Estimation of Annual Runoff of Galal Badra Transboundary Watershed Using Arc Swat Model, Wasit, Eastern of Iraq

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Abstract

Optimal investment of natural water resources in an area is an effective way to provide significant amounts of water that can contribute to reduce the negative impacts of climate extremism. Proper assessment of the components of any hydrological system is a priority in watersheds studying. SWAT (Soil and Water Assessment Tool) model was used within ArcGIS, to assess the hydrological situation in general, and surface runoff in particular for Galal Badra Watershed GBW (Wasit Governorate, eastern Iraq). GBW has an area of 2,655 square kilometers (89% of which is in Iran and the rest 11% within Iraq). The data set for SWAT model running were digital elevation model, slope map, soil map, LULC map, and climatic data (precipitation, relative humidity, wind speed, solar radiation, minimum/maximum air temperature). SWAT simulation concluded that the annual average surface runoff in GBW was 244x106 cubic meters (with an average discharge of 7.8 M3 / s), which accounts for about 25.7% of the total precipitation. This ratio can be used in preliminary forecasting of surface runoff resulting from different amounts of precipitation. The model was not calibrated due to insufficient data available to complete the calibration process. However, the results provided by the SWAT model regarding the water balance elements in the watershed, make the SWAT model an effective tool for hydrological assessments, especially in cases where the necessary data are scarce for various reasons. Also, SWAT results can be considered as a preliminary assessment, which gives an overview of the hydrological situation of the area, contributes to building an initial perception of the water system, determining the most important elements in it, and anticipating the factors most influencing it. This enables policymakers, decision-makers, and stakeholders to adopt future plans at the level of research and implementation that will develop the reality of water investment in the region under conditions of climate extremism.

Keywords: Galal Badra; SWAT; Runoff; Wasit

1. Introduction

Among the many watershed simulations and assessment models, the SWAT (Soil and Water Assessment Tool) is one of the important and effective tools in this field. Several researchers have evaluated SWAT model under different conditions around the world and at different watershed scales.

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Thus, SWAT model has emerged as one of the most popular models for basin studies and has been widely used in dealing with many hydrological and/or environmental problems (Gassman, et al. 2014). The SWAT model is a basin-scale, continuous-time model that works on a daily time step and estimates the effect of management acts on water, sediment, and agricultural chemical yields in ungauged basins (Arnold et al. 1998). The major components of SWAT model are hydrology, weather, erosion, land management, soil temperature, pesticides, nutrients, plant growth, channel, and reservoir routing. Only a few studies examined the hydrological status of the target area using the SWAT model.

Surface runoff is one of the most important components of the hydrological cycle, which, like other elements of the cycle, receives great attention in terms of quantitative and qualitative assessment and frequency, and perhaps this comes from being the clearest and largest influence on its environment. Some other researchers used other models and methods to calculate surface runoff, for example, Aziz, et al. (2020), used different methods to estimate runoff in Nazanin catchments such as SCS, HEC-HMS, and HEC-1. Also, Heedan, et al. (2017) used GIS and NRCS to estimate the volume of runoff in the Koya Basin. Concerning the area in question, the Galal Badra watershed (GBW) is transboundary, extending into both Iran and Iraq. The areas through which the Galal Badra River passes inside Iraq and the adjacent areas witness from time to time extreme conditions represented in periods of scarcity of water resources, followed by periods of high rainfall, as some neighboring areas are exposed to high surface runoff rates that cause material and human damage.

According to unpublished official data for the period 1989-2006, the average annual discharge of Galal Badra was 10.3 m³/sec (Al Rekabi and Kadum, 2016). Also, Hilo and Saeed (2019) used SWAT model to predict the average income of surface runoff entered to Ash Shuwaicha Wetland (last destination of Galal Badra) which was about 5.5 m³/sec with a maximum peak of 5510 m³/sec. In some events, the discharge rate reaches to 1500 m³/sec or even 2000 m³/sec (WRDW, 2019). In the past few years, it has been observed that such events recur during successive years, accompanied by a great weakness in the preparation or handling procedures, which calls for reconsidering the evaluation of such situations and trying to deal with them in a way that achieves their benefit instead of remaining as a potential threat that emerges from time to time.

