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Hydrological Model for Derbendi-Khan Dam Reservoir Watershed Using SWAT Model

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K E Y W O R D S

Derbendi-Khan dam; Runoff; SWAT model; Rainfall depth.

A B S T R A C T

In this study, the watershed's runoff of Derbendi-Khan dam reservoir within the upper part of Diyala River reach the northeast of Iraq was modeled by Soil Water Assessment Tool (SWAT). The model calibration and validation were based on monthly measured inflow to the dam reservoir. They extended for a period between 1979 and 2008 with a warm-up period of two years, twenty-year for calibration, and eight-year for validation. Sequential Uncertainty Fitting version 2 (SUFI2) automatic calibration algorithm method used for model calibration and sensitivity analysis. Results demonstrate that the model performance for the studied watershed which is evaluated, with many statistical criteria, was very good. The sensitivity analysis pointed parameters (CH_K2, CN2 ALPHA_BF, SFTMP, SOL_AWC, and CH_N2) are the most useful parameters on runoff calibration for the studied watershed. Moreover, it was found that the average annual areal snowmelt ratio to the average annual areal precipitation during the simulation period is approximately 24%.

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1. Introduction

Hydrological modeling is making more straightforward the conceptual representation of a part of the hydrology cycle and, it is fundamentally used to describe the physical processes in a watershed that controlling the conversion of precipitation to runoff. The watershed is the entrance step that acts as a beginning for addressing issues regarding sustainable water resources management beneficently. To deal with water resources management issues, the different hydrological processes elements that are taking place within the watershed should be analyzed and quantified. Undoubtedly, the watershed must be the basis of this analysis that carries out because all these hydrological processes are occurring inside individual micro-watersheds. Subsequently, when the spatial and temporal variation and the interaction of hydrological processes components are understood, then the strategies of runoff and soil conservation can scientifically be formulated. Recently, there are different hydrologic models created with various structural characteristics. Many researchers categorized these models based on their visions and objectives [1]. Thus, several purposes can be served with hydrological models [2], where the decisions that regard to water resources management are directly impacted by the accuracy and skill of stream flow prediction models. Several conceptual and statistical watershed runoff prediction models have been developed to help policymakers, urban planners, and administrators make better and more informed decisions [3].

Among the different kinds of models, semi-distributed models are the most efficient model for hydrological simulation as it exceeds the difficulties commonly be faced with fully distributed model and lumped model [4]. Out of these models, the Soil and Water Assessment Tool (SWAT) is a continuous daily step, long period, physically-based parameter, and distributed hydrologic model has been used widely for simulate agricultural watersheds management practices [5], help to evaluate the climate change impacts [6], identify water quality in watersheds [7, 8], and assess the surface, subsurface flow and sediment yield transfer in various watersheds with varying soils [9, 10]. Researchers have applied the SWAT model in several wet and semi-arid areas around the world, such as southern Australia [11], South Asia [12], North and southeast Africa [13–15], and in the Mediterranean coastal basin in Spain [16]. Several researchers have studied the water balance of the dam's reservoir watershed using SWAT model, in China [17], and Pakistan [18]. Regarding the calibration and validation techniques of the SWAT model in this study, Arnold et al. [9] reported that several calibration techniques had been developed for the SWAT, including manual calibration procedures and automated procedures using the shuffled complex evolution method. Recently, SWAT Calibration and Uncertainty Program (SWAT-CUP) has been developed, which provides a decision-making framework that incorporates a semi-automated approach Sequential Uncertainty Fitting-2 (SUFI-2) using both manual and automated calibration and incorporating sensitivity and uncertainty analysis [19].

However, the Arc-SWAT model application has been demonstrated for the Derbendi-Khan dam reservoir watershed at the upper part of the River Diyala basin, which is the main part of water resources, where the study given by [20]. Hence, the objectives of this study were: (1) modeling of hydrological processes of the upper River Diyala watershed using the semi-distributed hydrological model Arc-SWAT-2012; (2) to evaluate the spatial contribution of the upper River Diyala watershed to surface runoff that inters to Derbendi-Khan dam reservoir; (3) to examine use of the Climate Forecast System Reanalysis (CFSR) of daily global weather station data, where acceptable measured weather data face scarcity in this watershed and (4) to get a calibrated Arc-SWAT model which will be harnessing to study of the possible future climate changes Impacts on water resource in this watershed.

2. Study Area

The Diyala River, a tributary of River Tigris which originating from the north-west border of Iran and located within longitude 44˚30'- 47˚50' and latitude 33° 57' - 35˚50', and is one of the essential rivers in Iraq draining an area reaching 29675.5 km^2 up to Hemren dam site, Figure 1. Two dams have been constructed on the river, Derbendi-Khan dam, which situated in the upper parts and Hemren dam, which located in the middle parts of the river watershed (360 and 188 km upstream the confluence with the Tigris river south Baghdad respectively) [20]. However, the data of the upper part of the Diyala river basin was used for modeling of runoff by SWAT in the resent study. Derbendi-Khan dam reservoir watershed is located between latitude 34° 13' to 35° 47' N longitude 45° 11' to 47° 58' E with an elevation between 369 m to 3350 m above mean sea level and covers an area of 16745.3 km^2 which distributed as 19.8% and 80.2% in Iraq and Iran respectively. The hydrological records for the period between 1981 and 2008 indicate that the average annual runoff volume for the measured data reached to the value of 4.54 BCM, while the maximum and minimum yearly runoff volumes were 9.74 and 1.14 BCM, respectively. Derbendi-Khan dam reservoir fed by the rainfall during the wet seasons, groundwater flow, and snowmelt.

