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Impact of Climate Change on the Spatiotemporal Distribution of Stream Flow and Sediment Yield of Darbandikhan Watershed, Iraq

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K E Y W O R D S

Climate change, Diyala River, SWAT model.

A B S T R A C T

The impact of climate change on stream flow and sediment yield in Darbandikhan Watershed is an important challenge facing the water resources in Diyala River, Iraq. This impact was investigated using five Global Circulation Models (GCM) based climate change projection models from the A1B scenario of medium emission. The Soil and Water Assessment Tool (SWAT) was used to compute the temporal and spatial distribution of streamflow and sediment yield of the study area for the period 1984 to 2050. The daily-observed flow recorded in Darbandikhan Dam for the period from 1984 to 2013 was used as a base period for future projection. The initial results of SWAT were calibrated and validated using SUFI-2 of the SWAT-CUP program in daily time step considering the values of the Nash-Sutcliffe Efficiency (NSE) coefficient of determination (R2) as a Dual objective function. Results of NSE and R2 during the calibration (validation) periods were equal to 0.61 and 0.62(0.53 and 0.68), respectively. In addition, the average future prediction for the five climate models indicated that the average yearly flow and sediment yield in the watershed would decrease by about 49% and 44%, respectively, until the year 2050 compared with these of the base period from 1984 to 2013. Moreover, spatial analysis shows that 89.6 % and 90 % of stream flow and sediment come from the Iranian part of Darbandikhan watershed while the remaining small percent comes from Iraq, respectively. However, the middle and southern parts of Darbandikhan Watershed contribute by most of the stream flow of the watershed while the parts of lack land cover and steep slopes produce most the sediment.

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1. Introduction

Recently, climate change is considered as a major challenge facing the world. The hydrologic system is significantly affected by this change especially in precipitation and temperature patterns [1-3], this change in hydrologic system addressed by a long period of drought followed by an extreme flood in a short period [4]. In the recent few decades, Iraq experienced serious problems in the water resources sector. These problems are represented in form of water resources decreasing, pollution and desertification [5]. However, a significant change in climate elements can be observed in form of extreme climate events where a drought years recorded in 2007 and 2009 followed by extreme rainfall in some months recorded in central and southern of Iraq [6]. Geographic information system (GIS) used to digitize the climate change in Iraq and Jordan [7]. The study indicated that climate would be drier, poor natural land cover, decreasing in water resources and high temperature.

Diyala River is one of the most important tributaries of Tigris River; the river's water resources suffer from scarcity and an increase in sediment rate. The main purposes of water use in Diyala River are the agricultural, drinking and industrial use. Water resource deterioration in Diyala River was indicated for the future [8]. However, a severe shortage in all water resources of the Tigris Basin especially in stream flow is expected [9]. The water shortage that will face Tigris and Euphrates rivers in the future is attributed to the increase in demand and climate change [10]. The author of [11] concluded that sediment is the main problem facing the Dokan Reservoir (near Darbandikhan Reservoir) referring to rapid decreasing in Dokan Dam Reservoir capacity. The negative effects of sedimentation in Mosul Dam Reservoir were investigated [12], the results showed that sediment plays an important issue in the reservoir capacity and it is usually blockage the intakes of pump stations.

The soil and water assessment tool (SWAT) is a semi-distributed physically based hydrologic model developed by the United States Department of Agriculture (USDA) for the purposes of the impact of land management and climate on simulated runoff, sediment and point source pollution [13]. SWAT hydrologic model is an efficient tool in assessment and analysis the water resources include the evaluation of the current and future amounts of stream flow and sediment yield with it are distributed in the watersheds. The SWAT model was implemented to compute the stream flow of Wadi Al-Naft watershed, Northeast of Diyala Governorate in Iraq [14]. In addition, the same model was used to predict the sediment yield and evaluate the impact of land management on the same area [15].

The impact of climate change on runoff and sediment yield in different watersheds in China and Philippines was assessed using the SWAT model [16-18]. In addition, the performance of the SWAT model for long-term stream flow modeling within Al-Adhaim Watershed, Iraq was assessed [19]. Subsequently, the interactive and complementary effects of the digital elevation model` and land cover/land use resolutions on the estimated stream flow of Adhaim Watershed were evaluated by using the SWAT model [20].