The main objective of the study is to estimate the amount of surface runoff in particular, and to assess the hydrological condition of the Galal Badra watershed in general, by using the SWAT model and with the available digital data related to the model's operating requirements, where the SWAT model has never been used in studying the hydrological condition of the Galal Badra watershed, except for one research paper, of which Galal Badra was a part. Additionally, the outputs of SWAT model, contribute to clarifying the vision for decision-makers or beneficiaries in a simplified and concise manner by the language of numbers aiding to take appropriate measures to deal with these outputs which may make a tangible change in the conditions of the region if it is correctly directed.

2. Study Area

Badra district is located in Wasit, east of central Iraq, 180 km south of Baghdad, bordered on the north by Mandali district (Diyala), on the south by Kut district, and from the west by Dubouni district. From the east, the district represents the international eastern border of Wasit governorate with I. R. Iran. The city of Badra is the center of the district, and it is located about 70 km northeast of Al-Kut, the governorate's center. The district includes other important cities such as Jassan and Zurbatiah, which contain one of the important border crossings with Iran (Fig. 1). Agriculture and animal husbandry represent the predominant activity in the region, where the number of practicing this profession reaches approximately 50% of the total population of the district (Al Rekabi and Kadum, 2016). Galal Badra river is, almost, the only source of surface water in the Badra area, and this is what has made it so important. The headwaters of the river are located in Iran within the Poshtkuh Mountain Range. The
The river is formed at the confluence of its two main streams, Kanjan Chim and Kafi Rod near the Iraqi-Iranian border at the Ta’an border post. The river enters Iraqi territory in Sadr Arafat area (4 km south of Zurbatia). It runs west for about 10 km, then towards the south and southwest, passing through the city of Badra and then Jassan until it ends at Hor Ash Shuwaicha (Ash Shuwaicha marsh). From both sides of Galal Badra, about 18 irrigation channels distribute their water to the areas of Zurbatia, Badra, and Jassan and flow to the southwest. As usual, natural conditions and levels of water consumption affect the availability of water in the river channels, sometimes reaching the level of flooding, and in times of scarcity, they may dry up completely like a natural response to the amounts of rain falling over the whole watershed. These channels disappear due to the lack of water discharged into them due to the high values of evaporation and penetration (Hassan et al. 1977). There is a recharge-discharge relationship between the groundwater and Galal Badra along the river channel, where the groundwater discharges its water to the river near the Iraqi-Iranian border, after that and at the city of Badra, the river recharges the groundwater, then south of Badra city, the groundwater returns recharging the river. (Al-Shamaa and Al-Azzawi, 2012).

![Fig. 1. SRTM DEM 30 m superimposed on a hill shaded shows the location of the study area](image)

2. Materials and Methods

2.1. Data Set

The study area has special conditions, as a large important part of it is located outside Iraq, and it is not logical to adopt more than one data source to reach acceptable results due to the difference and multiplicity of methods of measurement and data analysis, so it was imperative to use unified source data covering the whole region and working according to the same standards and methods of analysis. The digital data provided by accredited scientific sites is one of the most useful means in completing the requirements of some scientific research whose spatial conditions require the use of this data exclusively. In the first basic step, the model begins by creating a work project, and then starting with a series of subsequent steps in which the following data will be used:

- Digital Elevation Model (DEM): the STMR (Shuttle Radar Topography Mission) digital elevation model with a 30-meter resolution was used.
- Land Use Land Cover map (LULC): Landsat 8 satellite images with a spatial resolution of 30 meters which was processed within the ERDAS software was used. For creating LULC map, the unsupervised classification was applied.
- Soil map: extracted from Digital Soil Map of the World (DSMW) version 3.6 that provided by Food and Agriculture Organization (FAO) (FAO, 2007).
- Climate data: The National Centers for Environmental Prediction (NCEP) produced the Climate Prediction System Reanalysis (CFSR). SWAT requires precipitation, relative humidity, wind speed, solar radiation, and min/max air temperature. SWAT allows the user to select some options regarding the methods of calculation and analysis, which the model uses in processing, in proportion to the case study to obtain the required results. These options will be addressed later.

