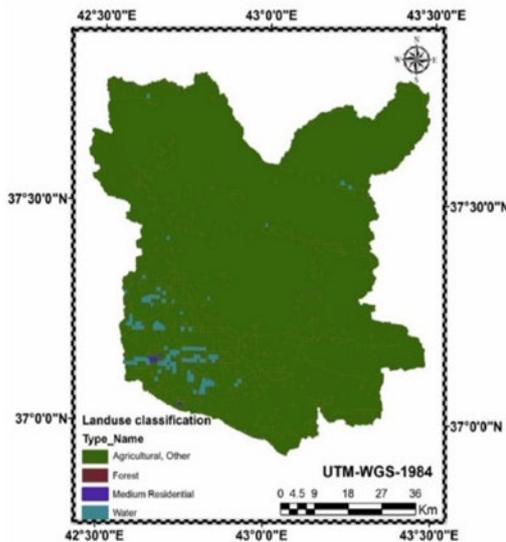


Figure 3: Land use map of Khabour watershed

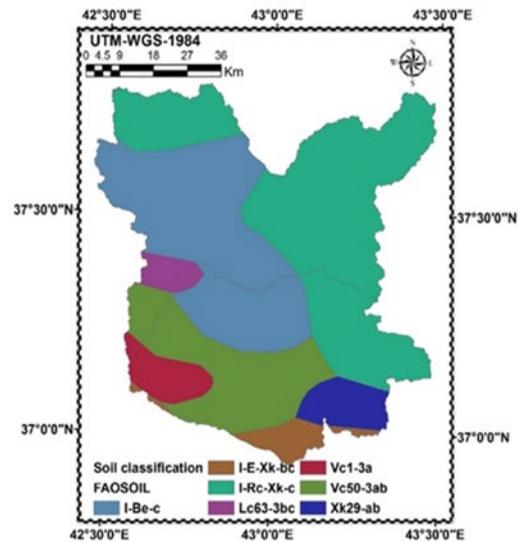


Figure 4: Soil map of Khabour watershed

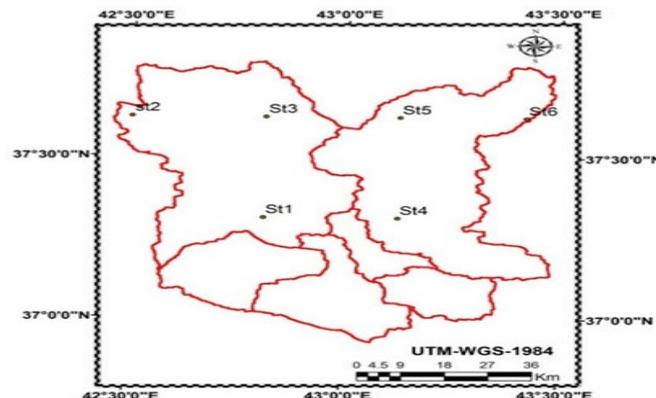


Figure 5: Distribution of Khabour River watershed weather stations according to CFSR

2.2.3 Flow Data

Considering the purpose of this study, the HEC-HMS model was firstly calibrated and validated against the observed discharge values at the watershed outlet. These data were recorded (by the Iraqi Ministry of Water Resources (MoWR)) at the Zakho gauge station on the Khabour River, which is located at coordinates $37^{\circ} 08' 00''$ N, and $42^{\circ} 41' 00''$ E.

Daily flow data were obtained from the MoWR for the period from 01Jan2004-30Jun2009 measured in m^3/sec . In addition, monthly flow data were obtained from the MoWR for the period 2000-2009 to be used as a reference period for the estimation of future climate change anomalies.

2.3 Hydrological Model (HEC-HMS)

It is reasonable to use a less complex hydrological model to determine the effect of climate changes on river flow regimes, which can accommodate the insufficient information of a future catchment [31]. In this study, HEC-HMS was used to perform

the hydrological analysis of the Khabour River. HEC-HMS is a semi-distributed hydrological model developed by the Hydrologic Engineering Center of the U.S Army Corps of Engineers for simulating the rainfall-runoff process which allows users to choose a series of different methods to simulate different hydrological processes according to data availability and research goals. Its design allows it to be applied in wide geographical areas to solve various problems, including water supply in large river basins and flood hydrology and runoff in small urban or natural river basins [32,33]. This model was chosen because of its versatility, the suitability of the studied basin shape, and the available data (which can be used to derive the required input parameters) [19]. In many studies, the application of the HEC-HMS model has been practiced as an effective hydrological model for simulating rainfall-runoff processes [34,35]. HEC-HMS model setup consists of a basin model, meteorological model, control specifications, and input data (time series data) [1]. A detailed explanation of model structure can be found in the user's manual and technical reference manual. To calculate the different water balance components of this present study, the Initial and Constant Loss method was used to compute the runoff volume of the catchment. Clark Unit Hydrograph Transform method was used to simulate direct runoff. The recession Baseflow method was used to account for the base flows. Muskingum method of channel routing was used to generate discharge hydrograph at relevant downstream points in the channel.