The impact of climate change in Iraq was studied [21]. Firstly, the capabilities of five hydrologic models which are SWAT, CREAMS, WEPP, AGNPS, and EUROSEM were investigated. Accordingly, the SWAT model was selected as the high capabilities in water resources and climate change modeling. The Climate Forecast System Reanalysis (CFSR) data more reliable to be used in the SWAT model in ungauged watersheds or watersheds of poor gauging [22]. The author of [23] recommended using CFSR in the SWAT model for stream flow simulation. Currently, IPCC (Intergovernmental Panel on Climate Change) provides General Circulation Models (GCMs) to predict the monthly precipitation and surface air temperature that can be projected to the sediment and stream flow using the SWAT model. The Geophysical Fluid Dynamics Laboratory-Climate Model 2-1.1(gfdl_cm2_1.1), Goddard Institute for Space Studies Model (giss_model_e_r.1), Center National de Recherché Meteorologiques Coupled Global Climate Model 3.1(cnrm_cm3.1), Meteorological Research Institute- Climate Global Circulation Model (mri _cgcm2_3_2a.1) and Bjerknes Centre for Climate Research (bccr_bcm2_0.1) climate models are most popular and cover all scenarios of future climate change [24].

This research aims to study the temporal and spatial distribution of stream flow and sediment yield and the potential future impact of climate change on stream flow and sediment yield in Darbandikhan Watershed, Iraq. This assists with a deep understanding of Diyala River's water resources that may be employed in planning future projects. To this end, the SWAT model was implemented in the daily time step using required spatial and temporal input data.

2. Methods and Materials

I. Study area

Diyala River Basin is one of the main tributaries of Tigris River. The river's watershed cover 32600*km*^{2} located between the latitudes 33.216° N and 35.833° N, and the longitudes 44.500° E and 46.833° E, Figure 1 [25].The river originates from Zagros Mountains near Hammadan City then reached Tigris River south of Baghdad City with a total length of 445 *km*. Construction of Darbandikhan and Hemrin Dams divided the watershed into three parts: the upper part is the Darbandikhan Watershed, the middle part is the Hemrin Watershed and the last part which is located between Hemrin Dam and the outfall of Diyala River in Tigris River[6]. Darbandikhan Watershed is the largest water supplier of Diyala River located between the latitudes 35.818° N and 34.223° N, and the longitudes 45.28° E and 47.96° E. It covers 17800*km*^{2}, 18.4 % inside Iraq, the reminder in Iran, with mean daily average income to Darbandikhan Reservoir of 170*m*^{3}*/sec* (Ministry of Water Resources (MoWR), Iraq, 2018, unpublished data). This watershed is located in the semi-aired region of the Middle East with an average yearly precipitation of 420 *mm* and an average temperature of 36 *°C*. The daily average suspended load observed by **(**Al-Ansari, 1988, unpublished report) is 177 *tons/day* with a soil erosion rate of 2.17 *tons/km*^{2}.

II. Input data

The minimum required input data to the SWAT model for stream flow and sediment simulation is Digital Elevation Models (DEMs), land cover digital maps, soil and weather data. The datasets suggested by [20]were used in this study, includes; The Shuttle Radar Topographic Mission (SRTM) DEM which were produced by the join of National Aeronautics and Space Administration (NASA) and German space agency, the DEM cover entire world with 90x90*m* in spatial resolution Figure 2. The Moderate-resolution Imaging Spectroradiometer (MODIS) land cover produced by Aqua and Terra seniors with 500×500*m* of spatial resolution, the land cover was classified using supervised classification techniques for the year 2001Figure 3 using high-resolution images. The Food and Agricultural Organization (FAO 1995) of the United Nation (UN) produced a digital soil dataset for the entire world at 1:500000 in vector scale Figure 4. The data contain two layers of soil and all hydrologic parameters required by SWAT [26]. The Climate Forecast System Reanalysis (CFSR) provides the global maximum and minimum temperatures, precipitation, solar, relative humidity and wind speed in the format required by SWAT in 38×38*km* of virtual stations, the weather data generated by CFSR based in satellite observation and international ground stations. The CFSR dataset was used, after assessing it by comparing it with available monthly gauged precipitation data that were recorded in Khaneqen Gauge Station for the period from 1/1/1984 to 1/12/2002 (unpublished data).

The observed stream flow recorded in Darbandikhan Dam was provided by MoWR for the period from 1/1/1984 t0 31/12/2013 in the daily time step (unpublished data).

Five General Circulation Models (GCMs) of global climate namely: gfdl_cm2_1.1, bccr_bcm2_0.1, cnrm_cm3.1, giss_model_e_r.1 and mri_cgcm2_3_2a.1 were nominated for Darbandikhan Watershed for future climate projection to year 2050 based on A1B scenario of medium emission. The future monthly-based change in the precipitation and surface air temperature was processed and redefined to the calibrated SWAT model. The climate change data were downloaded from the climate wizard website of Nature Conservancy of Universities of Washington and Southern Mississippi. All the spatial input data were projected to the UTM_Zone_38_N coordinate system then applied to the SWAT model. Table 1 shows the types, sources, and resolutions of the input data.