### 2.2. Methodology

After preparing the required data in the appropriate manner for the model work, in terms of its extensions and geographical projections (here UTM was chosen), work begins with the establishment of a special project that will contain all the inputs, outputs, methods of measurement and analysis, and its detailed reports. The SWAT sequence of operations is shown in Fig. 2. Watershed delineation is the next step in the sequence of work steps. SWAT uses DEM (Fig. 3a) in this step. According to Winchell et al. (2010), SWAT allows users to define a sub-watershed threshold (the minimum area to construct the tributary network). Therefore, 200 ha (2 km²) has been defined as the threshold. Three outlets were manually sited on the main tributaries with the highest stream order, based on which, the model delineated the watershed and divided it into three sub-basins. Each sub-basin then was subdivided into smaller units called hydrological response units HRU.

HRUs are physically homogeneous non-contiguous areas assumed to respond similarly to inputs (Li et al. 1977). In SWAT model, HRUs are created by merging three layers, LULC map that contains 5 classes, the soil map with seven types of soils, and the third is the slope map resulting from DEM. To facilitate computational efficiency and enhance simulation operability of SWAT model, thresholds must be set when creation HRUs (Srinivasan, et al. 2010). The value of 0 was chosen as a threshold for all three layers to ensure that all parts, no matter how small, were represented. Note, that threshold values of 5,8,12 and 20,20,20 for each of the LULC, soil, and slope respectively were selected and applied, which resulted in some small parts not being represented in the watershed, so they were dispensed with a threshold value of 0. After the HRUs are defined, the weather data that are supposed to be previously entered into the model’s database are read. The Climate Prediction System Reanalysis (CFSR) was used. With the ending of this step, SWAT has completed reading all data needed to be run, and storing it in the database. Thirty-five years are determined as a simulation period from 1979-2013. Two years have been set as warming up years, so the model skips it with no results. It is worth noting the selected methods within the model that are included in the SWAT model. SCS curve number method is selected for estimating surface runoff. The amount of runoff and the peak runoff rates for each HRU (Hydrologic Response Unit) are predicted by SWAT model using SCS-CN equation:

\[
Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)}, \quad R_{day} > Ia \quad (1)
\]

Where \(Q_{surf}\) is the daily runoff or rainfall excess in mm, \(R_{day}\) is the depth of daily rainfall in mm, \(S\) is the retention parameter (mm). \(I_a\) is the initial abstractions which are usually approximated as \((0.2 S)\) Usually, so the equation 1 becomes:

\[
Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} - 0.8S)} \quad (2)
\]

The retention parameter \(S\) equation is:

\[
S = 25.4 \cdot \frac{1000}{CN} - 10 \quad (3)
\]

Where \(CN\) is the curve number.
Also, SWAT depends on the water balance equation when simulating (Neitsch, et al., 2005):

\[ SW_t = SW_0 + \sum_{i=1}^{t} (R_{\text{day}} - Q_{\text{surf}} - E_T - W_{\text{seep}} - Q_{\text{gw}}) \tag{4} \]

Where: \( SW_t \) is the final content of soil water content (mm); \( SW_0 \) is the initial soil moisture content on a day \( i \) (mm); \( t \) is the time (days); \( R_i \) is the rainfall amount on a day \( i \) (mm); \( Q_i \) is the surface runoff on a day \( i \) (mm); \( E_T \) is the Evapotranspiration on a day \( i \) (mm); \( P_i \) is the percolation on a day \( i \) (mm); \( Q_R \) is the volume of return flow on a day \( i \) (mm). Regarding estimating potential evapotranspiration, SWAT using Penman-Monteith method (Neitsch, et al. 2005), which requires solar radiation, air temperature, relative humidity, and wind speed. The general equation is:

\[ \lambda E = \frac{\Delta (H_{\text{net}} - G) + \rho_{\text{air}} \cdot c_p \cdot (e_z - e_o) / r_a}{\Delta + \gamma \cdot (1 + \frac{r_c}{r_a})} \tag{5} \]

where \( \lambda E \) is the latent heat flux density (MJ m\(^{-2}\) d\(^{-1}\)), \( E \) is the depth rate evaporation (mm d\(^{-1}\)), \( \Delta \) is the slope of the saturation vapor pressure-temperature curve, \( de/dT \) (kPa °C\(^{-1}\)), \( H_{\text{net}} \) is the net radiation (MJ m\(^{-2}\) d\(^{-1}\)), \( G \) is the heat flux density to the ground (MJ m\(^{-2}\) d\(^{-1}\)), \( \rho_{\text{air}} \) is the air density (kg m\(^{-3}\)), \( c_p \) is the specific heat at constant pressure (MJ kg\(^{-1}\) °C\(^{-1}\)), \( e_o \) is the saturation vapor pressure of air at height \( z \) (kPa), \( e_z \) is the water vapor pressure of air at height \( z \) (kPa), \( \gamma \) is the psychometric constant (kPa °C\(^{-1}\)), \( r_c \) is the plant canopy resistance (s m\(^{-1}\)), and \( r_a \) is the diffusion resistance of the air layer (aerodynamic resistance) (s m\(^{-1}\)). Due to the fact that the data used in this research are calculated and estimated, an error is to be expected. SWAT model calibration requires the availability of measured data (streamflow data) to be used in the calibration. In fact, Galal Badra River is devoid of any type of streamflow measuring equipment along its section within the region, which means that there is no continuous measured data for its discharge that can be used in hydrological studies and specialized hydrological models as well as calibration for SWAT models. All discharge data regarding Galal Badra issued by the official authorities are “estimated” as that depends mainly on the guesswork of the observer.
3. Results and Discussion

3.1. Watershed Delineation

The raw data processing, analysis, and classification produced the maps shown in Fig. 3 and Fig. 4. SWAT uses DEM (Fig. 3a) in this step. The results showed that the total area of GBW is 2,655 km$^2$. Its major part is located in Iran (about 2355 km$^2$). As three outlets were manually identified, GBW included three sub-basins represented by, Kanjan Chim (sub-basin 1), Kafi Rod (sub-basin 2) (both located in Iran), which together form Galal Badra River (sub-basin 3), (Fig. 3b). The area of the Kanjan Chim and Kafi Rod sub-basins are 1300 Km$^2$ and 993 Km$^2$ respectively. The rest (362 Km$^2$) represents Galal Badra sub-basin, about only 300 km$^2$ of which is located inside Iraq.

![Fig. 3. (a) DEM of GBW (elevation in meter); (b) Sub-basins of GBW](image)

3.2. HRUs

The number of defined resulting HRUs were 202 units, distributed over the three sub-basins as, 92 HRUs in sub-basin (1), 92 in sub-basin (2), and 18 HRUs in sub-basin (3). The large difference in the distribution of HRU number over sub-basins is attributed to the presence of variation in the LULC classes, slope, and soil types in both 1 and 2 sub-basins, compared to the degree of variation in the sub-basin 3, especially as it contains only one class of slope and a little diversity in the LULC classes, which did not produce many variations in the resulting HRUs, (Fig. 4). The results showed that approximately 55% of the watershed’s area is classified as barren land, and the remainder is distributed between agricultural and grassland lands with few areas of sparsely vegetated, (Fig. 4b, and table 1), all soil classes are of D type, regarding hydrological group, with loam and clay-loam texture, (Fig.4c and table 2). In table 3, the CN values of the sub-basins are clearly high, indicating the potentiality of a high rate of surface runoff. The availability of different conditions in terms of soil type, forms of land use, and slope determine the potentiality surface runoff occurrence. For the fact that all the watershed’s soils are of type D, the majority of the presence of barren lands, lack of vegetation cover, and high slope rates (especially in the two sub-basins 1 and 2), all of this, in turn, would produce high surface runoff values when the simulation was performed within a SWAT model.
Fig. 4. (a) Landsat 8 image (b) LULC classes (c) Soil classes (d) Slope map (slope in degree)

