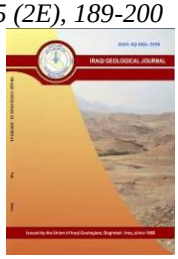
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Applying SWAT Model to Estimate the Annual Runoff of Wadi Al-Mohammadi Basin, Western Iraq

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Abstract

In arid and semi-arid regions, with unexpected periods of floods or droughts as a result of extreme variability in rainfall rates, runoff occurs in separate periods after clear occasional rainstorms. People living in these areas are greatly affected by water shortages during droughts and often have unsafe livelihoods. Wadi Al-Mohammadi is one of the main valleys in the Western Desert flows into the Euphrates River. It is considered an important area, due to many characteristics, including its relatively large area, the amount of water drained through, and has significant storage of groundwater, which is used mainly in agriculture and watering livestock, in addition to industrial purposes such as the production of washed sand, gravel that scattered on both sides of the valley. The Soil and Water Assessment Tool (SWAT) model is proven to be effective as a working platform in the hydrological cycle and to clarify its components and factors affecting the hydrological situation in a region. By applying the SWAT model using the required data set (LULC, slope, and soil types), Wadi Al-Mohammadi is subdivided into 199 HRU (hydrologic response units). The annual average flow discharge was 0.138 m3/s with an average annual water volume about 4.366 Mm^3, while the average annual water volume is calculated from runoff which was of about 4.651 Mm^3. There is a difference in the average annual volume of water calculated from surface runoff and discharge, due to a little slope, and not all the surface runoff water reaches the mainstream, or it ends in secondary valleys or collecting in pits, and there for the discharge is less than the surface runoff. Peak runoff is observed in Wadi Al-Mohammadi basin mostly during the winter season, from November to March.

Keywords: SWAT; Runoff; Wadi Al-Mohammadi; Semi-arid regions; Western Iraq

1. Introduction

The Soil and Water Assessment Tool (SWAT) model is one of the most effective and important tools in watershed assessment and simulation (Sahar et al., 2021). At different scales of watersheds around the world and under different conditions, SWAT model has been evaluated by many researchers. Thus, to study basins and deal with environmental and/or hydrological problems, this model is used, which is the most common and has appeared on a large scale (Gassman et al., 2014). SWAT model consists of major components such as weather, hydrology, land management, pesticides, erosion, soil temperature, plant growth, nutrients, reservoir routing, and channel (Manhi and Al-Kubaisi, 2021). In

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the study area, there are no studies concerned with the hydrological situation, especially the use of the SWAT model. Although it is rich in studies that have examined it, such as study that was presented by Awadh, (2018) studied the suitability of groundwater and surface water resources in the Western Desert. Determining the hydrogeological conditions and characteristics of Mulussa aquifer in the Western Iraq were studied by (Al-Kubaisi and Al-Kubaisi, 2018a). (Al-Kubaisi and Al-Kubaisi, 2023b; Al-Kubaisi and Al-Kubaisi, 2023a) focus on the water balance and hydro-morphometric characteristics of Wadi Al-Mohammadi basin. (Awadh et al., 2021) focuses on the nature of the aquifers and characteristics of groundwater in the Iraq and Arabian Gulf countries.

The hydrological cycle consists of many main components, the most important of which is surface runoff. In terms of qualitative and quantitative assessment and frequency, it is receiving wide and great attention because of its great impact on its environment. Runoff was also calculated by other methods and models, e.g., Aziz et al. (2020) use HEC-HMS, SCS, and HEC-1 as runoff calculation methods in Nazanin basin. Also, the NRCS and GIS methods were used by (Heedan et al., 2017) to calculate its volume in the Koya catchments. The climate has considered an important factor affecting the amount of runoff and its difference from one season or year to another, and from place to place, depending on latitude, distance to the sea, vegetation, presence or absence of mountains, or other geographical factors, where rainfall and evaporation are the basic factors in the hydrological cycle. It is directly affects the abundance of water as a natural resource in rural and urban environments (Al-Kubaisi, 2020). It is important to study climate change in a region because it is closely related to quantities and water quality (Al-Kubaisi and Al-Kubaisi, 2018b). The study area is undergoing the influences of the dry desert climate and to a lesser degree the influences of the climate of the Mediterranean and the Arabian Gulf (Alalwany et al., 2018).