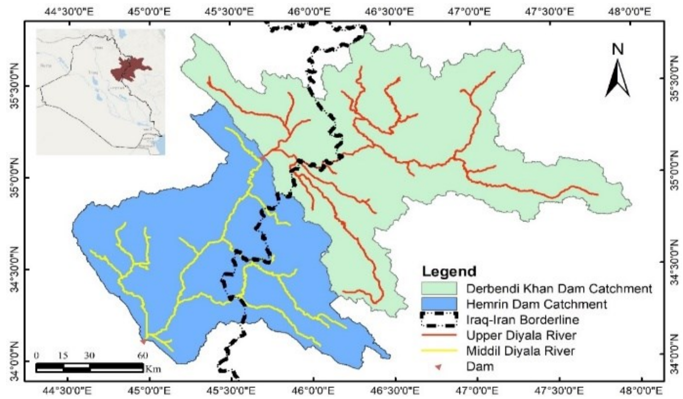

Figure 1: Watersheds of Derbendi-Khan and Hemren dams in upper and intermediate parts of Diyala River, after [20]

3. Simulation Tools Description and Methodology

I. Simulation Tools

Two requested tools are harnessed for achievement the hydrological model for the studied watershed and are described as following:

1. Soil and Water Assessment Tool (SWAT)

Soil and Water Assessment Tool (SWAT) is a physically semi-distributed and continuous calculation model that can be simulating surface and subsurface flow, sediment yield, and water quality of agricultural watersheds [21]. A short overview of SWAT model, the basic part of the Simulator for Water Resources in Rural Basins (SWRRB) model is the combination of the GLEAMS and CREAMS models which are acronyms for (Groundwater Loading Effects of Agricultural Management Systems) and (Chemicals, Runoff, and Erosion from Agricultural Management Systems), respectively [22, 23]. Progressively, the building of the first version of the SWAT model was developed based on Routing Outputs to the Outlet model by interfacing in SWRRB. Subsequently, the transport capabilities of pollution were embedded within the SWAT model (i.e., reservoir, pond, point source, wetland, and sediment routing). Additionally, improving representations for conservation and management practices were submitted to the SWAT model (i.e., management practice with temporal accounting, plant growth, land-use changes evaluation, and irrigation plans. It is used worldwide for the evaluation of water balance allocation and climatic changes in the watershed. The major advantage of the SWAT model is, it can be used to explore the impact of land management practices with relative impacts of scenarios on runoff and eroded sediment yields from the watershed. This process can also be applied in large, and additionally for complex watersheds of un-gauged and semi un-gauged river basins with different soils, land use and management conditions over significant lots of time [24]. Furthermore, SWAT has a weather simulation model also that generates daily data for rainfall, relative humidity, solar radiation, temperature, and wind speed from the monthly average values variables of these data,which gives a helpful tool to fill in missing daily information in the watched records. Watershed hydrology simulation in the SWAT model includes two phases, the earthen part (land phase) and the routing phase. A complete description of theoretical and input/output data for SWAT version 2012 can be found in the works by Arnold and colleagues [24, 25]. Moreover, sufficient information about the SWAT model application and development can be found at https://swat.tamu.edu/. In addition, Gassman et al. [26] reported a review of climatic inputs and pollutant losses and flow routing across the globe. Gassman et al. [10] presented an innovative application and adaptations for the SWAT code and simulation capabilities. Daniel et al. [27] focused on the popular context for the application of watershed modeling and related new technologies involved with the SWAT model. Regarding the current development and presentation of performance statistics for the SWAT model, twenty types of research have been summarized by Douglas-Mankin et al. [28].

2. Calibration and Validation Tool

Calibration and valuation of the SWAT model do not depend on a single parameter as an indirect model (i.e., in the later model, a single-valued parameter results in a single model signal), while in

SWAT model calibration follows the inverted model (IM) properties. Where, in an IM, a measured value can be producing multiple sets of a different parameter, i.e. the IM has a natural characteristic of non-uniqueness. Recently, the IM has become an acceptable and motivating procedure for calibration [29]. The inverse model solves the problem of figuring out the physical systems from measuring the output variables of the model. Inverse modeling is simplified due to its straightforward and direct measurement of parameters, which opposes the physical system that is usually described to be time-consuming, costly, and annoying. Often, measured outputs have limitations for application, and almost all measurements are subjected to some uncertainties. Generally, the derivations are statistical. Furthermore, the other reason is that only a limited number of (noisy) data can be measured and a range of equations usually models the physical systems;; no hydrological inverse problem is uniquely solvable. Therefore, IM is used to characterize the set of models, mainly through the transformation of the uncertainties to the parameters that fit the data and convincing attributed assumptions as well as other initial information [23]. The SUFI-2 is an example of IM, which is developed for calibration and uncertainty analysis of the SWAT model. In SUFI2, parameter uncertainty calculates for the attributed sources of uncertainties in a semi-distributed hydrological model such as the uncertainties in driving variables, the concept of model, parameters, and measured data. The two important factors (P-factor and R-factor) in this calculation become the index of the evaluation of the results. Therefore, the degree, which all uncertainties are calculated for uncertainties, is quantified by a measurement referred to as the P-factor. P-factor is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). In SUFI-2, the 95PPU is calculated at 2.5% and 97.5% degree of the cumulative distribution of an output variable obtained through Latin hypercube sampling, by forbidding 5% of the very bad simulations. The R-factor, however, is related to the strength of the calibration and uncertainty analysis. It is the average thickness of the 95PPU band divided by the standard deviation of the measured data. Sequential Uncertainty Fitting-2 tries to bracket most of the measured data with the smallest possible uncertainty band. In this research, SWAT-CUP has been used as a computer program for calibration of the SWAT model. The SWAT-CUP is a public domain program and, as such, may be used and copied freely. The program links SUFI-2 procedures to SWAT. It enables sensitivity analysis, calibration, and uncertainty analysis of a SWAT model.

II. Methodology

1. Creation of Model Data Base

The behavior of the SWAT model to represent the physical characteristics of any river watershed is related to the quality and the quantity of data which are a feeder to the SWAT model. Subsequently, modeling in SWAT needs to the database that represents the relief of a surface or Digital Elevation Model (DEM), land use and land cover (LU/LC), soil properties, precipitation in a daily or sub-daily detail, solar radiation, maximum and minimum air temperature, wind speed and relative humidity. These input databases are used to evaluate the runoff property and related parameters for the hydrological simulation of monthly streamflow in the Derbendi-Khan dam reservoir watershed, Figure 2-A. Input data information of the SWAT model are summarized below:

A. Digital Elevation Model

The DEM employs for delineation of stream networks, sub basins and delineates the watershed boundary in watershed modeling with ArcSWAT interface by applying fundamental raster functions provided by ArcGIS along with its spatial analyst extension. Subsequently, the parameters of each sub basin in the watershed (longest path of the stream and the topography of sub basins) are calculated [24]. In the recent study DEM with a spatial resolution of 1 arc-second of SRTM source which is given on the website (https://earthexplorer.usgs.gov) and shown in Figure 2-B.