Table 1. Distribution of LULC classes (% of basin’s area)

| Watershed ID | GBW | Kanjan Chim sub-basins | Kafi Rod sub-basins | Galal Badra sub-basin |
|--------------|-----|------------------------|---------------------|----------------------|
| Water        | 0.63| 0.61                   | 0.47                | 1.16                 |
| Agriculture, |     |                        |                     |                      |
| land-row crops | 24.88| 25.54                  | 21.89               | 30.74                |
| Grassland    | 10.97| 14.52                  | 8.09                | 6.11                 |
| Baren or sparsly vegetated | 8.55 | 9.52                   | 8.35                | 5.6                  |
| Barren       | 54.97| 49.81                  | 61.21               | 56.38                |

Table 2. Distribution of soil classes, texture, and hydrological groups (% of the watershed area), contents values after (FAO, 2007)

| SWAT soil class | Texture       | Clay | Silt | Sand | Hydro. group | Coverage area (km²) | (%)  |
|-----------------|---------------|------|------|------|--------------|---------------------|------|
| Rc33-3bc-3254   | Loam          | 27   | 39   | 34   | D            | 862.1               | 32.5 |
| Zo7-2-3a-3634   | Clay-loam     | 33   | 40   | 27   | D            | 781.3               | 29.4 |
| I-Re-Yk-2-3506  | Loam          | 26   | 39   | 35   | D            | 469                 | 17.7 |
| Yk34-b-3602     | Loam          | 26   | 37   | 36   | D            | 297.1               | 11.2 |
| I-Re-Xk-c-3122  | Loam          | 26   | 41   | 33   | D            | 233.3               | 8.8  |
| Zo22-2-3a-3627  | Clay-loam     | 30   | 37   | 33   | D            | 6.4                 | 0.2  |
| Jc40-2-3a-3529  | Loam          | 26   | 41   | 33   | D            | 5.9                 | 0.2  |
Table 3. CN numbers and values of the sub-basins

| Sub-basin                      | No. of HRUs | CN   | CN   | CN   | CN average |
|--------------------------------|-------------|------|------|------|------------|
| Kanjan Chim sub basins (1)     | 92          | 73.3 | 86.7 | 94.6 | 84.9       |
| Kafi Rod sub basins (2)        | 92          | 74.8 | 87.6 | 95   | 85         |
| Galal Badra sub basin (3)      | 18          | 75   | 87.7 | 95.1 | 85.9       |

3.3. Water Balance of GBW

The monthly averages water balance of GBW for the period from 1979-2013 is shown in Fig. 5 and Table (4). The water balance ratios of GBW were: streamflow 25.7% of precipitation, evapotranspiration ET 74% of precipitation, percolation 2% of precipitation, base flow 4% of the total flow, surface runoff 96% of total flow. The results showed that the annual average precipitation was 357.8 mm, 95.66 mm of which represents the water yield of GBW, which accounted for 26.7% of the precipitation. The estimated runoff was 92.6 mm, which corresponds to 25.7% of precipitation. Approximately 74% of rain is lost annually due to evapotranspiration and this indicates the dominance of factors affecting evapotranspiration and their great impact on the water balance of the watershed.

Fig. 5. Water balance elements of the GBW as shown by the hydrological simulation of SWAT model. All units are in mm. CN without units.
### Table 4. Average monthly values of water balance components for GBW resulted from SWAT simulation for the period 1981-2013