2.4 Model Set Up

DEM, soil map, land use map was collected for the purpose of this research. The Khabour River Basin was divided into six sub-basins for computing percolation and evaporation, base-flow, and transforms and routing, and parameters were defined to convert rainfall into runoff. The HEC-GeoHMS and ArcHydro tool were used with ArcGIS 10.4 to derive land use and the river network of the basin and to delineate sub-basins of the Khabour River basin. Using HEC-GeoHMS, the study area was automatically delineated and the basin characteristics (area, river slope, reaches a length, etc.) were generated. The soil and land use datasets were merged together. The gridded curve number was created with HEC-GeoHMS for the watershed as seen in Figure 6 were estimated for the hydrological model. Sub-basin areas, times of concentration, and reach lengths were calculated using the ArcHydro tool in ArcGIS based on the DEM geospatial information of the watershed [33][17]. In addition, the HEC-GeoHMS created background map files and basin model files, which were later used by HEC-HMS to develop the hydrologic model. The sub-basins delineation resulted in sub-basins: (W1), (W2), (W3), (W4), (W5) and (W6) (see Figure 7) and their areas and other details are presented in Table 1. The HEC-HMS 4.3 was used for the rainfall-runoff simulation. Figure 8 shows the Khabour river basin model set-up in HEC-HMS. The hydrological data (daily flow data) and climate data were input into the HEC-HMS model. The HEC-HMS model was calibrated and validated for periods (01Jan2004-31Dec2006) and (31Dec2006-30Jun2009), respectively. Three well-known statistical descriptors NSE, R^2 and RMSE were used to evaluate the accuracy of model calibration and validation. Future climate scenarios data of RCPs (RCP2.6, RCP4.5, RCP6, RCP8.5) of atmospheric greenhouse gas (GHG) concentrations for three future slice periods (2021-2030), (2041-2050), and (2061-2070) were input into the calibrated model to analyze the impact on streamflow. The methodology used in this research is schematically depicted in Figure 9.

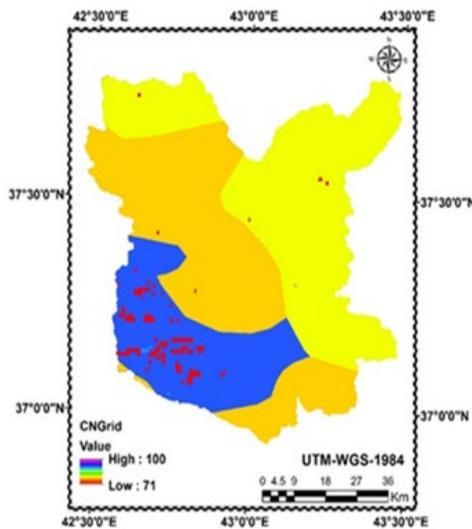


Figure 6: Runoff curve number (CN) map of Khabour River basin

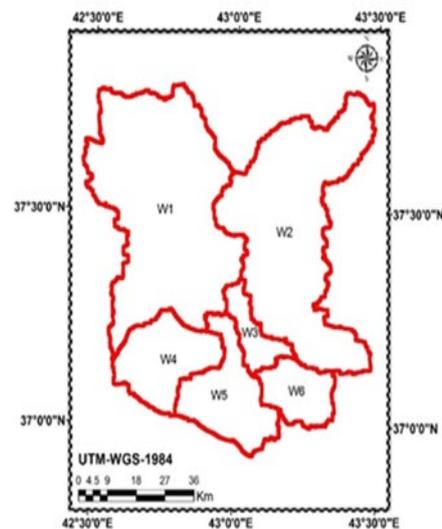


Figure 7: Khabour River sub-basins

2.5 Model Calibration and Validation

Before the output of the hydrological model can be considered reliable, it needs to be calibrated and validated using the observed streamflow. The simulated streamflow must be compared with the observed flow to assess the goodness of fit and draw conclusions about whether the model can predict and provide credible results.

Table 1: Information of Sub-basins

Name	Shape	Sub-Basin Slope	Shape Area (km2)	Shape Length (m)
W1	Polygon	0.0139	2191	382233.67
W2	Polygon	0.0115	1891	376491.97
W3	Polygon	0.0665	208.9	121981.99
W4	Polygon	0.0164	548	147995.44
W5	Polygon	0.0216	580.7	184496.3
W6	Polygon	0.0182	317.6	112900.72