Regarding the study area, it experiences severe conditions from time to time, represented in periods of water scarcity followed by periods of heavy rain, and therefore the neighboring areas are exposed to high runoff causing damage to agricultural and residential areas. The assessment of runoff intensity and magnitude is a key step in flood management planning since it allows for the development of appropriate flood-prevention measures. When runoff occurs when rainfall on the Earth's surface exceeds its rate of infiltration. The dry soil has a high infiltration rate at the start of the rainfall, but as the rainfall continues, the infiltration rate decreases until the soil is entirely saturated. Then the surface ground depressions begin to fill, and surface runoff occurs as soon as they are full (Jasim, 2021).

The main goal of this study is to estimate the amount of the runoff, as well as the assessment of the hydrological conditions in general for the watersheds in Wadi Al-Mohammadi basin. This is done through the digital data necessary to run the SWAT model. This objective was important because the study area had no previous studies that used the SWAT model to know the hydrological status of the watersheds in the Wadi Al-Mohammadi basin.

2. Study Area

The Wadi Al-Mohammadi is an ephemeral valley. It is located in Al-Anbar, within the eastern part of the Iraqi Western Desert. The valley flows from southwest toward northeast and drains its waters in the Euphrates River, 15 km south of the city of Heet. Wadi Al -Mohammadi watershed is bordered on the east by the Euphrates River and the south by the Abu-Jir depression, while from the north, the topographic boundary of the Wadi Al-Mohammadi basin is represented by Wadi Al-Hajiya of the Kubaisa basin, and the Kilo-160 area represents the western borders of the basin.

The expressway 1 (Baghdad - Jordan, and Syria) passes through the basin. The basin is bounded by the following coordinates: Latitudes 33˚ 34′ 18.1″–33˚ 4′ 44.4″ and longitudes 41˚ 55′ 3.8″ – 42˚ 56′ 31.6″ (Fig. 1). The total area of the basin is 2286.8 km^2, while the basin's perimeter was estimated at 487 km. Its elevation ranges from 52 to 367 m above sea level. Wadi Al-Mohammadi basin is

characterized by an uncomplicated topography of varying elevations and descends towards the Euphrates River, with an average slope of 0.006.

Geologically, the study area was characterized by the presence of several outcrop formations. They are (from the oldest to the youngest) as the Ms`ad Formation (Late Cretaceous, Cenomanian – Turonian) with an area of about 96 km$^2$, the Euphrates Formation (Early Miocene) with an area of about 591 km$^2$, the Fat`ha Formation (Middle Miocene) with an area of about 56 km^2, the Nfayil Formation (Middle Miocene) with an area of about 939 km^2, the Zahra Formation (Pliocene – Pleistocene?) with an area of about 594.8 km^2 and in addition to Quaternary Deposits with an area of about 10 km^2 (Sissakian, 2000).