III. Setting of SWAT model

In this study, the Arc GIS 10.3 and Arc SWAT 2012 were used in all spatiotemporal processing such as clipping, projection, transfer from vector to raster and temporal simulation of stream flow and sediment. The DEM based method suggested by SWAT used in the delineation of the watershed, determine the positions of streams and slopes calculation. In addition, the land cover, soil and slope data were used to generate the HRUs. In order to cover all variations in watershed's slopes, the slopes were classified into four classes, which are: 0-10, 10-20, 20-30 and >30according to slopes calculated by DEM based method implemented in SWAT. All data sets were considered with zero approximation suggested by SWAT. The SWAT model was run for a period of 30 years from 1/1/1984 to 31/12/2013 in the daily time step. Moreover, the stream flow and sediment yield for this period were extracted and the spatial distribution of sediment source was presented according to the sediment yield of each sub-basin.

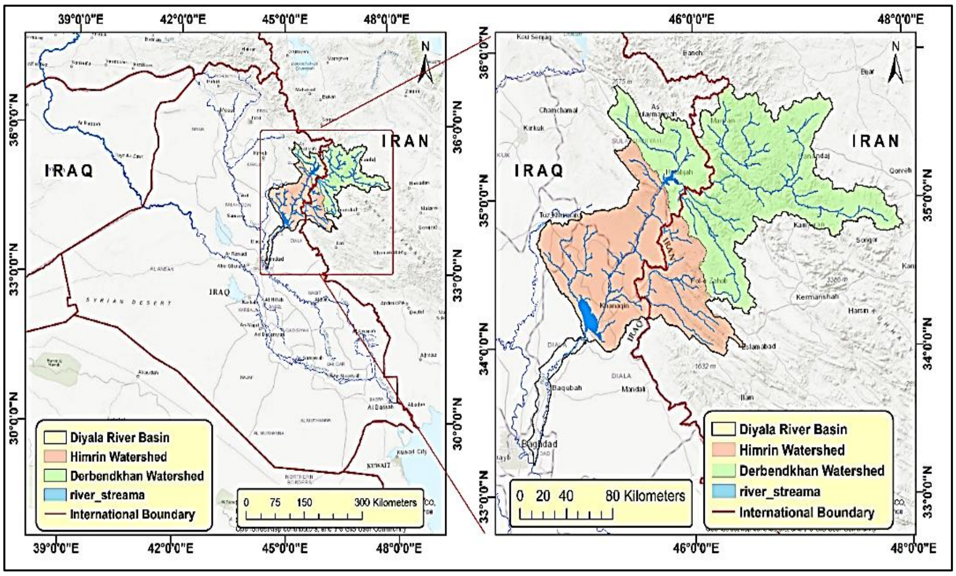

Figure 1: Location map for Diyala River Basin [25]

Table 1: Input data used in the simulation model

Data	Producer	Spatial resolution (m)	Source
DEM	SRTM	90×90	https://earthexplorer.usgs.gov/
Land cover and land use	MODIS	500×500	https://earthexplorer.usgs.gov/
Soil	FAO	1:500000	www.fao.org
Weather	CFSR	38000×38000	https://globalweather.tamu.edu/
Climate change	Nature Conservancy	-	http://www.climatewizard.org
Observed Discharge	MoWR	-	Unpublished data