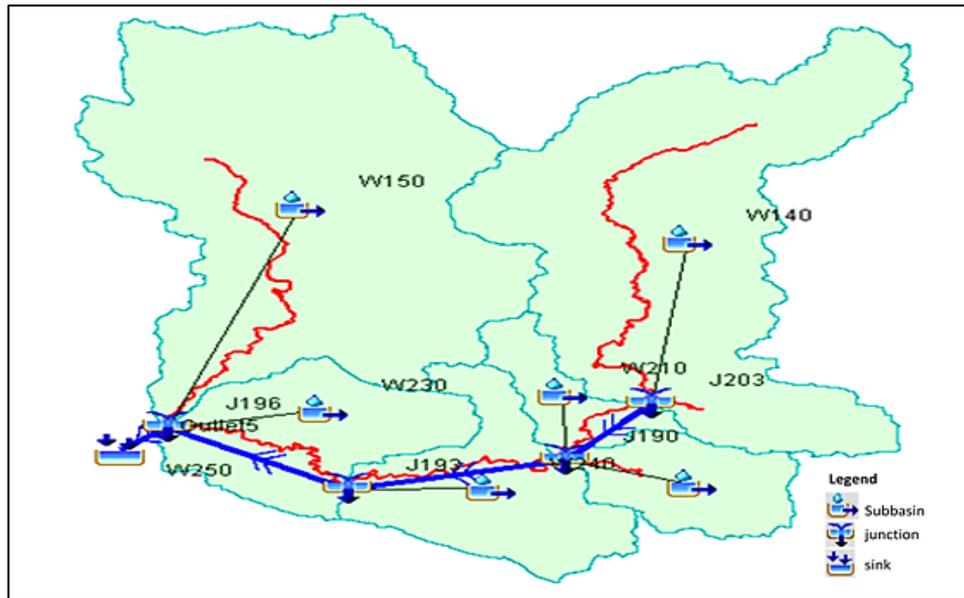


Figure 8: Khabour River basin model set-up in HEC-HMS

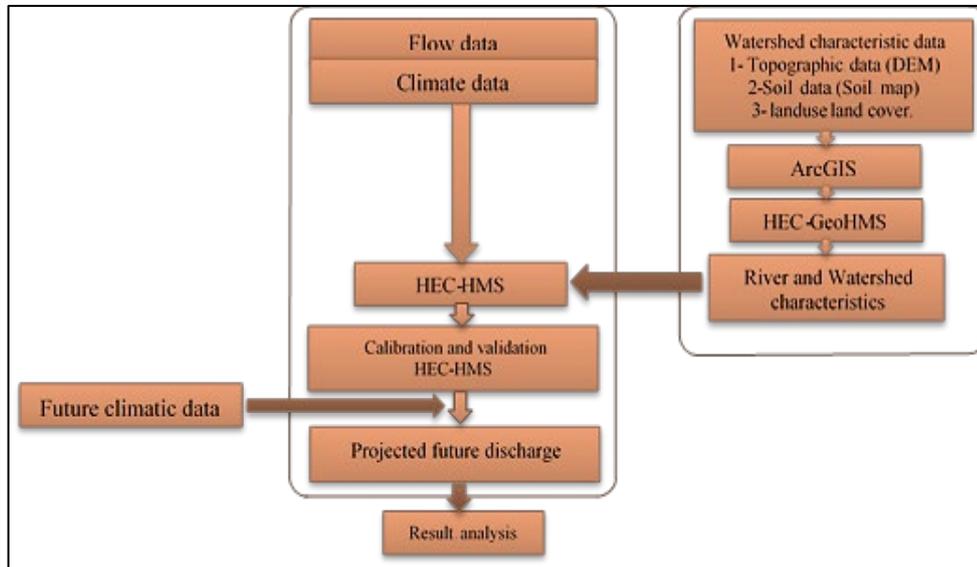


Figure 9: Schematic diagram of methodology

In this study, a combination of manual and automatic calibration techniques was used. Automatic calibration is called “trial optimization” in HEC-HMS, was used to obtain optimum parameter values that give the best fit between observed and simulated flow volume values [36]. At HEC-HMS, the systematic search for the best (optimal) parameter values follows the procedure illustrated in Figure 10.

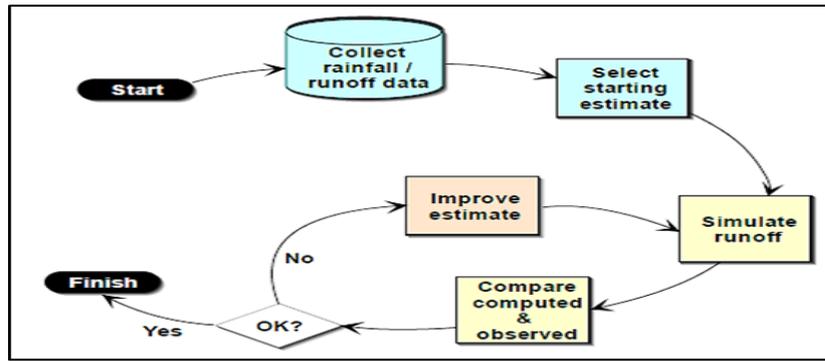


Figure 10: Schematic overview of the calibration procedure.[32]

2.6 Model Performance Evaluation

Model performance was assessed using Nash-Sutcliffe efficiency (NSE), coefficient of determination (R^2) and root mean square error ($RMSE$) because they are effective and commonly used in hydrological calibration and validation [34].

- 1) The Nash–Sutcliffe Coefficient of Efficiency (NSE) is a dimensionless type parameter. NSE ranges from $-\infty$ to 1 and measures how well the simulated versus the observed data match [34] as follows:

$$NSE = 1 - \left[\frac{\sum_{i=1}^n (Q_i^{obs} - Q_i^{sim})^2}{\sum_{i=1}^n (Q_i^{obs} - Q^{mean})^2} \right] \quad (1)$$

Where Q_i^{obs} and Q_i^{sim} are the observed and the simulated streamflow data, respectively; Q^{mean} is the mean value of observations from $i = 1$ to n observations. NSE index value greater than 0.75 is considered "good" and a value between 0.75 and 0.36 is considered "satisfactory".

- 2) The coefficient of Determination (R^2) is the square of the correlation (r) among observed and simulated values. R^2 ranges between 0 to 1. R^2 is presented, Mathematically as:

$$R^2 = \left[\frac{\sum_{i=1}^n (Q_i^{obs} - Q_{ave}^{obs})(Q_i^{sim} - Q_{ave}^{sim})}{\left[\sum_{i=1}^n (Q_i^{obs} - Q_{ave}^{obs})^2 \sum_{i=1}^n (Q_i^{sim} - Q_{ave}^{sim})^2 \right]^{0.5}} \right]^2 \quad (2)$$

Where Q_i^{obs} is an observed value (m^3/s), Q_{ave}^{obs} is the average observed value of n value, Q_i^{sim} is a simulated value (m^3/s), Q_{ave}^{sim} is the average simulated value of n value and n is the number of observations.

- 3) The Root Mean Square Error ($RMSE$) is an error-index type parameter commonly used in hydrological modeling and it is a commonly used measure of the difference between the values predicted by the model and the values observed at the station. The $RMSE$ of a model prediction with respect to the estimated variable Y^{sim} is defined as the square root of the mean squared error:

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (Y_i^{obs} - Y_i^{sim})^2}{n}} \quad (3)$$

Where Y_i^{obs} has observed values and Y_i^{sim} is simulated values and n is the total number of observations.

2.7 Future Climate Data and Scenarios

The predicted climate of the entire world is usually assessed by General Circulation Models (GCMs) for the long-term or mid-term future period [35]. The Intergovernmental Panel on Climate Change (IPCC) had reported envisioned four Representative Concentration Pathways (RCPs) of future greenhouse gas concentrations [34]. In climate research, RCP is a crucial development that helps scientists to examine emission reduction and impacts analysis [35].