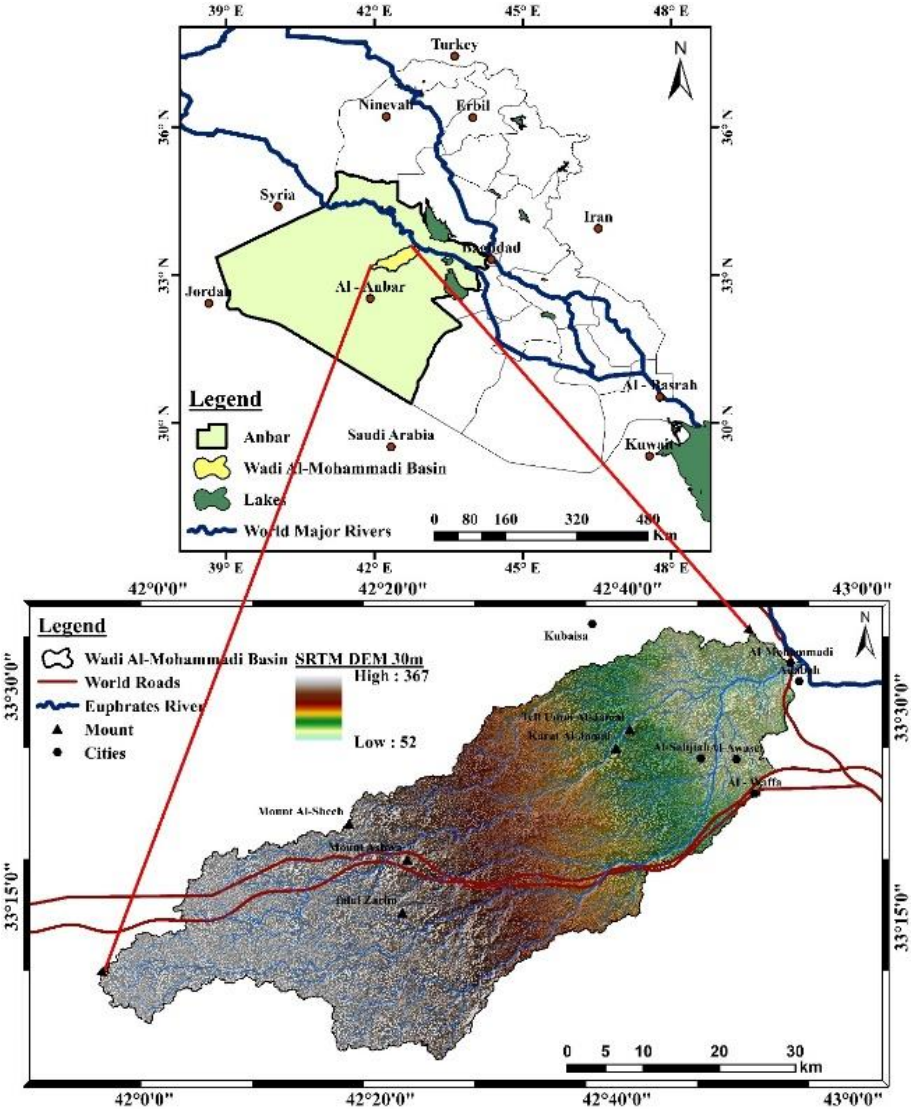


Fig. 1. Location map of the study area

3. Materials and Methods

3.1. Data Set

Accredited scientific websites provide the necessary digital data, which is one of the means used to obtain the requirements of some scientific research, especially in places whose conditions require the use of this data only (for example, the lack of climatic stations on the site, there are no studies on soil type, and the lack of description of vegetation cover region, etc.). The work project is created by the

model, which is considered the first basic step, after which it begins to complete a series of subsequent steps that need the following digital data:

- DEM (Digital Elevation Model): The Shuttle Radar Topography Mission digital elevation model (SRTM DEM) download from the USGS website with a resolution was 30-meter utilized.
- LULC (Land Use Land Cover): Images from the Landsat 8 satellite were used, which have 30 meters as spatial resolution. In this study, an unsupervised classification method was used to prepare a map of LULC.
- Soil data: The data was obtained from the Food and Agricultural Organization of the United Nations (FAO).
- Weather data: Downloaded from the Prediction of Worldwide Energy Resources (POWER). Daily climate data for the rainfall (mm), relative humidity (%), minimum/maximum air temperature (°C), wind speed (m/s), and solar radiation (MJ/m^2/day) are playing an important role in determining the variables related to the quantity of water that's kept through the water harvesting method. Thus, it is among the essential criteria for the SWAT in terms of climatic data.

3.2. Materials and Methods

Before starting the model, all the data it needs must be prepared in an appropriate manner, for example, its geographical projections, which are UTM, and its extensions also must be prepared appropriately. Establishing a special project at the beginning of the work, which contains all measurement methods and their detailed reports, outputs, inputs, analysis, etc. There are four main steps for the SWAT model setup. These essential steps are depicted in a schematic diagram (Fig. 2). It is vital to note that all data must be in the same projection before doing these stages. The UTM projection is preferred over the geographic projection because it uses metric units and is more precise.