B. Soil Properties

Data on soil types for Derbendi-Khan watershed was classified according to FAO-UNESCO soil, which is given by the global soil dataset of the Food and Agriculture Organization of the United Nations [25]. The important hydrological processes which are required for watershed modeling by the SWAT model and related with soil type are given in the FAO-UNESCO soil such as soil texture, available water content, bulk density, organic carbon content, hydraulic conductivity and hydrologic group (HG). However, the required properties for this study were analyzed to get the soil classification input data to the model and founded the soils of the watershed were clay, clay-loam, and loam soils with hydrologic soil group C and D as shown in Figure 2-C. Table 1 below gives information about the studied watershed soil data.

C. Land Use and Land Cover

The land surface condition during rainfall events effects runoff and surface erosion so the land use and cover (LU/ LC) data are required for the SWAT model input database. In this study, the LU/LC data has given by Global Land Cover Characterization (GLCC) was adopted. Which is consist string of global LC classification data sets that are primarily depend on the unsupervised classification of 1.0 km Advanced Very High-Resolution Radiometer (AVHRR), 10-day Normalized Difference Vegetation Index (NDVI) composites. Figure 2-D and Table 2 are illustrating the coverage areas of several of the LU/LC categories for Derbendi-Khan watershed.

Table 1: The various soils types in the studied watershed and the required codes in the SWAT model

NO	Soil Type	Raster Value	Code in ArcSWAT	Hydrologic Group	% Area of Watershed
1	LOAM	3108	I-E-Xk-bc	D	0.855
2	LOAM	3109	I-E-bc	C	4.15
3	LOAM	3122	I-Rc-Xk-c	D	67.47
4	LOAM	3129	I-Re-Yh-c	C	8.424
5	CLAY	3276	Vc1-3a	D	11.661
6	CLAY-LOAM	3288	Xh31-3a	D	1.129
7	CLAY-LOAM	3292	Xh39-3ab	D	1.078
8	CLAY-LOAM	3300	Xk28-b	D	2.003
9	LOAM	3508	I-Rc-Yk-c	D	2.809
10	CLAY-LOAM	3565	Xh32-3ab	D	0.002
11	CLAY-LOAM	3578	Xk5-2-3a	D	0.419

Table 2: Coverage areas of various land use/cover categories in the Derbendi-Khan dam watershed area

Land Use Category	Raster Value	Code in SWAT	% Area of Watershed
Agricultural Land – Generic	150	AGRL	16.249
Agricultural Land – Row Crops	14	AGRR	5.806
Barren Land	200	BARR	0.851
Forest-Deciduous	50	FRSD	0.028
Forester – Mixed	20	FRST	33.839
Forest-Evergreen	70	FRSE	3.115
Pasture	30	PAST	39.834
Water	210	WATR	0.278

D. Land Slope

The watershed topography variation effects on over-land flow where it is the main gravidity driving force. However, the generation of HRUs was classified into four categories of land slope (0-10, 10-20, 20-30, 30-40, and above 40%), as shown in Figure 2-E. After the creation of LU and LC, soil classification and the HRUs were analyzed by overlapping the unique spatial datasets of LU and LC, Land slope and Soil map. The values of threshold adopted to create the HRUs were assigned as 0% for all spatial datasets land use, slope, and soil; subsequently, then the HRUs have been generated all across the 39 sub-basins of the area under study was 1699.

E. Weather Data

Water balance in the SWAT model for any watershed simulation mainly depends on daily or sub-daily weather data inputs that includes precipitation, maximum and minimum air, wind speed, relative humidity and solar radiation. Out of these variables, precipitation and temperature, are required, at least. Measured weather data by spatially distributed ground stations mostly face a shortage as in the resent study. This scarcity of weather data can be avoided through the use of daily weather data from the generated data by using a weather generator model but after confirmation of the validity of the available monthly measured data by statistical evaluation as it carried out by many researchers [20, 30]. However, the only available monthly measured precipitation data for Sulaymaniyah weather station, which lies in the studied watershed were, assessed statistically with the Climate Forecast System Reanalysis (CFSR) of the global weather station. Which is a satellite-derived weather forecasting data produced by the National Centers for Environmental Prediction (NCEP) [31]. The CFSR provides weather data distributed in the form of a grid with a 34 km distance approximately. In the recent study, data form twenty stations were used, as shown in Figure 2-F. Results of data assessment showed that the CFSR is acceptable for use, where the value of coefficient of determination (R^2) is with 0.74. Also, the test of the probability distribution function (PDF) type showed that both of the measured and CFSR monthly weather data follow the beta distribution, see Figure 3 and Figure 4-(A and B).

2. Model Set up

The runoff simulation model was accomplished by using the hydrologic model Arc-SWAT version 2012 (revision 627), which works as an extension of ArcGIS version 10.2.2 that makes an ArcMap project file; this file contains links to the retrieved data and incorporates all customized GIS functions into the ArcMap project file. Initially, the required spatial data have been arranged for the studied watershed area (Derbendi-Khan dam watershed in the upper part of Diyala River) and projected to the UTM datum. Then the SWAT models have set up to establish hydrological simulation for the watershed under observation. ArcMap tools applied the projections and maps clipping of the watershed. The model setup was done under the following steps: At the beginning it requires to create the SWAT model project setup. Subsequently, automatic delineation of the watershed, the definition of the land use-land cover, soil properties, and topography, then analysis of HRUs, weather data definition then write the input tables, editing input information, SWAT simulation; run SWAT model and read outputs. Detailed information to apply these steps founded in the ArcSWAT interface for SWAT-2012 user's guide. The number sub basins were thirty-nine sub basin (see Figure 5), and the areas of these sub basins ranged between 219.7 and 223400 hectares with total numbers of HRUs of 1,699. Finally, the SWAT model was run to simulate the various hydrological components with default parameters.