Khayyun et al., [36] studied the selection of the appropriate source of the possible future precipitation time series data sets by examining some of the models for GCMs, the results showed that the HadGEM2-ES was the best model for data projections and suitable for studying scenarios involving future water resources in Iraq. Therefore, HadGEM2-ES global circulation model developed by the Met Office Hadley Centre was selected for climate change projections in the Khabour River basin under four possible scenarios of RCPs (RCP2.6, RCP4.5, RCP6, and RCP8.5) of atmospheric greenhouse gas (GHG) concentrations for three future periods. These periods are 2021-2030, 2041-2050, and 2061-2070. The daily projected precipitation and temperatures were then input to the calibrated HEC-HMS model. The impact of climate change on the stream-flows of the study area were then investigated.

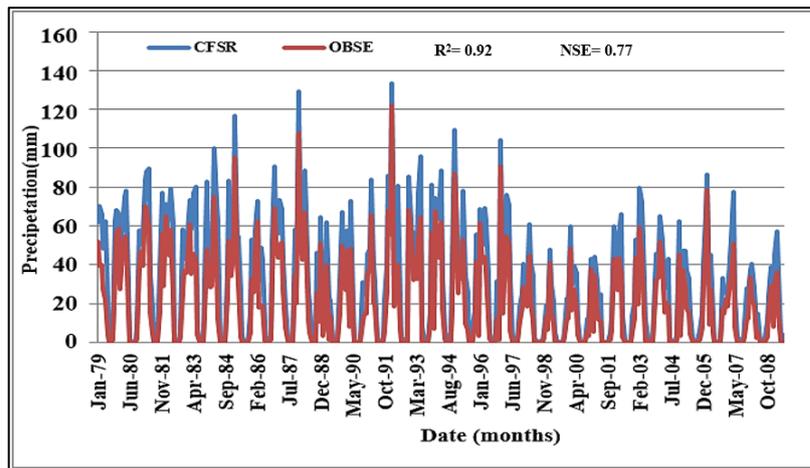
3. Results and Discussion

3.1 Cfsr Data

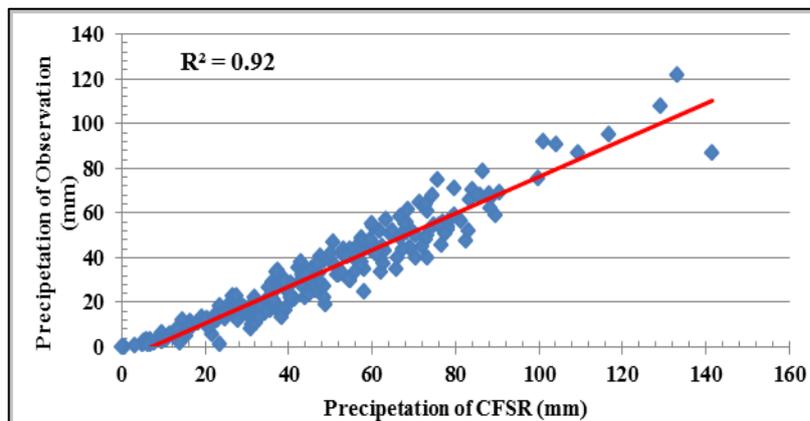
The recorded monthly precipitation that collected from MoWR at Zakho gauge station on the Khabour River, which is located at coordinates Latitude $37^{\circ} 08' 00''$ N and Longitude $42^{\circ} 41' 00''$ E was compared with corresponding CFSR weather data according to available recorded data from January 1979 to December 2009. The comparison was carried out with the nearest station of CFSR stations used in the study area. The results of this evaluation are shown in Figure 11. It can be indicated that there was a good correlation between CFSR and Zakho gauge station. NSE , R^2 and $RMSE$ value was 0.77, 0.92 and 16.35, respectively.

3.2 Model Calibration and Validation

The hydrological model was calibrated using observed data to improve the predictability of the model, and hence the reliability of the model might be enhanced with greater confidence. In this research, the HEC-HMS model was calibrated and validated against the observed data at the Zakho gauge station. This station is located at coordinates Latitude $37^{\circ} 08' 00''$ N and Longitude $42^{\circ} 41' 00''$ E near to the watershed outlet. Observed daily flow data (01Jan2004-31Dec2006) were used for calibrating the hydrological model and the remaining data (31Dec2006-30Jun2009) for validation. The auto-calibration (through optimization trials) tool available in the HEC-HMS model was used to optimize the estimation of model parameters. The parameters have been optimized to achieve a closer agreement between the simulated and observed streamflow. The final calibrated parameters are presented in Table 2 and the final calibrated and validated graphs are presented in Figures 12 and 13, respectively. The flow calibration result of the Zakho monitoring station shows that a good agreement exists between the observed value and the simulated value. NSE , and $RMSE$ values were 0.871, 0.89 and 26.7, respectively for calibration and 0.936, 0.9364 and 18.0, respectively, for validation. Obviously, the calibrated HEC-HMS model simulates the flow and obtains reasonable results, so it can be used to evaluate the impact of different scenarios in the study area on streamflow.