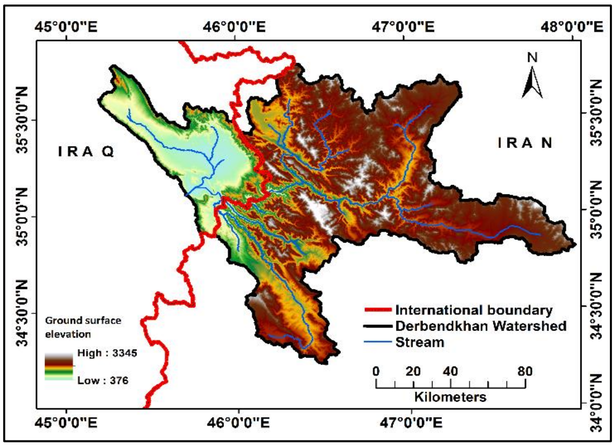

Figure 2: SRTM DEM applied in SWAT model

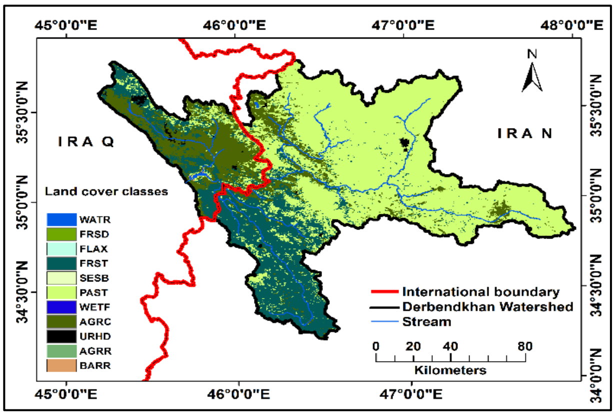

Figure 3: MODIS land cover classes digital map

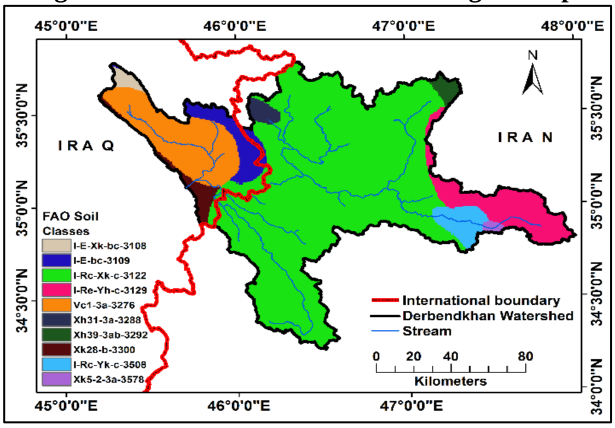

Figure 4: FAO soil classes' digital map

IV. Calibration, validation and sensitivity analysis

The automatic calibration by SWAT-Calibration and Uncertainty Programs (CUP) was used to calibrate the initial result of SWAT using SUFI-2 program with Nash-Sutcliffe Efficiency (NSE) [27] and coefficient of determination (R^2) as a dual objective function in optimization algorithm for calibration and validation processes. The observed daily discharges for the period from 1/1/1984 to 31/12/2004 and from 1/1/2005 to 31/12/2013 were used in calibration and validation, respectively, in daily time step. Firstly, the parameters suggested by [28] and [8], and the parameters extracted by sensitivity analysis were used in calibration with 300 simulations at the first iteration. Moreover, five iterations were used in the calibration, the best ranges of parameters extracted in the last iteration applied in the next iteration [29]. The calibrated model was used to project the future climate using the predicted precipitation and surface air temperature for the period from 2015 to 2050 according to the scenario of moderate emission (A1B). The original CFSR weather data were multiplied by the climate change factors for the gfdl_cm2_1.1, giss_model_e_r.1, cnrm_cm3.1, mri_cgcm2_3_2a.1 and bccr_bcm2_0.1 models and changed to date of 2050 then SWAT-CUP run for one iteration. The future projected streamflow and sediment yield were compared with the streamflow of 30 years base period (recorded streamflow from1/1/1984 to 31/12/2013). Due to the unavailability of recorded sediment data the best simulated sediment yield of the base period (for the 30 years) was considered as the observed sediment to compare with the future prediction of sediment.

3. Results and Discussion

I. Certainty of weather data and climate change effect

The statistical values of the NSE, R^2, and Root Mean Squared Error (RMSE), for the monthly comparison between the CFSR and recorded weather data in Khaneqen Station were equal to 0.7, 0.705and 19.5, respectively as shown in Figure 5. According to [30], these values are within the acceptable ranges. Although it was not possible to compare the daily precipitation due to the data unavailability, the monthly verification can be considered.

II. Calibration, Validation and Sensitivity Analysis

The results of calibration Figure 6 and Table 2 show that the curve number (CN) is the most sensitive parameter for Darbandikhan Watershed followed by available water capacity of the soil layer (SOL_AWC) and other parameters ranked, as listed in Table 2, according to t-Stat and P-value. In addition, the snow parameters set showed a significant sensitivity to simulated stream flow. However, the simulation is satisfied and considered as a good simulation if the NSE is greater than 0.5 [30]. The result of stream flow simulation shows that the NSE andR^2equal to 0.61and 0.62, respectively with good calibration assessment factors, R-factor equal to 1 and P-factor equal to 0.84, also, for validation period the NSE andR^2 equal to 0.53 and 0.68, respectively with R-factor equal to 0.77 and P-factor equal to 0.21 as shown in Figure 6.