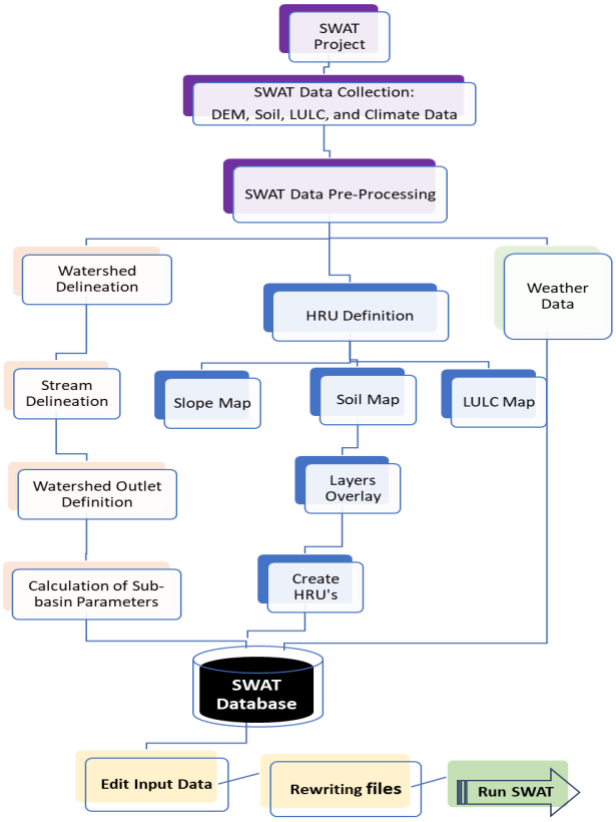


Fig. 2. SWAT model's setup as a schematic diagram

The next step is the delineation of watersheds, which is one of the most important steps in the work and operation of the model. Watershed, catchment, wadi ,or drainage basin are hydrological terminology that describes a key system for managing surface water resources, whereas the aquifer is the most important system for managing groundwater resources (Dixon and Uddameri, 2016). A watershed is a whole area that contributes to the flow or drain of water to a known point called an outlet point or pour point.

The initial stage in preparing the SWAT model is to identify watersheds using a DEM, and then a watershed is divided into sub-basins (Tolosa, 2015). Stream definition, watershed outlet definition, and sub-basin parameter calculation are the three primary steps in the watershed delineation process. The size of the sub-basins can be estimated by manually revising (editing outlet and inlet points manually) (Lewarne, 2009), which should be defined before the delineation process begins. The next stage is to create HRUs after the watershed delineation procedure is done. HRUs are lumped ground areas within a sub-basin (Neitsch et al., 2011) generated by overlaying the LULC layer, soil layer, and slope with various thresholds to recognize unique homogenous individual areas. SWAT model discretizes each sub-basin to the smallest HRU (Neitsch et al., 2005) which is supposed to be a spatially uniform unit in terms of LULC, soil, and slop type.

All basin weather data should be imported into the SWAT after the HRU has been defined. The SWAT-weather generator was used to calculate all the required statistical data from the basin weather stations, in addition to the locations table, air temperature, rainfall, solar radiation, relative humidity, and wind speed were prepared in text format. Then, all are loaded and written into the SWAT model (Bokan, 2015). The database of Arc SWAT will be connected to all layers of data to get all the necessary parameters for assessing the runoff for every HRU (Tolosa, 2015). SWAT model was running on a daily basis after its set up and the overall pre-processing of the inputs required data for it. The simulation was carried out for a period from 1990 to 2020 (31 years). The first two years of them were utilized as a warm-up period and for best simulation rendering (Gilfanova, 2012), then the simulation results were applied to the analysis of the sensitivity of hydrological parameters to evaluate its ability to predict the surface runoff (White and Chaubey, 2005).

Runoff was estimated by the SCS curve number method. The SCS-CN equation was utilized in the SWAT model to predict runoff volumes and peak runoff rates per HRU (Hydrologic Response Unit):

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \qquad .(R_{day} > I_a) \tag{1}$$

Q_{surf} represents the daily rainfall excess or runoff in millimeters; R_{day} represents the depth of the daily rainfall in millimeters; S represents the parameter of retention in millimeters (mm); Ia represents the initial abstractions which is normally rounded as 0.2 S.