(a)

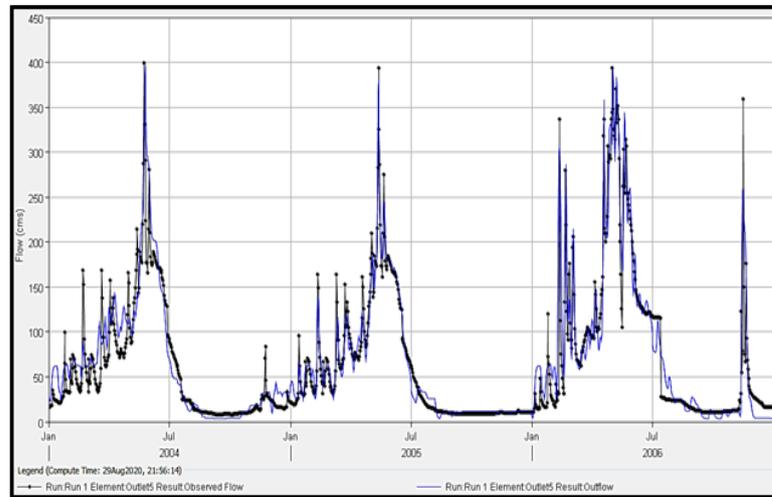


(b)

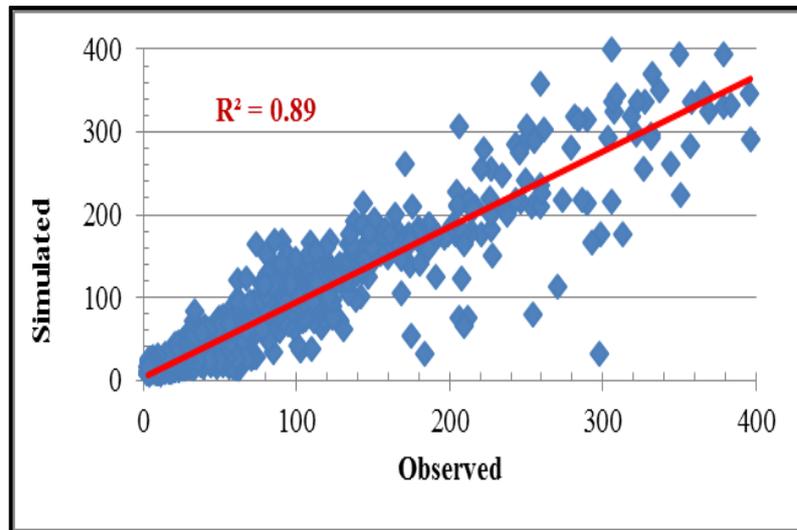
Figure 11: Result of correlation between CFSR and Zakho gauge station for the period from 1979 to 2009; a- Time series of CFSR and observed precipitation, and b- Scatter plot of CFSR and observed precipitation

Table 2: Final Calibrated Parameters

Element	Parameter	Units	Initial Value	Optimized Value	
For all Subbasins	Initial and Constant - Constant Rate Scale Factor		1	1.252	
	Initial and Constant Initial Loss Scale Factor		1	0.875	
Reaches	R110	Muskingum - k	HR	28	28.697
	R110	Muskingum - x		0.23	0.069
	R120	Muskingum - k	HR	26	26.247
	R120	Muskingum - x		0.22	0.486
	R80	Muskingum - k	HR	27	27.575
	R80	Muskingum - x		0.24	0.070
	R90	Muskingum - k	HR	28	27.545
	R90	Muskingum - x		0.2	0.499



(a)



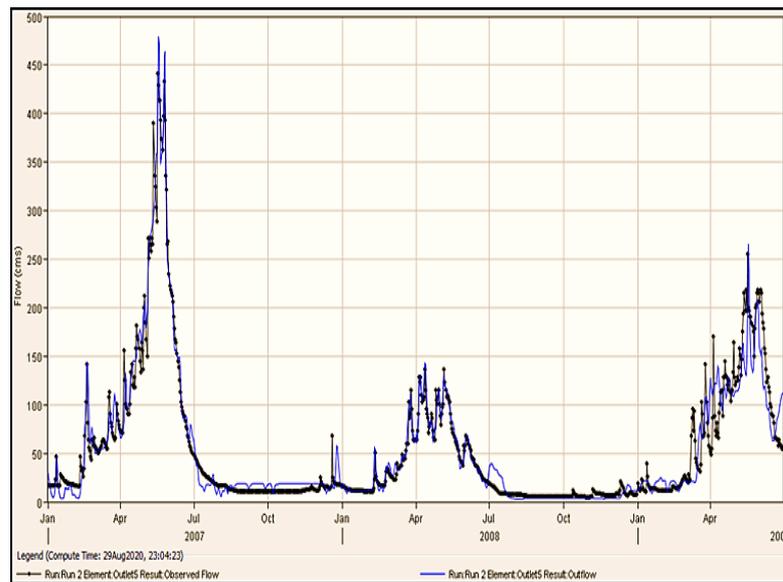
(b)

Figure 12: Calibration results; a- Time-series of observed and simulated discharge for model calibration (01Jan2004-31Dec2006), and b- Scatter plot of observed and simulated discharge

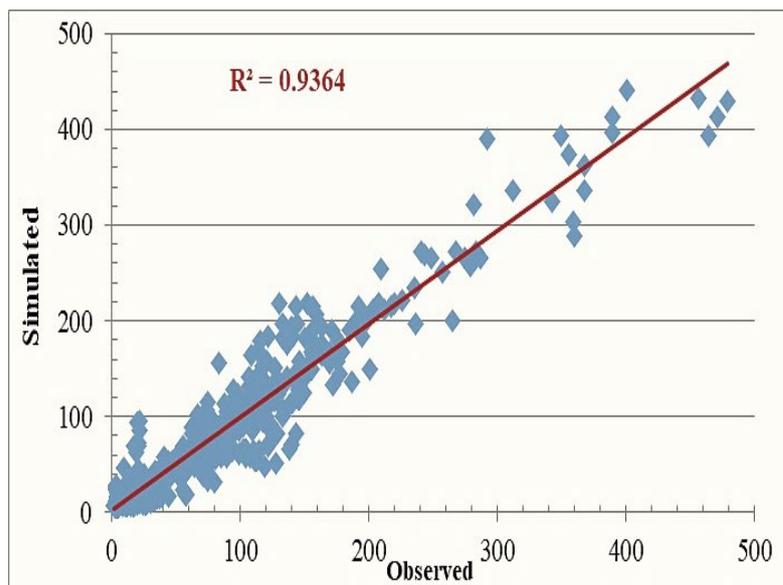
3.3 Impacts Of Climate Change In Temperature