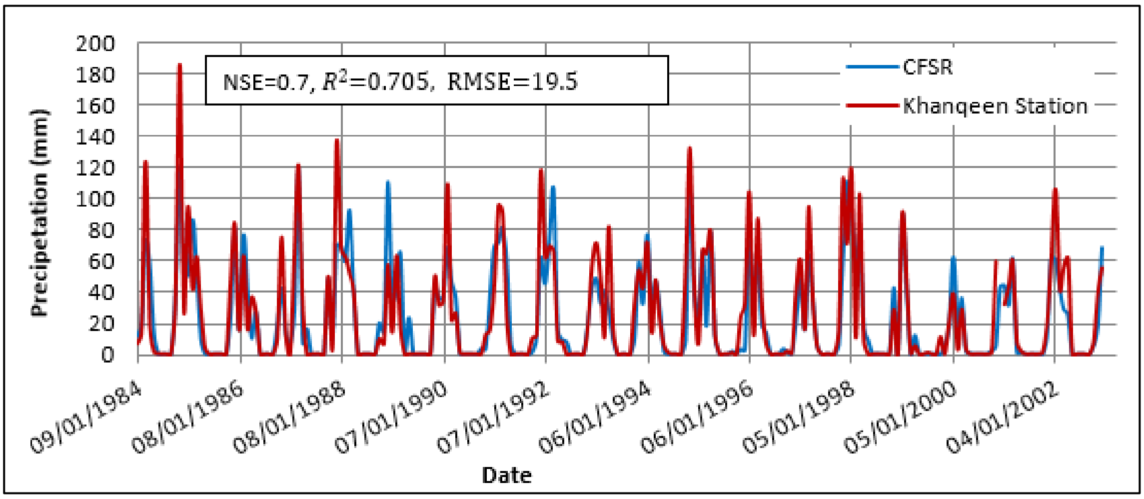

Figure 5: Monthly correlation between CFSR and observed precipitation for the period from 1984 to 2002

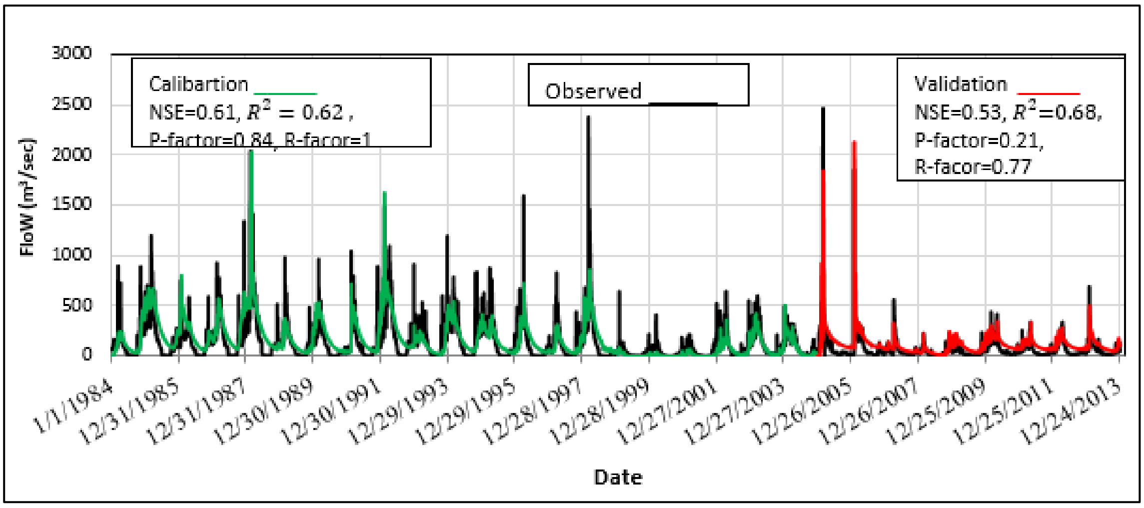

Figure 6: The calibrated and validated stream flow

Table 2: The parameters used in calibration process

Parameter Name	Description	Input values Min.	Input values Max.	t-Stat	P-Value
1: R_CN2.mgt	SCS streamflow curve number	-0.5	0.3	-20.08	0.00
2: R_SOL_AWC().sol	Available water capacity of the soil layer	-0.3	0.5	2.36	0.02
3: R_ ESCO.hru	Soil evaporation compensation factor	-0.3	0.5	-0.74	0.46
4: V_GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur(mm)	-0.5	0.3	0.72	0.47
5: R_GW_REVAP.gw	Groundwater "revap" coefficient	-0.5	0.3	0.49	0.63

6: R_REVAPMN.gw	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)	-0.3	0.5	-0.49	0.63
7: V_GW_DELAY.gw	Groundwater delay (days)	30	450	0.17	0.87
8: V_ALPHA_BF.gw	Base flow alpha factor (days)	0	1	-4.57	0.00
9: V_ SFTMP.bsn	Snowfall temperature	-10	10	-5.30	0.00
10: V_S MTMP.bsn	Snow melt base temperature	-10	10	-2.96	0.00
11: V_ SMFMN.bsn	Minimum melt rate for snow during the year	0	20	-0.53	0.60
12: V_ SMFMX.bsn	Maximum melt rate for snow during year	0	20	-1.37	0.17
13: V_ TIMP.bsn	Snow pack temperature lag factor	0	1	0.77	0.44

III. Spatiotemporal distribution of stream flow and sediment yield

The computed stream flow temporal distribution for the period 1984 to 2013 is shown in Figure 7. These results are clearly indicating that the recorded stream flow decreased at Darbandikhan Dam from around 150 m^3/sec in earlier 1984 to 75m^3/sec at the end of 2013, in the other words the flow rate was decreased by 50% in 30 years period. This trend can be attributed to the impact of climate change on the weather parameters and then on the land cover. In addition, the computed spatial distribution for the average stream flow for the period from 1984 to 2013 is shown in Figure 8. This figure shows that the middle and southern parts of the watershed are the most stream flow producers than the other parts of the watershed. This is because that the elevations of the ground are higher than the other parts in other meaning the isohyets of precipitation increase in high mountains. In addition, the soil of type D hydrologic group, which has the highest runoff rate among other types, is the dominant soil in these parts. Moreover, the land cover of agricultural and forested is dominated in these parts.