| Month | Preci. (mm) | Water yield | Surface Q | PET  | LAT Q | ET  |
|-------|-------------|-------------|-----------|------|-------|-----|
| 1     | 56.62       | 16.41       | 16.05     | 55.25| 0.53  | 25.1|
| 2     | 61.57       | 19.49       | 18.87     | 72.69| 0.55  | 31.84|
| 3     | 64.94       | 22.36       | 21.71     | 138.4| 0.55  | 45.7|
| 4     | 35.31       | 9.11        | 8.45      | 210.78| 0.4  | 41.65|
| 5     | 15.14       | 5.75        | 5.39      | 301.4| 0.25  | 36.7|
| 6     | 0.55        | 0.28        | 0.03      | 385.1| 0.12  | 12.53|
| 7     | 0.01        | 0.1         | 0         | 418.06| 0.06 | 5.32|
| 8     | 0.01        | 0.06        | 0         | 393.32| 0.03 | 3.8 |
| 9     | 0           | 0.04        | 0         | 314.2| 0.02  | 2.74|
| 10    | 15.8        | 0.75        | 0.67      | 207.23| 0.06 | 13.19|
| 11    | 43.96       | 6.5         | 6.42      | 108.97| 0.19 | 20.26|
| 12    | 63.89       | 14.81       | 14.47     | 65.9 | 0.42  | 25.59|
| Sum   | 357.8       | 95.66       | 92.06     | 2671.3| 3.18 | 264.6|

### 3.4. Estimation of Surface Runoff

The average annual estimated surface runoff of GBW is 92.06 mm that represents 25.7% of precipitation (corresponds to about 244.4 million m³/year), with an average annual discharge of 7.8 m³/sec at the Galal Badra outlet, table (5). In light of the results of some studies that dealt with estimating the runoff using the SWAT model and comparing it with what was obtained here, a convergence among these results was found. In (Mohammad et al., 2016), SWAT model was applied to estimating surface runoff in the Dohuk Dam catchment and found that it constitutes up to 20% of the total rainfall. Khayyun et al. (2020), conducted a hydrological model for Derbendi-Khan dam reservoir watershed using SWAT model and found that the average annual areal snowmelt ratio to the average annual areal precipitation during the simulation period was approximately 24%. Also, 17% was the surface runoff percentage of the total rainfall, resulting from applying a calibrated SWAT model simulation in Al-Muhammad valley (Farhan, and Al Thamiry, 2020). The Hydrological simulation of a small ungauged agricultural watershed in Northern India using SWAT model showed that the resulting surface runoff was about 36% of the total rainfall (Mishra et al., 2017). Emam et al. (2017), used SWAT model for hydrological modeling and runoff mitigation in two sites of an ungauged basin in central Vietnam and found that the resulting surface runoff varied from 22.5% - 26% of the total precipitation, and attributed this variation to the difference in slope between the two sites. Based on the foregoing, the ratio of 25.7% represents an acceptable value that falls within the range of values resulting from other studies, and it is useful as a preliminary estimate of the water situation in the area, taking into account that this value is subject to change when the calibration conditions are available for the SWAT model, and then it will be more representative and closer to reality. The annual discharge rates in channels 1, 2, and 3 belonging to sub-basins 1, 2, and 3 respectively. Total discharge of GBW is the volume of water passing at the outlet of channel 3, which represents the discharge of channel 3 itself plus the discharge of channels 1 and 2, which both represent the largest part of the total discharge.
Table 5. Annually average of precipitation, surface runoff (SURQ), and discharge of GBW for the Period 1981-2014