Mean monthly temperature outputs from the HadGEM2-ES global circulation model identified earlier were processed for the Khabour basin under four possible scenarios (RCP2.6, RCP4.5, RCP6, and RCP8.5). Figure 14 below captures the projected changes in mean monthly temperature for three future periods (2021-2030), (2041-2050), and (2061-2070) relative to the base period (2000-2009). These charts are useful to assess the magnitudes of temperature changes. The results indicate all

the scenarios showed increasing trends in temperature. RCP8.5 scenario was expected the highest increases in mean temperature; however, RCP2.6 predicted the lowest increases. Between all the four possible scenarios it can be found that the greatest increase in average annual temperature would occur under RCP8.5 by 6.8 °C for the period (2061-2070).



(a)

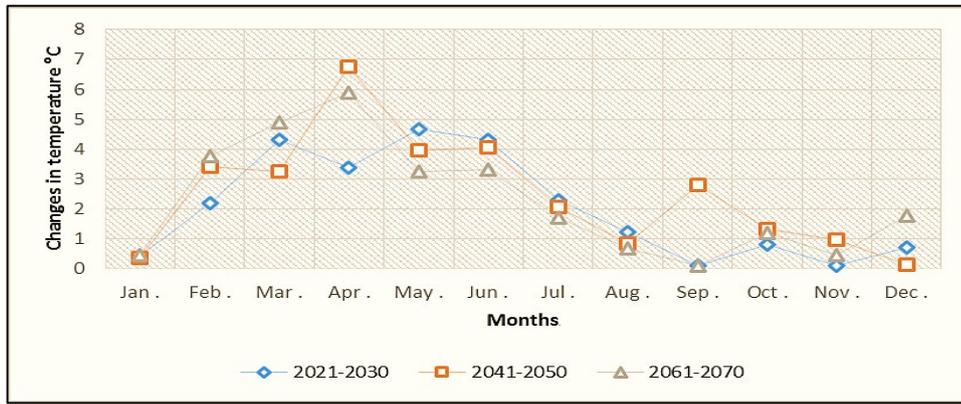


(b)

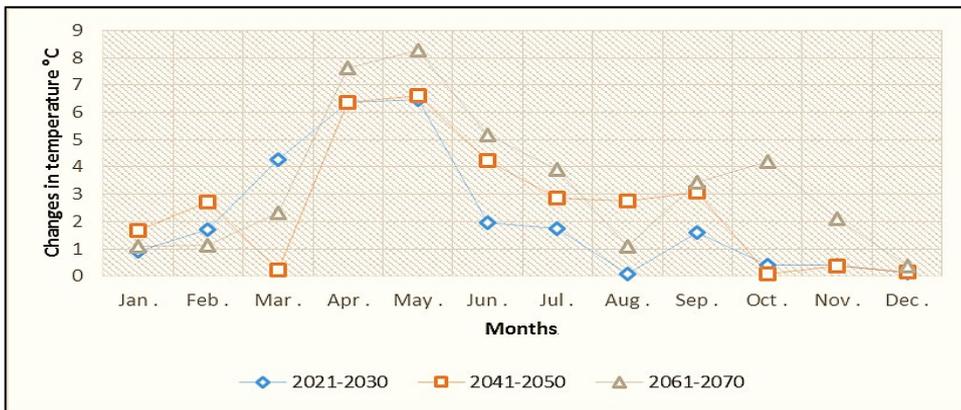
Figure 13: Validation results; a- Time-series of observed and simulated discharge for model validation (31Dec200630Jun2009), and b- Scatter plot of observed and simulated discharge

3.4 Impacts Of Climate Changes In Precipitation

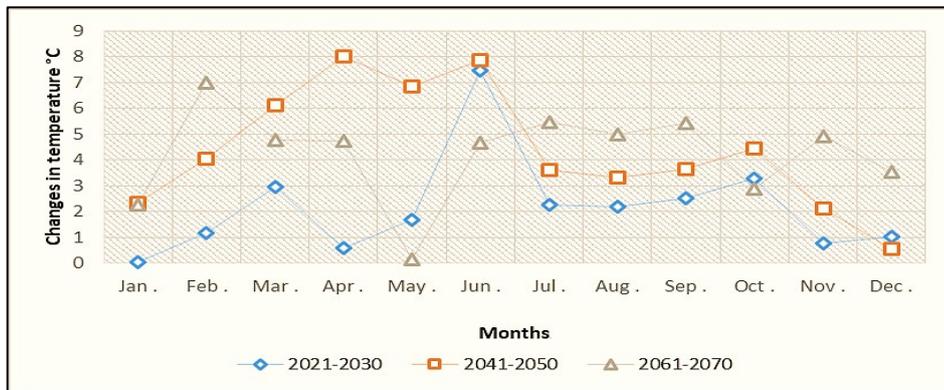
Mean monthly precipitation outputs from the HadGEM2-ES global circulation model identified earlier were processed for the Khabour basin under four possible scenarios (RCP2.6, RCP4.5, RCP6, RCP8.5). Figure 15 below captures the projected changes in mean monthly precipitation for three future periods (2021-2030), (2041-2050), and (2061-2070) relative to the base period (2000-2009). These charts are useful to assess the magnitudes of precipitation changes. The future data showed decreases in general in precipitation for all months, except for the months of June, July, and August, which showed a very small increase in some scenarios. RCP8.5 scenario projected the highest decreases in mean precipitation; however, RCP2.6 predicted the lowest decreases. Between all the four possible scenarios it can be noticed that the largest decrease in average annual precipitation would occur under RCP8.5 by 59.2 % for the period 2061-2070.