3. Performance Evaluation of the Model

Evaluation of SWAT model performance was dependent on graphical and statistical criteria by comparing the model outputs with the measured data. In this study four statistical criteria were adopted, [*i*] the Nash-Sutcliffe efficiency (E_{NS}) with values range between $-\infty$ and 1, [*ii*] the ratio of root-mean-square error to the standard deviation of observed data (*RSR*) which its values extends between 1 and 0, [*iii*] the percent bias (P_{bias}) with a perfect simulation when the P_{bias} equal to zero, and [*iv*] the coefficient of determination (R^2) with values range between 0 and 1. However, based on these statistical values result in the model simulation quality ratings as very good, good, satisfactory, and unsatisfactory. Details of these model performance evaluation equations and ratings can be found in [20, 32].

4. Results and Discussion

I. Sensitivity Analysis of Model Parameters

SWAT model has been initially executed with default parameters for the Derbendi-Khan dam watershed and results have been generated. Subsequently, based on these results automatically calibration adopted using the software of SWAT Calibration and Uncertainty Program (SWAT-CUP) which is specially developed for calibration and uncertainty analysis that can be coupled with the SWAT model in which the factors for the representation can be selected in accordance with the objectives of the study, there are different algorithms for automatically model calibration by SWAT-CUP. In this study, the Sequential Uncertainty Fitting version 2 (SUFI2) algorithm, as detailed in [21, 33], was used for calibration of the model and parameter sensitivity analysis. However, at initial, the most affected parameters that are related to the runoff were analysis to distinguish the sensitive parameters for model calibration, as shown in Table 3.