| Year | PREC. (MM) | SURQ (MM) | Water volume (M3 *106) | Discharge m³/sec |
|------|------------|-----------|------------------------|-----------------|
|      |            |           | Subbasin 1             | Subbasin 2      | Subbasin 3      | Total discharge |
| 1981 | 295.6      | 83.1      | 220.5                  | 3.2             | 4.2             | 7.1             | 7.14 |
| 1982 | 243.5      | 41.6      | 110.5                  | 1.8             | 1.9             | 3.5             | 3.53 |
| 1983 | 390.3      | 127.6     | 338.9                  | 5.1             | 5.9             | 10.8            | 10.82 |
| 1984 | 411.4      | 82.2      | 218.3                  | 3.5             | 3.7             | 7.0             | 6.99 |
| 1985 | 340.5      | 103.6     | 275.0                  | 5.7             | 3.4             | 8.8             | 8.84 |
| 1986 | 455.2      | 148.7     | 394.7                  | 6.0             | 6.7             | 12.7            | 12.66 |
| 1987 | 421.6      | 134.9     | 358.2                  | 5.2             | 6.7             | 11.6            | 11.65 |
| 1988 | 373.0      | 87.8      | 233.1                  | 3.6             | 4.2             | 7.5             | 7.48 |
| 1989 | 420.4      | 115.3     | 306.1                  | 4.2             | 6.0             | 10.1            | 10.06 |
| 1990 | 389.3      | 121.1     | 321.6                  | 4.5             | 6.0             | 10.4            | 10.40 |
| 1991 | 302.5      | 57.7      | 153.3                  | 2.7             | 2.0             | 4.9             | 4.89 |
| 1992 | 308.0      | 63.8      | 169.3                  | 3.1             | 2.5             | 5.4             | 5.42 |
| 1993 | 333.8      | 74.8      | 198.6                  | 4.0             | 2.5             | 6.4             | 6.36 |
| 1994 | 359.2      | 104.6     | 277.6                  | 3.9             | 5.2             | 8.9             | 8.88 |
| 1995 | 404.1      | 101.8     | 270.3                  | 5.1             | 3.8             | 8.6             | 8.65 |
| 1996 | 397.7      | 120.9     | 321.1                  | 4.3             | 6.3             | 10.4            | 10.40 |
| 1997 | 299.3      | 61.8      | 164.1                  | 2.5             | 2.9             | 5.2             | 5.23 |
| 1998 | 350.5      | 68.3      | 181.4                  | 2.9             | 3.0             | 5.8             | 5.82 |
| 1999 | 350.6      | 71.4      | 189.6                  | 2.7             | 3.5             | 6.2             | 6.15 |
| 2000 | 313.0      | 56.4      | 149.7                  | 2.2             | 2.8             | 4.8             | 4.78 |
| 2001 | 328.4      | 66.0      | 175.2                  | 3.6             | 2.3             | 5.6             | 5.65 |
| 2002 | 289.2      | 48.5      | 128.7                  | 1.9             | 2.4             | 4.1             | 4.10 |
| 2003 | 368.2      | 100.7     | 267.4                  | 5.8             | 3.0             | 8.6             | 8.57 |
| 2004 | 340.0      | 87.3      | 231.6                  | 2.3             | 5.3             | 7.4             | 7.39 |
| 2005 | 413.8      | 132.8     | 352.6                  | 4.7             | 7.0             | 11.5            | 11.48 |
| 2006 | 389.6      | 106.1     | 281.6                  | 5.0             | 4.3             | 9.1             | 9.13 |
| 2007 | 386.3      | 104.6     | 277.8                  | 5.0             | 4.1             | 8.9             | 8.95 |
| 2008 | 396.0      | 138.8     | 368.4                  | 6.5             | 5.6             | 11.8            | 11.83 |
| 2009 | 395.3      | 101.7     | 270.0                  | 3.2             | 5.5             | 8.6             | 8.64 |
| 2010 | 272.3      | 69.5      | 184.4                  | 2.6             | 3.7             | 6.0             | 6.05 |
| 2011 | 365.4      | 79.9      | 212.1                  | 4.2             | 2.8             | 6.8             | 6.75 |
| 2012 | 426.6      | 107.7     | 286.0                  | 4.7             | 4.8             | 9.2             | 9.21 |
| 2013 | 276.4      | 67.0      | 177.9                  | 2.5             | 3.4             | 5.7             | 5.68 |
| Aver.| 357.8      | 92.1      | 244.4                  | 3.9             | 4.2             | 7.9             | 7.86 |

Galal Badra sub-basin, (speaking of it as an independent sub-basin), provides only about 7.7. mm as a surface runoff (1.3% of GBW total surface runoff) that corresponding 2.7 million m3 of water annually, and that due to the natural conditions of its existence in terms of the characteristics of its sub-basin and the amount of rain falling within its borders comparing with the other two mountainous sub basins 1, and 2, where the size of their participation reaches more than 98% of the total surface runoff. Despite its small contribution to the GBW total discharge, Galal Badra stills an important water resource. This importance comes from being the final stream that contains all the water coming from the far sides of
the watershed, which supplies the network of streams branching from it, which represents the only source of surface water in the surrounding villages. Considering the high variation in surface runoff amounts among the three sub-basins, many factors could lead to this variation. The amount of precipitation represents the most effective factor in this disparity, as the two upper sub-basins receive much more rain than that fall on sub-basin 3, (Fig. 6).