By removing Ia (Usually, Ia is rounded as 0.2 S) the equation becomes as follows:

$$Q_{surf} = \frac{(R_{day} - 0.2\,S)^2}{(R_{day} - 0.8\,S)} \tag{2}$$

The following formula can be used to compute the retention parameter:

$$CN = \frac{1000}{(10 + \frac{S}{25.4})} \qquad S: in\ (millimeter) \tag{3}$$

By rearranging the equation, it becomes as follows:

$$S = 25.4\ (\frac{1000}{CN} - 10) \qquad S: in\ (millimeter) \tag{4}$$

CN: The curve number for the day

4. Results and Discussion

4.1. Watershed Delineation

The first stage in creating a SWAT model is to automatically delineate the entire basin and each sub basin's catchment. Wadi Al-Mohammadi basin was delineated using the major outlet point, which is located near the main steram confluence with the Euphrates River. The accurate and correct selection of the outlet point location gives results closer to reality and guarantees (to a large extent) all the areas that considered within the watershed (Fig. 3). The sub-basins have been delineated based on the area threshold of 4712 ha (47.12 km^2) and manual adjustment of the sub-basins outlets sites (Fig. 4). The results of the Wadi Al-Mohammadi basin delineation show the overall drainage area was 2286.8 km^2 with 7 outlets and 7 sub-basins named sub-basin1 to sub-basin 7. Sub-basin-3 (SB3) is the largest sub-basins of Wadi Al-Mohammadi basin, which has an area of 636.12 km2 and represents 27.82% of the total area of Wadi Al-Mohammadi basin. Sub-basin-1 (SB1) recorded the lowest percentage, and scored 3.49%, with a total area of 79.79 km^2. However, they differ in the site, the drainage area, and the mean elevation. The sub-basin -1 (SB1) is located at the estuary and has an average height of about 84.52 m with a drainage area covering the entire Wadi Al-Mohammadi basin of 2286.8 km^2, while the sub-basin -2 (SB2) receives its water from the SB5, SB6, and SB7 in addition to its area as well, and thus the area of the drainage basin is covering these four basins 1280.89 km^2.

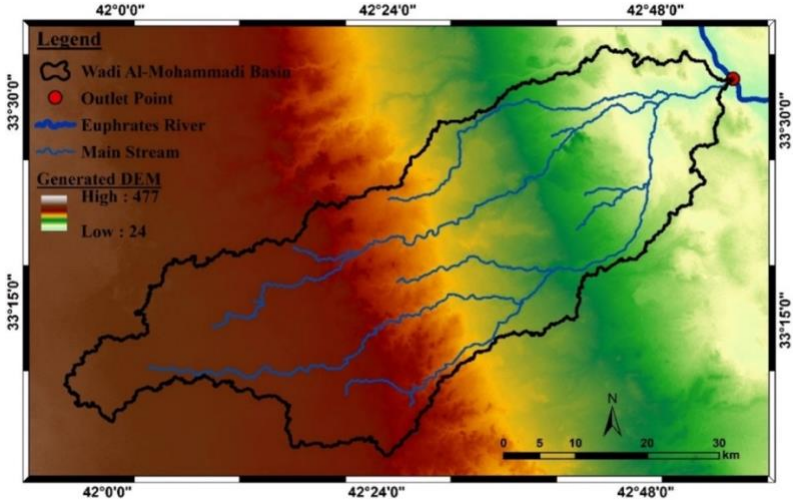


Fig. 3. The delineation of the Wadi Al-Mohammadi basin depended on the main outlet point