Results of the spatial analysis show that only 10.4% of stream flow comes from the Iraqi part of the watershed while most of the stream flow comes from Iran.

Results of temporal simulation of the sediment yield for the period 1984 to 2013 are shown in Figure9. These results indicate that the sediment yield is strongly related to the stream flow peak. In addition, it can be noticed that there is an increase in the peaks of sediment yield in spite of the decrease in the stream flow that shown in Figure 7. This can be attributed to the increase in air temperature and the decrease in precipitation, due to climate change, that consequent by stream flow decreasing and hiding the land cover that catches the surface soil. The results of the spatial distribution of sediment sources for the period 1984 to 2013 see Figure 10 shows that the sediment income with a high rate from the center of Derbrndkhan Watershed. This location has a large slopes see Figure2

compared with other parts of the watershed also the part of a large producer of sediment has a pasture land cover seeFigure3, which consider as a little capture of surface soil.

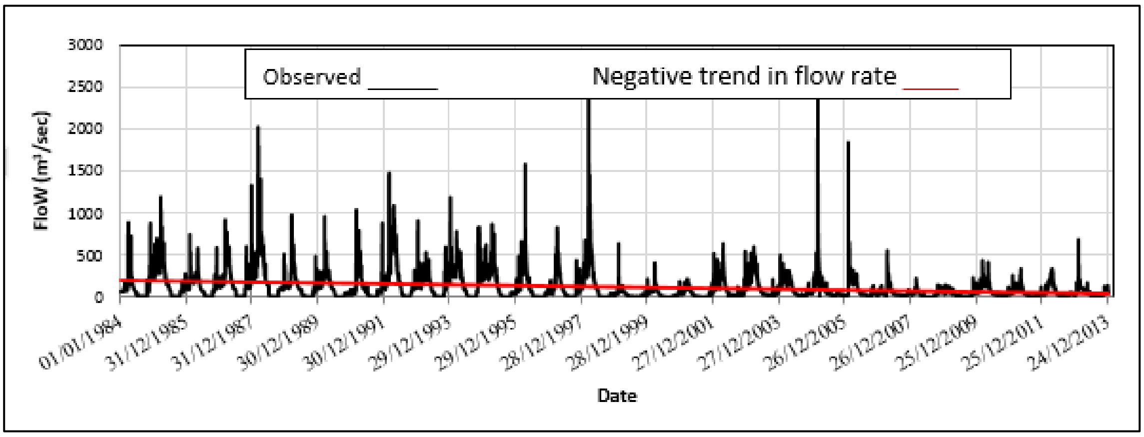

Figure 7: Temporal distribution of the streamflow for the period 1984 to 2013

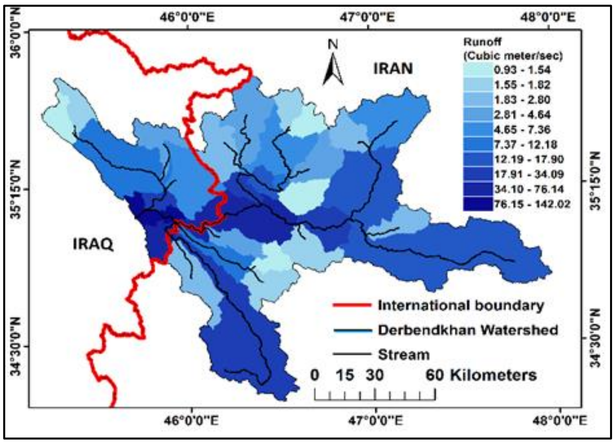

Figure 8: Spatial distribution for the average streamflow sources for the period 1984 to 2013