![Fig. 6. Annual precipitation of the three main sub-basins in GBW](image)

The surface runoff is also affected by temperature, humidity, and winds, for high temperatures and low humidity strong winds result in more water losses (evapotranspiration in particular), and thus less surface runoff. These conditions are more consistent with sub-basin 3 than in sub-basins 1 and 2, where these factors are less, due to the mountainous nature and geographic location of their basins. Regarding the shape and dimensions of the basin, both sub-basins (1 and 2) are wider, so the probability of being covered by rainstorms is higher compared to basin 3 of a narrow shape. Topographically, raised basins (such as sub-basins 1 and 2) are usually steeper and less permeable, so the resulting quantitative runoff is greater, (sub basin1 has elevations from 2700m–128m), (sub-basin 2 has elevations from 2580m – 130m). In Fig. 7, the annual precipitation values were plotted against annual discharge values. It is noticed that the discharge values rise or fall sometimes in response to the rise or fall of precipitation values, and at other times this response is not observed, but rather a reverse case occurs where the discharge values rise despite the low precipitation values, or they decrease with the presence of high precipitation values. This case is clear in the years 1984, 1990, 1995,1996, and 2009. In nature, this variation represents a normal situation due to the annual variation in the factors affecting the amount of

![Fig. 7. Annual average precipitation and discharge of GBW for 33 years of SWAT hydrologic simulation](image)
surface runoff and the possibility of another water source having a hydraulic connection with the channel affects the discharge volume. One of the most possible sources is the existence of reciprocal recharge-discharge between the stream channel and groundwater, which consequently leads to either increase or decrease in the flow rates within the river channel. Additionally, parts of the surface runoff may not reach the main channel and lag behind barriers or are trapped in ponds. This water either evaporates or infiltrates into the soil and then becomes part of the lateral flow that returns to the channel, or it percolates deeper to recharge the groundwater. In simulation models, including SWAT, some data represent a constant state along the years of the simulations, (which are LULC, slope, DEM, and soil type), and the only variable is the climatic factors (precipitation, temperature, humidity, wind, and solar radiation) Therefore, the above changes are logically in response to the changes occurring in the aforementioned climatic factors. Therefore, the need for field-measured data becomes necessary to calibrate the model and simulate the real conditions of the region, to reach more accurate results.

4. Conclusions

SWAT provided an effective work platform in clarifying the elements of the hydrologic cycle, and factors that affect the hydrological situation in any area and the study area in particular. The quantities of water produced by the simulation can be considered preliminary results and use to develop plans that invest these quantities of water in effective ways, which, if implemented, will achieve a relatively stable water supply for the area and positively affect the residents and the environment. The obtained results do not represent a fixed value, due to the occurrence of extremes (increases or decreases) in the water supply for the entire basin that occur from time to time. For example, a rainstorm that lasts for one or several days may provide a discharge of up to 1,500 m³/sec in the river section, that is, nearly two million cubic meters of water in just 24 hours. In other cases, in many seasons, the river channel, and also Hor Ash Shuwaicha become completely dry. In both cases (both ends of climate extremism), proper management will provide practical ways to store as much as possible of water in times of plenty for later use in times of scarcity and to shift from considering these quantities of water a threat that causes great damage to transform it into important reserves that can be used in the future. It is worth noting that the model was not calibrated due to the lack of streamflow data of Galal Badra. Nevertheless, these preliminary results can be used effectively in describing the water reality of the area and giving an initial view of its hydrological situation. Subsequently, these results can be subject to the necessary modification as soon as the necessary data for the calibration process becomes available. Installation of a streamflow measuring station on the river section is a top priority, to establish a realistic database that enables relevant authorities and researchers to make more accurate assessments and give more acceptable expectations to be included in any future water projects within the region.

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