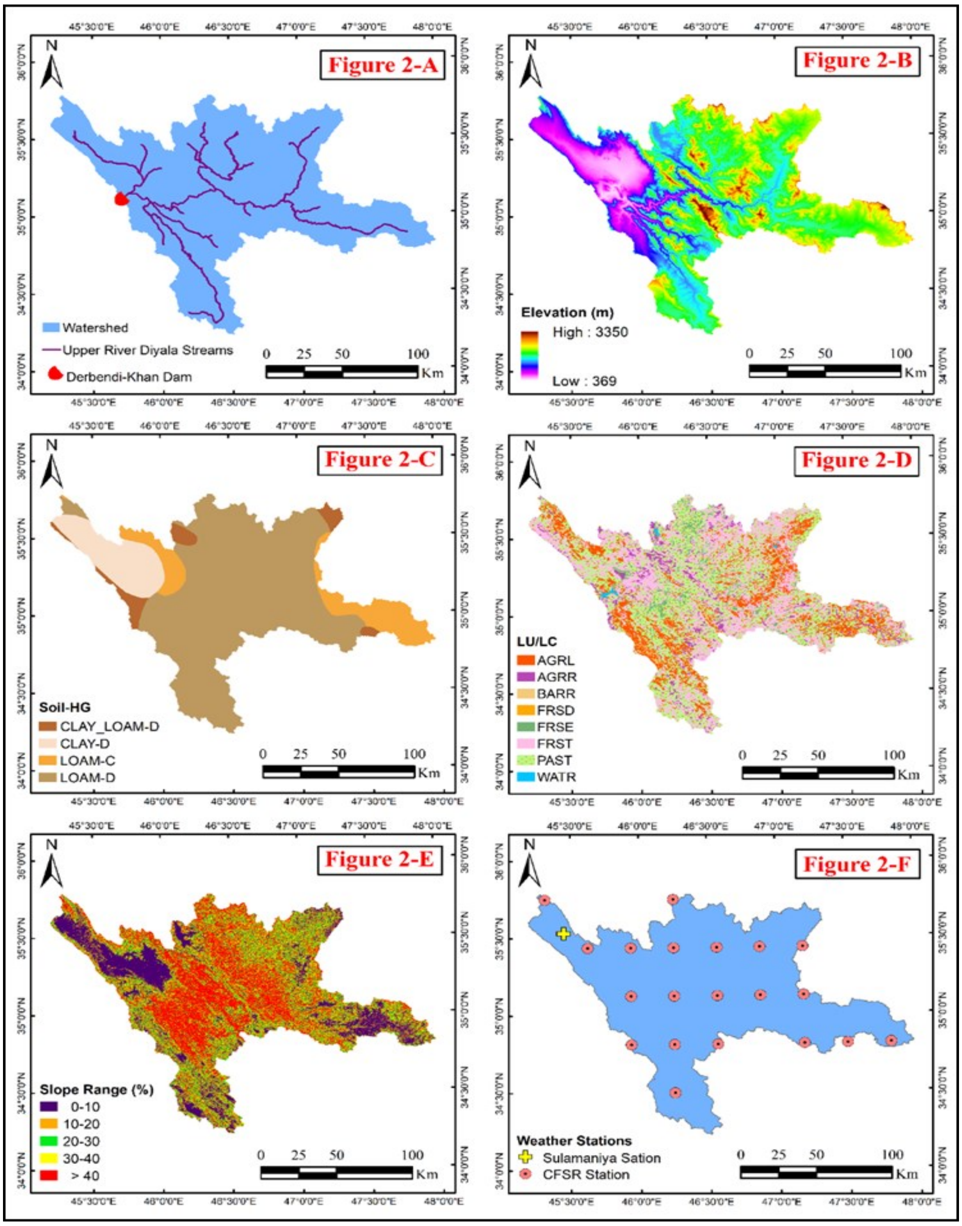

Figure 2: Derbendi-Khan Dam reservoir information maps used in SWAT Model

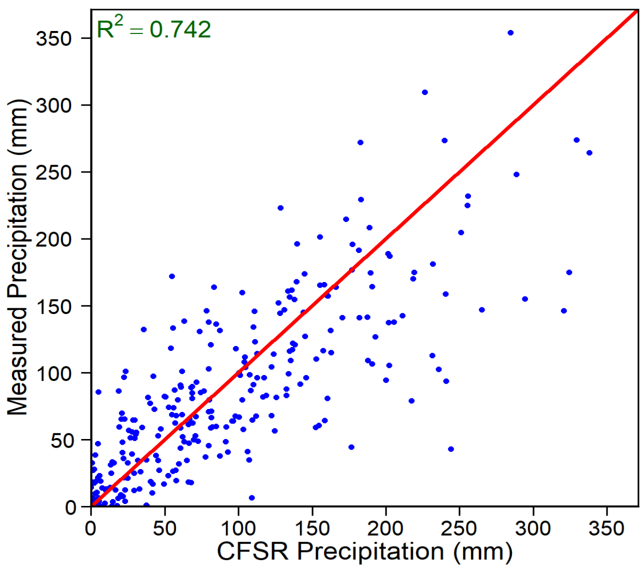

Figure 3: Comparison of Monthly observed and CFSR precipitation

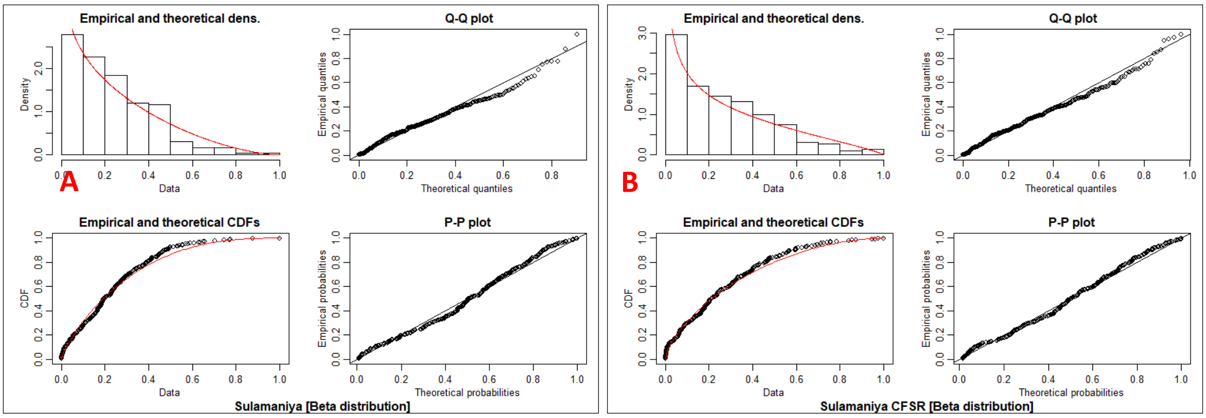

Figure 4: Distribution fit comparison of monthly measured and CFSR precipitation, A- measured precipitation and B- CFSR precipitation

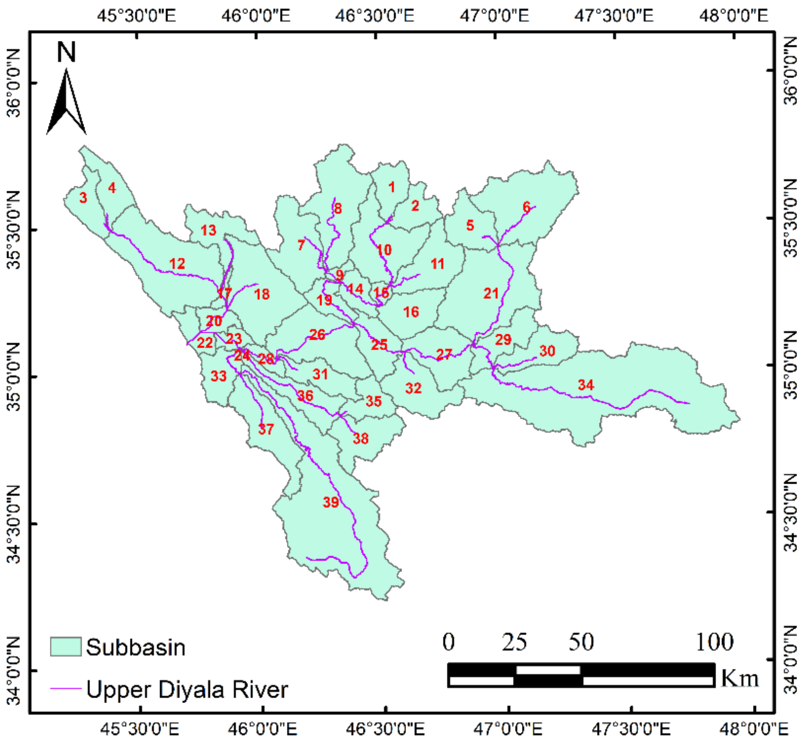

Figure 5: SWAT- DEM delineated sub basins of Derbendi-Khan dam reservoir watershed

The global sensitivity analysis method was adopted in the study that gives the rank of sensitivity based on the t-stat and the p-value of the parameters, the details of the method can be found in the SWAT- CUP user manual [34]. The first iteration with 500 numbers of simulation showed that the sensitive parameters that effects on runoff process in the Derbendi-Khan watershed are related to Effective hydraulic conductivity in main channel alluvium, SCS runoff factor, base flow alpha-factor, available water capacity of the soil layer, snowmelt base temperature, snowfall temperature, available water capacity of the soil layer, Manning's "n" value for the main channel, also the ranks of all parameters based on the sensitivity analysis illustrated in Table 3. Parameters that are not seen to have as much of a significant effect on the runoff of the watershed simulation its values also are taken into account in the calibration iterations in order to have more accurate simulation for runoff in the studied watershed. The final fitted values of these parameters are presented in Table 3.

II. Results and Evaluation of Model Calibration and Validation

The upper part of Diyala river tributary watershed up to the Derbendi-Khan Dam site was simulated the measured runoff which inters to the dam reservoir for thirty-year with two years kept as a warm-up period, twenty-year for model calibration (January-1981 to December-2000), an eight-year for model validation (January-2001 to December-2008) in monthly time scale with watershed area of 16745.3 km^2. Calibration of parameters was accomplished by two iterations with 500 numbers of simulations and fitted values of parameters as given Table 3; then, model validation was conducted through an additional iteration also with the same number of simulations. SWAT model simulation results for both of calibration and validation steps evaluated with statistical model evaluation parameters (E_{NS}, R^2, and *RSR* and P_{bias}) and showed that the observed flow values for the calibration period was predicted with model performance statistics values of E_{NS} of 0.80, R^2 of 0.81, RSR of 0.45 and P_{bias} of 7.3%, while these values for validation period were 0.75, 0.76, 0.5 and 8.6%, respectively. As a result of these model performance values, the model quality of the Derbendi-Khan Dam watershed model is classified as very good for both of the calibration and validation periods. So, the runoff calibration and validation processes are within an acceptable range of the measured flow.