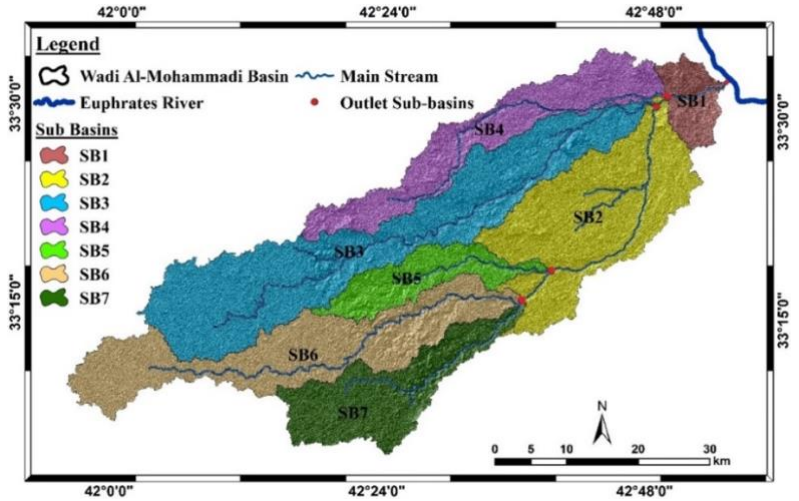


Fig. 4. Sub-basins delineation of the Wadi Al-Mohammadi basin

4.2. Hydrologic Response Units (HRUs)

Before the HRUs definition, the area threshold must be specified for layers of land use, soil, and slope to improve the estimation of hydrological components. The land use, soil, and slope layers are illustrated in Fig. 5. In this study, 10%, 15 %, and 5 % thresholds were used for the LULC layer; soil layer, and slope layer respectively, and the distribution of HRU was defined by setting multiple HRU per every sub-basin. Wadi Al-Mohammadi basin is subdivided into 199 HRUs based on LULC, slope, and soil layers. Table 1 shows the summary of HRUs data for each sub-basin. In general, the large number of HRUs (in any watershed) reflects the presence of high variability in one or more layers (LULC, soil, and slope) that were produced HRUs. Besides, the area of the watershed can influence the number of HRUs in some way. Fig. 6 shows the full HRUs of Wadi Al-Mohammadi basin.