(a)



(b)



(c)



(d)

Figure 14: Changes in average monthly temperature for Kabbour Basin for the future periods 2021-2030, 2041-2050, and 2061-2070 under; a- RCP2.6, b- RCP4.5, c- RCP6, and d- RCP8.5

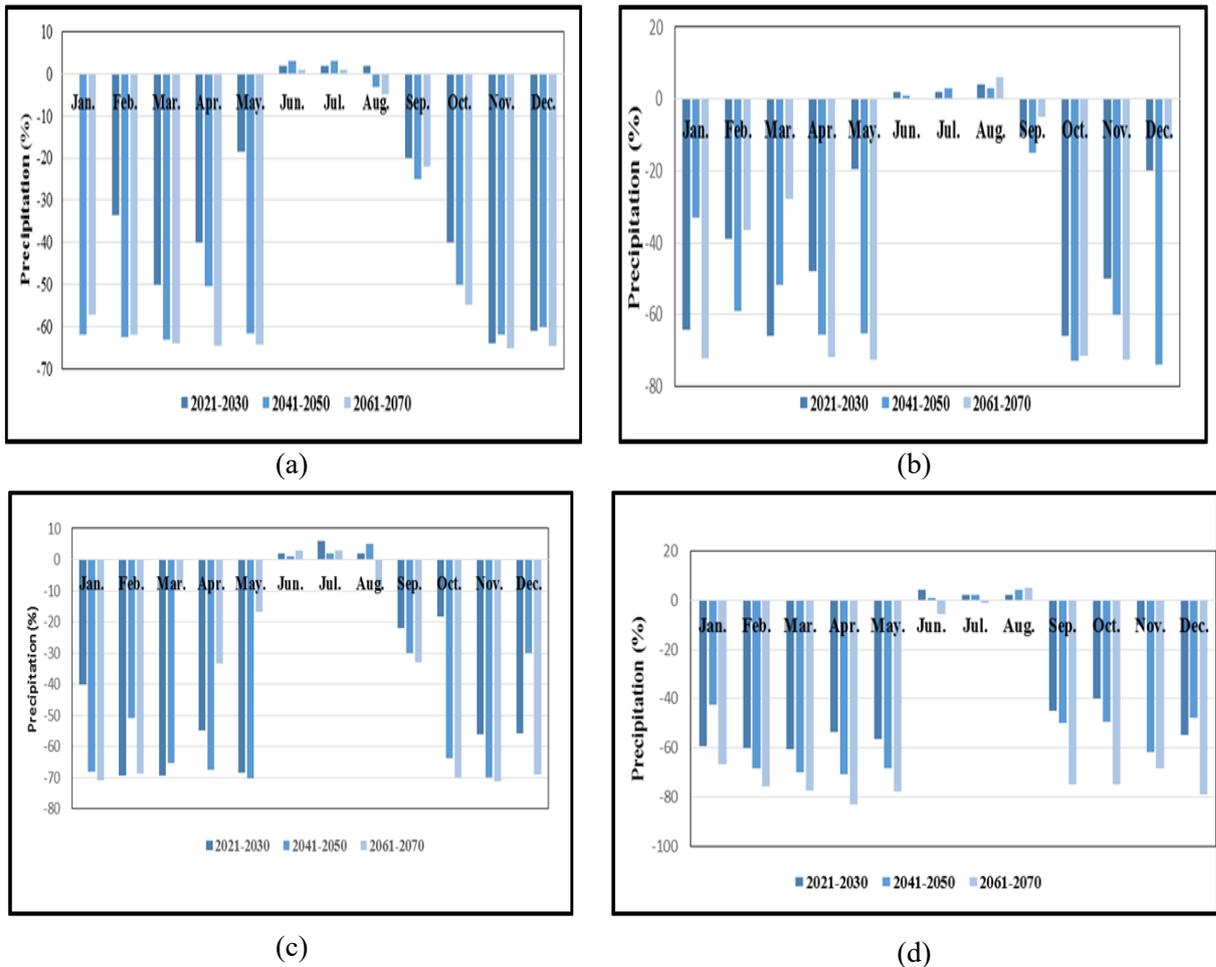


Figure 15: Relative changes in monthly precipitation averaged for Khabour Basin for the future periods 2021-2030, 2041-2050, and 2061-2070 under; a- RCP2.6, b- RCP4.5, c- RCP6, and d- RCP8.5