Results of monthly runoff simulation for calibration and validation periods were plotted in time series with observed streamflow for visual comparison to explore the similarity between these two-time series data, as presented in Figure 6. Also, the correlation between observed and simulated flow for calibration and validation periods is given by scatter plots in Figure 7- (A and B), respectively. From these figures, it can be seen that the SWAT produces a perfect agreement for a long-time trend between observed and simulated monthly flow that are interring to the Derbendi-Khan Dam reservoir for both calibration and validation periods. However, it can be observed in general that the model gives a reasonable estimation of the base flow values of most periods during the years of calibration and validation periods. Also, the model has the ability to simulate the runoff for seasons that have a sudden change in flow trend (low discharge) throughout the year (as seen in years 1993, 1999 to 2002, and 2008). There is some unsuccessful in capturing of annual peak flow especially at the calibration period and in the year 2007 of validation stage, where an under/over-prediction has happened with the high difference value. From the observed flow, this can be related to the uncertainty of inflow measuring and the snowmelt simulation method in the SWAT model has certain geographical application restrictions. It has an excellent precision in plain areas with abundant precipitation and flat terrain, but it has relatively lower accuracy in mountainous areas with complex terrain [35].

Also, the total annual runoff volume (ARV) in billion cubic meters (BCM) was computed for the simulated and observed runoff as presented with a bar plot in Figure 8, and results of ARV showed that the statistical evaluation parameters values were 0.74, 0.77, 0.49, and 7.5%, respectively. The average annual runoff volume for the observed, and simulated data is calculated and the values are 4.54 BCM, 4.20 BCM, respectively. Also, the average spatially contributions of average annual runoff volume according to all sub basins were calculated based on the average runoff depth during the simulation period (1981-2008) and sub basin area in a million cubic meters (MCM), and results showed that the average runoff volume ranged between 0.3 MCM and 539.1 MCM as illustrated in Figure 9-A. As a result, the spatially average runoff depth values during the simulation period were ranged between 95.74 and 362.84 mm as shown in Figure 9-B, where the sub basins (1,2,10, and 11) has the maximum effective annual runoff depth (more than 350 mm) while sub basin number 37 possessed the minimum runoff depth (approximately 95 mm).

Moreover, as the results demonstrate that the snowmelt has an effective ratio of the total precipitation value that falls on the studied watershed, this relates to the geography and climate of the watershed where it is located in the mountainous region and is characterized by low temperatures during the winter season. Figures 9- (C and D) gives the spatial distribution of average annual precipitation and snow depths during simulation period in the Derbendi-Khan watershed. From these figures, the sub basins (1, 2, 10, 11, 32, 35, and 38) have the maximum annual precipitation depth (more than 700 mm), while sub basins 34 and 37 have the minimum depth of annual precipitation (415 - 450 mm). Also, the sub basins (1, 2, 10, and 11) have the maximum snowpack wit values of more than 420 mm, while sub basin number 1 has the minimum annual snowpack 90 mm, approximately. It was found that the average annual areal snowmelt ratio to the average annual areal precipitation during the simulation period is approximately 24%. Furthermore, watershed water balance components were calculated with primary and calibrated SWAT model parameters for the thirty-year simulation with two warm-up years and illustrated in Table 4.

Table 3: Sensitivity rank and uncertainties range of the model parameters based on SUFI2 algorithm for runoff calibration on monthly basis

Rank	Parameter Name	t-Stat	P-Value	Fitted Value	Definition
1	V__CH_K2.rte	6.16	0.00	85.046	Effective hydraulic conductivity in main channel alluvium (mm/hr)
2	R__CN2.mgt	-5.69	0.00	-0.109	SCS runoff curve number factor
3	V__ALPHA_BF.gw	-4.38	0.00	0.104	Base flow alpha factor
4	V__SFTMP.bsn	2.88	0.00	4.696	Snowfall temperature (°C)
5	R__SOL_AWC(..).sol	2.74	0.01	0.107	Available water capacity of the soil layer (mm H_2O/mm soil)
6	V__CH_N2.rte	2.41	0.02	0.217	Manning's "n" value for the main channel
7	V__GW_REVAP.gw	-0.81	0.42	0.075	Groundwater "revap" coefficient
8	V__PCPD(..).wgn	0.65	0.52	7.245	Average number of days of precipitation in month (day)
9	V__SMFMX.bsn	-0.59	0.55	2.654	Maximum melt rate for snow during year (occurs on summer solstice) (mm H_2O/°C.day)
10	V__SURLAG.bsn	0.59	0.56	8.202	Surface runoff lag coefficient
11	V__REVAPMN.gw	0.56	0.57	3.044	Threshold depth of water in the shallow aquifer for "revap" to occur (mm)
12	V__RCHRG_DP.gw	0.55	0.58	0.898	Deep aquifer percolation fraction
13	V__ESCO.hru	0.39	0.70	0.506	Soil evaporation compensation factor
14	V__SMFMN.bsn	-0.38	0.70	2.874	Minimum melt rate for snow during the year (occurs on winter solstice) (mm H_2O/°C.day)
15	V__EPCO.hru	-0.37	0.71	0.569	Plant uptake compensation factor
16	R__SOL_BD(..).sol	0.35	0.73	0.038	Soil moist bulk density (g/cm^3)
17	R__SLSUBBSN.hru	0.27	0.79	0.439	Average slope length (m)
18	R__OV_N.hru	-0.26	0.79	0.301	Manning's "n" value for overland flow
19	R__SOL_K(..).sol	0.26	0.80	-0.093	Saturated hydraulic conductivity (mm/hr)
20	V__GW_DELAY.gw	0.23	0.82	169.92	Groundwater delay (days)
21	R__PCPMM(..).wgn	0.23	0.82	-0.051	Average amount of precipitation falling in month [mm/dd]
22	V__SMTMP.bsn	0.20	0.84	-2.062	Snow melt base temperature (°C)
23	V__GWQMN.gw	-0.08	0.94	80.661	Threshold depth of water in the shallow aquifer required for return flow to occur (mm).