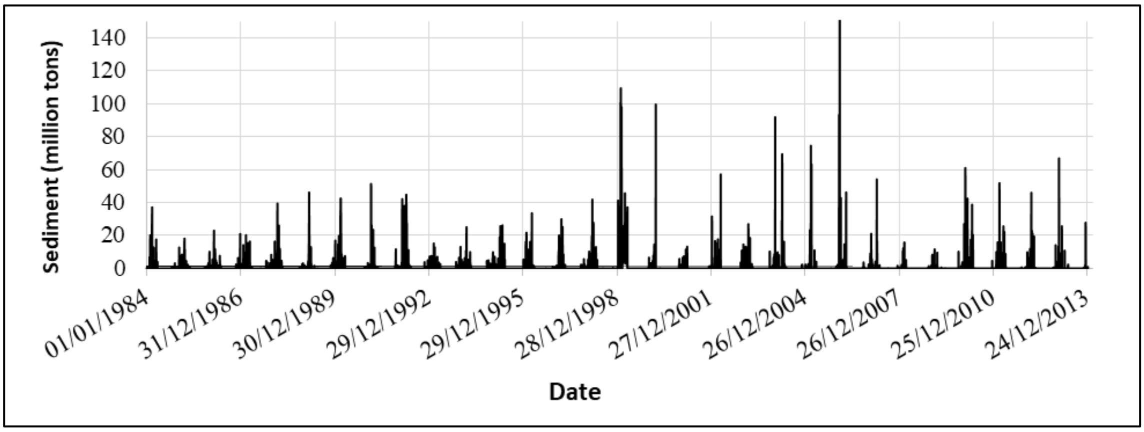

Figure 9: The best simulated sediment for the period 1984 to 2013

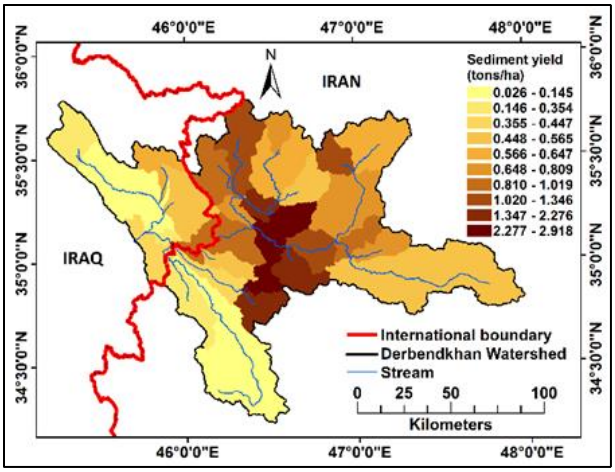

Figure 10: Spatial distribution for the average sediment yield for the period 1984 to 2013

Results of spatial analysis of the sediment yield show that only 10% of sediment comes from the Iraqi part of the watershed while most of the yielded sediment comes from the Iranian part. However, most of the yielded sediment (90 %) comes from the middle part of the watershed located in Iran with approximately 60 *km* (stream length) far from Darbandikhan Reservoir. Generally, all the climate change models show a decrease in flow rate for the period until the year 2050, the average of five climate models indicate about49% of Darbandikhan surface water will decrease compared with the average monthly observed flow, as shown in Figure11. The gfdl_cm2_1.1 indicates the largest decrease among other climate models with a 35% decrease in flow, while, the cnrm_cm3.1 indicates an increase of about 75%. All climate models show the same behavior except the cnrm_cm3.1 model indicates an increase in flow rate with 50 and 100% in December and June; respectively. These results correspond to the conclusions of [8], which is the stream flow will decrease to 47 % until 2064. The future sediment income to Darbandikhan Reservoir until the year 2050 is followed the flow, in general, the simulated sediment income decreases with a large decrease in March by about 50% compared with the best simulated sediment. The cnrm_cm3.1 climate model shows a large difference between best-simulated and projected sediment rates for June, the other models give the same behavior for sediment income in the future, as shown in Figure 12. Consequently, the computed spatial distribution for the average stream flow for the period from 2015to 2050 is shown in Figure 13.

The computed spatial distribution for the average sediment for the period from 2015 to 2050 is shown in Figure 14. Analysis of the spatial distribution of the stream flow and sediment yield for this period, shown in Figures 13 and 14, and the that of the period 1984 to 2013, shown in Figures 8 and 10, shows that the average yearly flow and sediment yield in the watershed will decrease into about 49 % and 44 %, respectively, during the period from 2015 to 2050. However, the contribution rate of the Iraqi part of the watershed for the stream flow and sediment yield will still the same with 10.4 % and 10%, respectively. In addition, the same middle part of the watershed located in Iran with approximately 60 *km* (stream length) far from Darbandikhan Reservoir produced most (90 %) of the sediment yield.