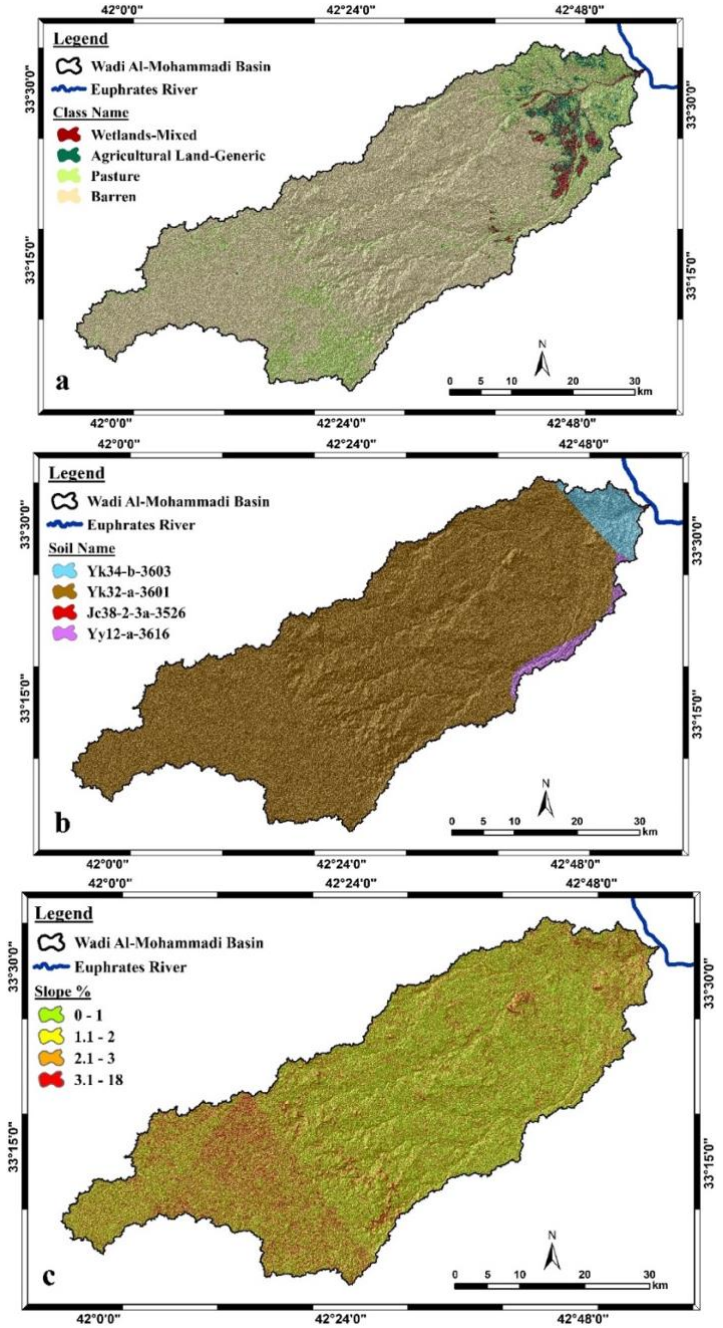


Fig. 5. (a) LULC map; (b) Soils map and (c) Slope map of Wadi Al-Mohammadi basin

Table 1. The HRUs data for each sub-basin of Wadi Al-Mohammadi basin, TC represents the time of concentration

Sub Basin	SB1	SB2	SB3	SB4	SB5	SB6	SB7	Total	Average
HRUs	56	48	16	32	16	15	16	199	-
CN1	70.70	77.10	77.10	74.20	77.10	77.10	77.10	530.40	75.77
CN2	85.5	89.00	89.00	87.33	89.00	89.00	89.00	617.83	88.26
CN3	94.25	95.70	95.70	94.97	95.70	95.70	95.70	667.72	95.39
TC (hr)	0.97	1.24	2.51	1.57	1.52	2.00	1.73	11.54	1.65