Notes: *i*. V_ means the current parameter value is to be replaced by a given value, and R_ means existing current parameter value is multiplied by (1+ a given value). *ii*. (..) means for different soil layers or months.

Table 4: SWAT model simulation of water balance ratios

Ratio details	Ratio Value
Stream flow / Precipitation	0.423
Base flow / Total flow	0.113
Surface runoff / Total flow	0.887
Percolation / Precipitation	0.089
ET / Precipitation	0.572

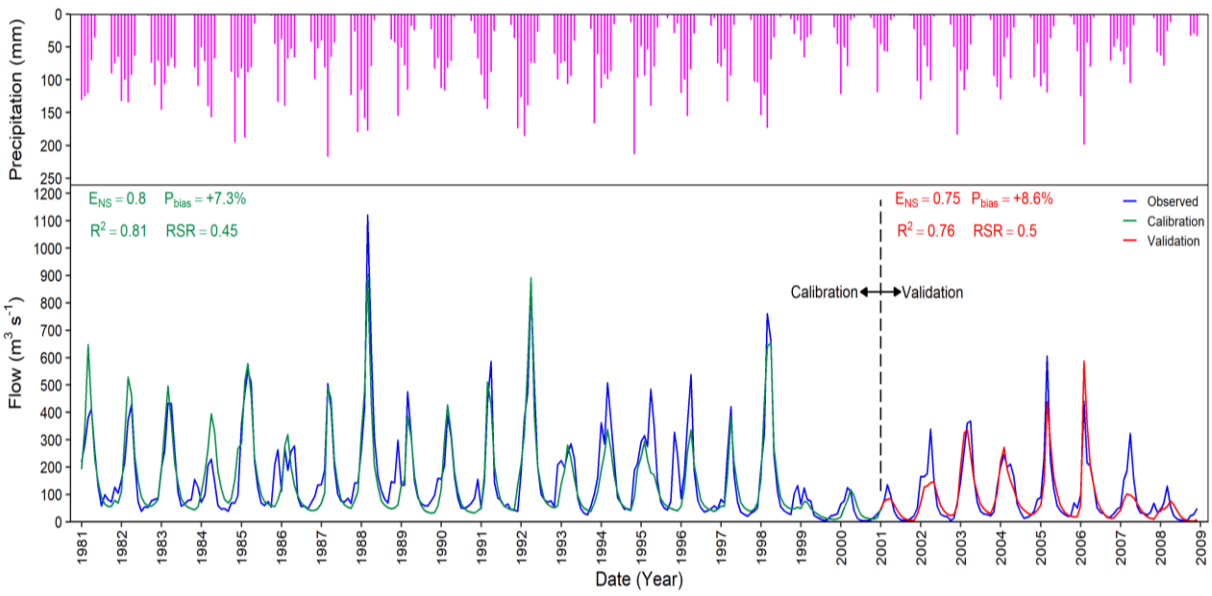

Figure 6: Monthly observed and simulated runoff at the Derbendi-Khan dam reservoir from 1981 to 2008

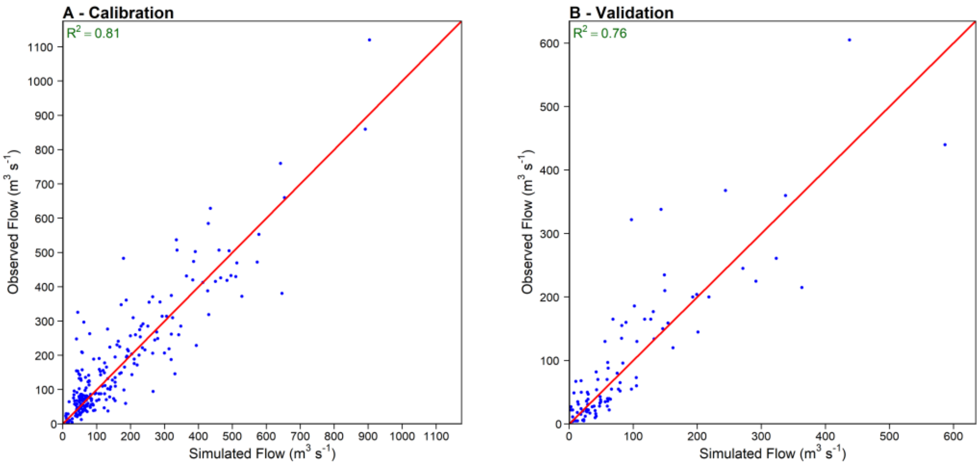

Figure 7: Correlation between monthly observed and simulated stream flow during calibration and validation periods

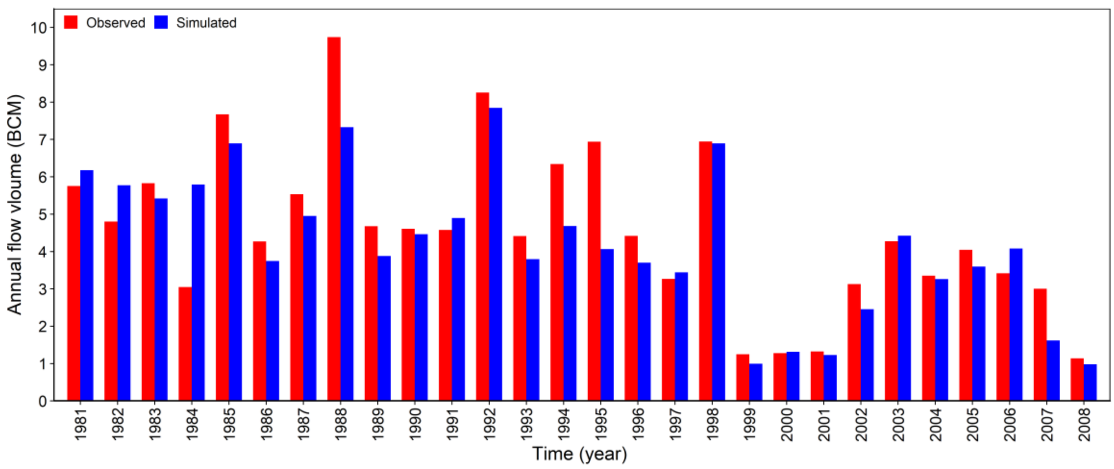

Figure 8: Annual runoff volume delivered to the Derbendi-Khan dam reservoir for the period 1981–2008