3.5 Impacts Of Climate Change On Stream Flow

After calibrating and validating the hydrological model with the historical data, the next step was to simulate flows corresponding to future climate conditions by using daily future data (precipitation and temperature data). To this end, data from HadGEM2-ES global circulation model for three future periods (2021-2030) 2025s, (2041-2050) 2045s and (2061-2070) 2065s under four possible scenarios of RCPs (RCP2.6, RCP4.5, RCP6, and RCP8.5) of atmospheric greenhouse gas (GHG) concentrations were employed. Flow discharge is an important hydrological element and is greatly affected by precipitation. Peak discharges during future periods are shown in Table 3. The table shows the highest value of the peak discharge for the period 2025s is 185.2 (m³/s) occurs on 18 November 2024 under RCP2.6, for 2045s is 222.1 (m³/s) at 29 April 2042 under RCP4.5 and for 2065s is 408.2 (m³/s) at 05 April 2068 under RCP4.5. The impact of climate change on the stream-flows of the Khabour River basin is investigated by comparing future stream-flows in the basin with the stream-flows of the baseline period (2000-2009). The predicted impact of climate change on the annual streamflow is captured in Figure 16. Using data from the HadGEM2-ES global circulation model, the streamflow showed decreases under all four possible scenarios of RCPs for the three-time periods 2025s, 2045s, and 2065s. There is a tendency that the future water availability is decreased with inter-annual changing patterns and unequal temporal distribution. The prospective decrease in future water availability for RCP8.5 is 52%, 58.6% & 66% for 2025 s, 2045s and 2065s, respectively. For RCP6 there is the prediction of a decrease in streamflow by 46%, 61%, and 53% for 2025 s, 2045s, and 2065s. For RCP4.5 there is the prediction of a decrease in streamflow by 48%, 58%, and 52% for 2025 s, 2045s, and 2065s, and for RCP2.6 there is the prediction of a decrease in streamflow by 46%, 52%, and 53% for 2025 s, 2045s, and 2065s. The model predicted the largest decrease under scenario RCP-8.5, while the model under scenario RCP-2.6 predicted the lowest flow reductions. These results indicate that the Khabour River is likely to suffer from a decrease in water availability because of the impact of climate changes in the future. This necessitates being managed appropriately and planning for future projects to meet projected future water shortages.

Table 3: Peak discharges during future periods

Future Period	2021-2030				2041-2050				2061-2070			
	RCP											
Representative Concentration Pathways	2.6	4.5	6.0	8.5	2.6	4.5	6.0	8.5	2.6	4.5	6.0	8.5
Peak Discharge (m ³ /s)	185.2	184.7	180.5	181.0	120.4	222.1	120.6	141.9	174.0	408.2	219.6	233.1
Date of occurrence of peak discharge	18 Nov 2024	18 Nov 2024	18 Nov 2024	18 Nov 2024	09 Dec 2048	29 Apr 2042	10 Mar 2044	09 Apr 2044	27 Oct 2069	05 Apr 2068	03 Nov 2067	10 Nov 2068

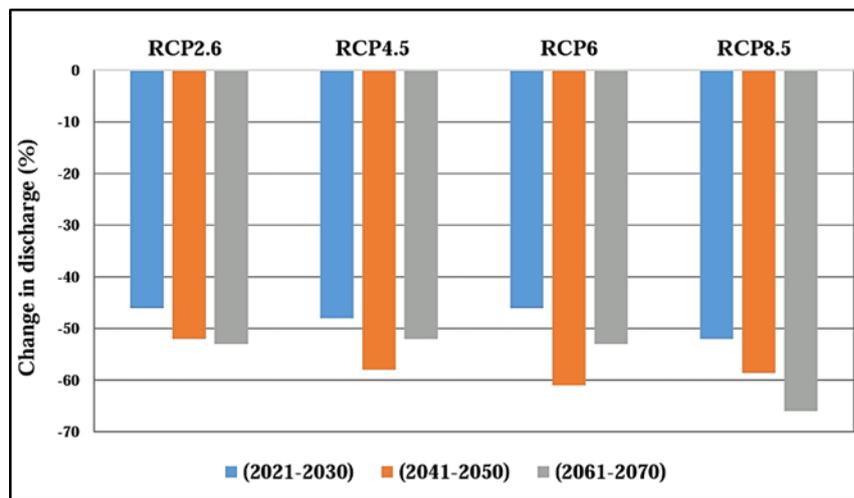


Figure 16: Change in annual streamflow due to climate change under four possible scenarios of RCPs for HadGEM2-ES global circulation model the periods (2021-2030), (2041-2050), and (2061-2070) expressed as a percentage of streamflow in the base period (2000-2009)

4. Conclusion

In this research, the HEC-HMS model was used to assess the impact of climate change on streamflow in the Khabour River Basin. The hydrological model was successfully developed in this research. The use of ArcGIS and HEC-GeoHMS to delineate the watershed of the basin helped to successfully represent watershed hydrology. The model was calibrated and validated at the Zakho discharge station at daily time steps to simulate the streamflow. The performance of this model was found to be reasonably good according to NSE, R², and RMSE indices during the calibration and validation periods. Next, the model was applied for assessing the impacts of climate change in the future for the three future periods (2021-2030), (2041-2050), and (2061-2070) under four possible scenarios of RCPs (RCP2.6, RCP4.5, RCP6, and RCP8.5) of atmospheric greenhouse gas (GHG) concentrations using the HadGEM2-ES global circulation model. The major conclusions from this study are as follows:

- 1) The Climate Forecast System Reanalysis (CFSR) weather data has been successfully used to model the Khabour basin. The reasonable correlation between CFSR weather data and the observed weather data, and good simulation results emphasize that CFSR is considered to be a satisfactory choice for weather input data when using the HEC-HMS model, especially in ungauged watersheds or remote watersheds.
- 2) In this research, the hydrological model of the Khabour River basin using HEC-HMS was established successfully. It performed well during the calibration and validation by reproducing the observed flow and simulating the observed peaks according to time and quantity. The model produced good results in calibration and validation in modeling and simulation, which shows that the simulation results are in good agreement with the observed data. The HEC-HMS model is suitable for the studied catchment. We can conclude that the complexity of the model structure does not determine its suitability and efficiency. Though the structure of HEC-HMS is simple, it is a powerful tool.
- 3) The future data from the HadGEM2-ES global circulation model in all the scenarios showed increasing trends in temperature and decreases in general in precipitation in the basin.
- 4) The model predicted that the basin would be drier in the future under four possible scenarios of the RCPs as the results showed a decrease in inflow in all three future periods.
- 5) The results of this research may be advantageous and help to understand potential future changes of water resources and water-related disasters to management and planning for future projects.

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Author contribution

All authors contributed equally to this work.

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Data availability statement

The data that support the findings of this study are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest.

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