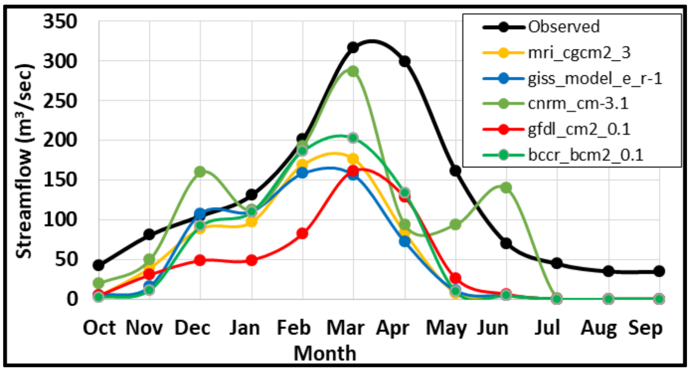

Figure11: Potential stream flow under climate change condition until 2050

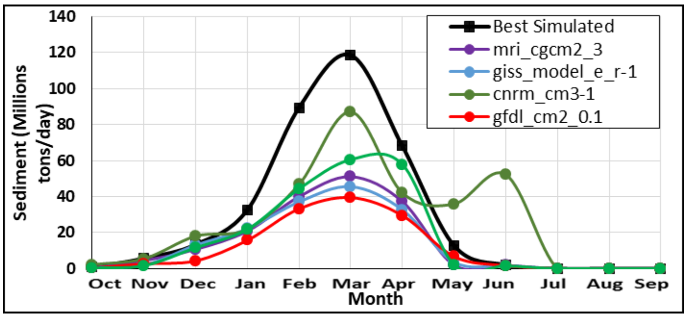

Figure 12: Potential sediment yield under climate change condition until 2050

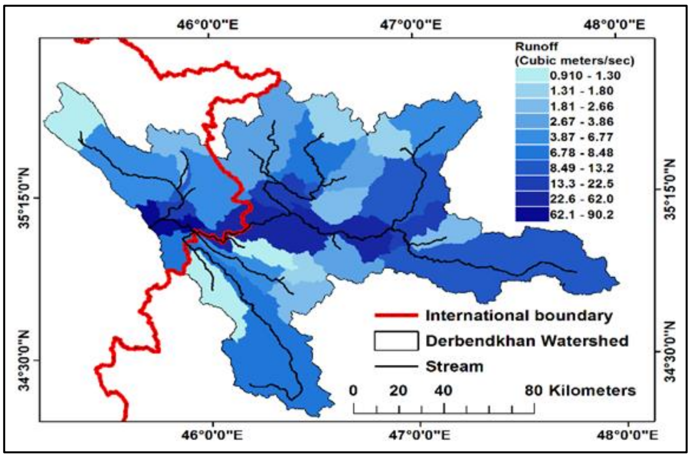

Figure 13: Spatial distribution for the average streamflow sources for the period 2015 to 2050

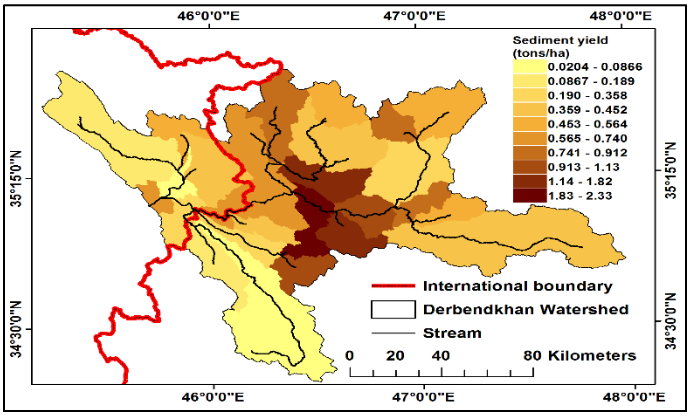

Figure 14: Spatial distribution for the average sediment yield fro the period 2015 to 2050

4. Conclusions

In this study, the SWAT model was implemented successfully in Derbendkhan Watershed to show the impact of climate change in stream flow and sediment yield. From the results, the CFSR weather data consider as a reliable source of weather data for Darbandikhan Watershed due to the unavailability of gauged data. According to previous researchers, CFSR weather data give acceptable stream flow simulation when using the SWAT model. In addition, the surface water resources and sediment yield in Darbandikhan Watershed will decrease by about 49% and 44%, respectively under the impact of climate change until the year 2050. This can be attributed to the decrease in precipitation and an increase in surface air temperature. The decrease in surface water resources for the future 30 years and the average stream flow of the past 30 years has the same negative trend. In addition, the study concluded that sediment peaks increased after 2000. This is because of the poor land cover hanging on the surface soil against the stream flow force for this period because of climate change.

Moreover, the middle and southern parts are most stream flow producers because of the highest isohyetal compared with other parts of the watershed. Whereas, the sediment come from steep and barren land parts of the watershed located in the middle parts. Most of the soil types of Darbandikhan Watershed are soils of type D hydrologic group, which has the highest rate of runoff, thus can produce more sediment due to erosion.

The results of this study can be used for planning future projects related to water resources. More investigation should be done for groundwater under climate change impact. However, cooperation between Iraq and Iran should be done for hydrologic data exchange, planning for sediment mitigation and justice in water usage in dry and wet seasons. The study explores some extreme hydrologic events like highest peaks of stream flow and sediment that occurred in Darbandikhan Watershed so, it is recommended to investigate a modification in the design of dams specifically the sediment gates and spillway capacity under climate change conditions.

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