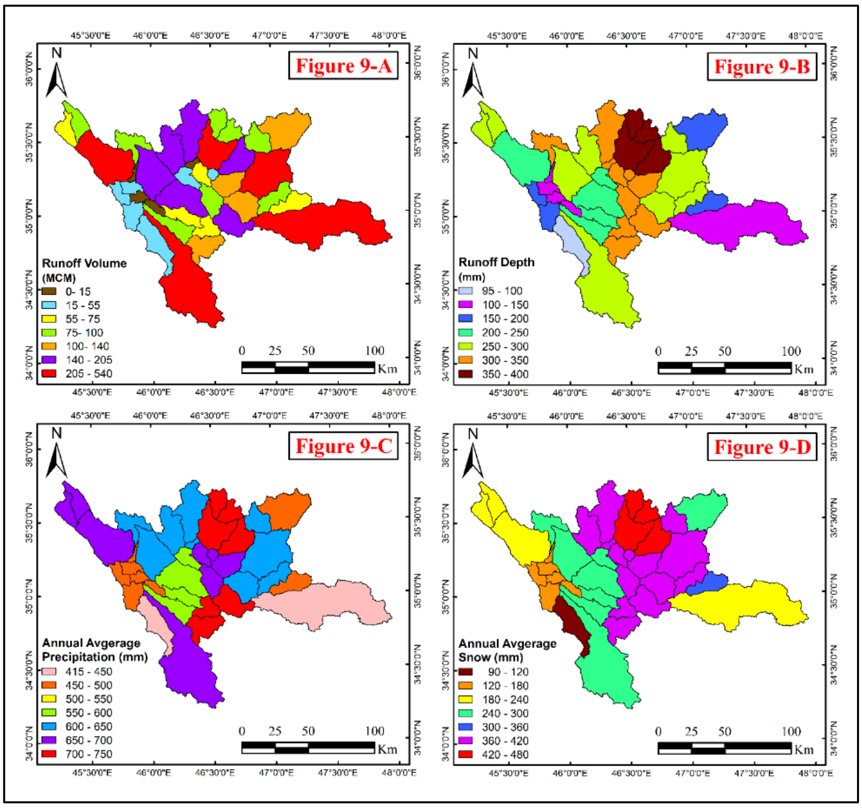

Figure 9: Average spatially distribution from 1981 to 2008: A- Annual runoff volume, B- Annual runoff depth, C- Precipitation, and D- Snow

In this study, results shown that the evapotranspiration (ET) has a 57.2 percent of precipitation to be removed from the studied watershed, this value is less than the ET value of the middle watershed which its ET value reached to 84 percent [20]. Moreover, the ratio of streamflow (runoff) to precipitation is 42.3 percent and less than the ET value which is higher than of middle part watershed because of the variation in the precipitation depths and temperature between these watersheds, this result in agreement with the conclusion given by Dingman "Evapotranspiration exceeds runoff in most river basins and on all continents except Antarctica" [24]. The base flow in the upper River Diyala watershed has a low active (11.3%) contribution in total runoff value in comparison with the direct surface runoff that contributes 88.7% of the total runoff.

5. Summary and Conclusions

In this study, SWAT 2012, a physical-based semi-distributed hydrological model having an interface with ArcGIS software was applied to Derbendi-Khan dam watershed at the upper part of Diyala River. The model simulated runoff that inputs to the dam reservoir by determining the optimal values of the hydrological model parameters based on the observed monthly stream flow data at the Derbendi-Khan dam reservoir site. The model was built with a threshold value 10,000 hectares. Then the thirty-nine sub-basins were produced included 1699 HRUs which were distributed in these sub basins, depending on the spatial data (LU and LC map, Soil type, and Slope map). The CFSR weather data sets on a daily basis at twenty different stations were used as input data to run the model, Where the statistical assessment between monthly observed precipitation data at Sulaymaniyah station and the CFSR demonstrated an acceptable statistical result and same probability distribution. The SWAT model simulated runoff was compared with the observed discharge data at the Derbendi-Khan dam site. For this study, the model was calibrated and validated for monthly streamflow using the observed data for a thirty-year between 1979 and 2008 of datasets. Out of this period, the model setup has been arranged the first two years were taken as a warm-up period for model initialization (1979-1980), and twenty-year (1981–2000) were used for calibration and rest of the years (2001–2008) for model validation respectively. The streamflow parameters by using SWAT-CUP software were calibrated, and based on the global sensitivity analysis, the variation between the parameter ranges indicated and then identified the most sensitive parameters for the studied watershed area. Six most sensitive parameters were found for the intermodal part of the Derbendi-Khan dam watershed (CH_K2, CN2, ALPHA_BF, SFTMP, SOL_AWC, and CH_N2 CH_N2). For monthly time step simulation, the values of statistical evaluation parameters E_{NS}, RSR, P_{bias}, and R^2 were 0.80, 0.45, +7.3%, and 0.81, respectively, for the time of calibration. While, for the time of validation values were 0.75, 0.50, +8.6%, and 0.76 respectively. These statistical values signify a good indicator of the high reliability of model performance. The study guides to the following conclusions:

1- Modeling with SWAT for the upper part of Diyala River achieved acceptable simulation for a runoff on the monthly time scale.

2- The CFSR weather data give useful alternative input data for the SWAT model when there is a scarcity problem in measured weather data spatially.

3- The spatial distribution of average runoff depth from sub basins indicated that the intermediate sub basins are the highest in contributing to the watershed runoff.

4- Snowmelt is a more productive part of precipitation, which leads to peak runoff during March and April. It was found that the average annual areal snowmelt ratio to the average annual areal precipitation during the simulation period is approximately 24%.

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