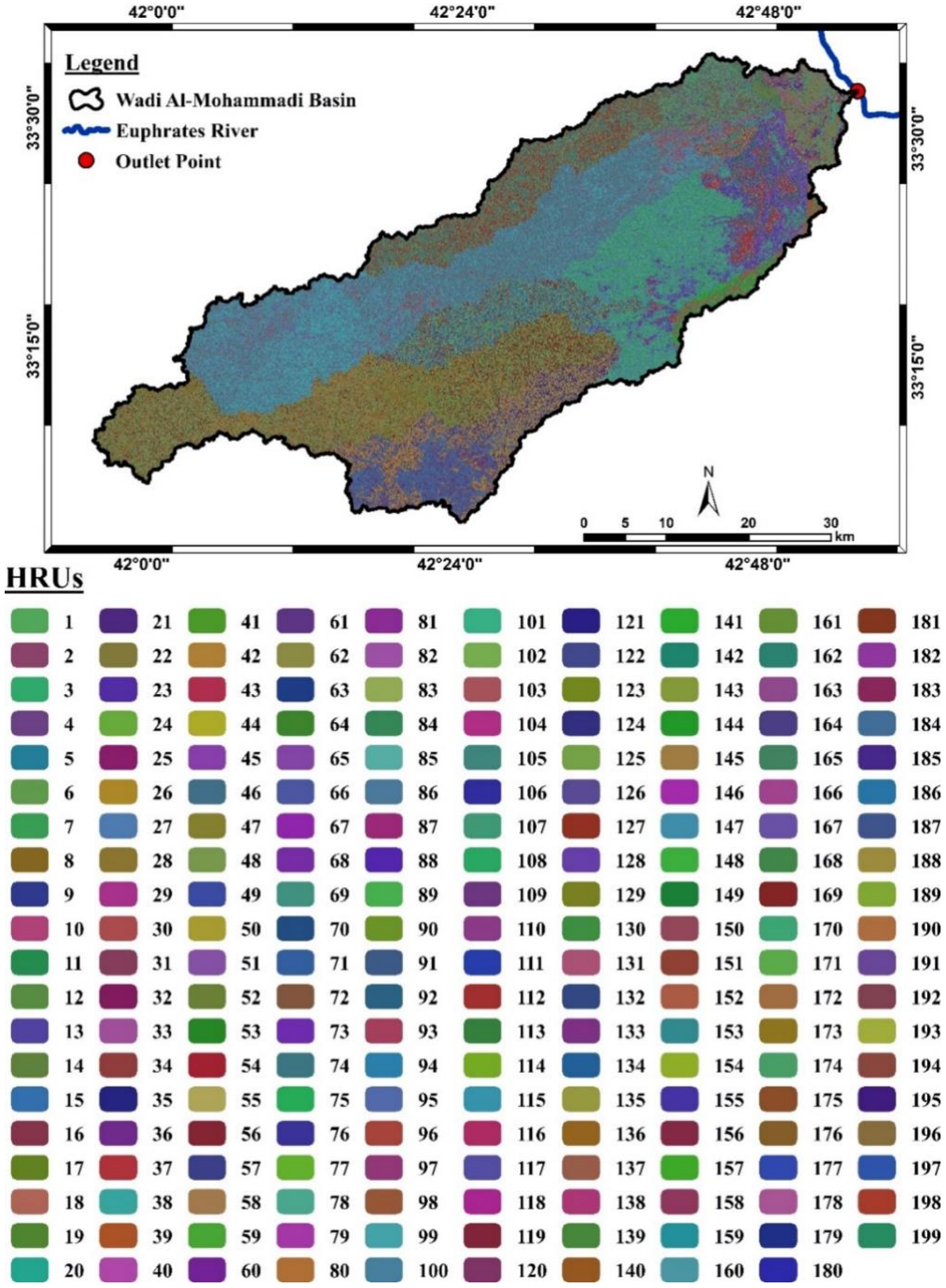


Fig. 6. The hydrologic response units of the Wadi Al-Mohammadi

4.3. Surface Runoff Estimation

Topography, gravity, and the area of contribution play a role in the movement of water within the basins, and the concentration of water flow which finally creates the saturated lands where runoff is produced (Dunne and Black, 1970). Solar radiation, precipitation, and local temperature are other elements that have an impact on the movement of water within the basins (Ahl et al., 2008). These factors play a direct influence on snow accumulation, evaporation, transpiration, snowmelt, and hence plant productivity. The main goal of this work is to use the SWAT model to simulate runoff and water flow (discharge) of the Wadi Al-Mohammadi basin. Table 2 shows the simulation of average annual rainfall, runoff, and water flow with the total water volume of the Wadi Al-Mohammadi basin from the period 1992 to 2020.

Table 2. Annual average of rainfall, runoff, and discharge with the total water volume of Wadi Al-Mohammadi basin the period 1992-2020.

Years	Precipitation (mm)	Surface Runoff (mm)	Volume (m^3)	Discharge (m^3/s)	Volume (m^3)
1992	41.81	0.03	68604	0.002	52560
1993	63.32	3.63	8301084	0.254	8015400
1994	46.66	0.15	343020	0.011	341640
1995	76.77	0.66	1509288	0.043	1366560
1996	86.16	10.93	24994724	0.789	24887160
1997	91.13	0.59	1349212	0.024	762120
1998	85.16	0.77	1760836	0.044	1392840
1999	75.65	0.78	1783704	0.047	1471680
2000	95.88	11.3	25840840	0.783	24676920
2001	70.66	1.7	3887560	0.113	3574080
2002	51.58	0.35	800380	0.018	578160
2003	64.94	0.82	1875176	0.056	1760760
2004	62.95	0.77	1760836	0.048	1524240
2005	85.95	6.88	15733184	0.512	16135920
2006	54.54	0	0	0.000	0
2007	51.69	0.09	205812	0.008	236520
2008	52.31	0.08	182944	0.002	52560
2009	54.46	0	0	0.000	0
2010	71.33	1.62	3704616	0.113	3574080
2011	79.31	6.15	14063820	0.405	12772080
2012	101.12	5.63	12874684	0.373	11773440
2013	44.36	0.15	343020	0.008	236520
2014	63.93	0.43	983324	0.018	578160
2015	80.39	1.69	3864692	0.106	3337560
2016	80.43	0.58	1326344	0.033	1024920
2017	53.52	0.32	731776	0.021	657000
2018	81.44	0.42	960456	0.022	683280
2019	58.54	0.43	983324	0.025	788400
Average	68.79	2.03	4651187	0.138	4366234

From Table 2, the annual average flow discharge was 0.138 m^3/s with a total annual water volume being about 4.366 Mm^3, while the average annual water volume calculated from runoff was about 4.651 Mm^3. There is a difference in the average annual volume of water calculated from surface runoff and discharge, this is because the Wadi Al-Mohammadi basin is of a little slope, and not all the surface

runoff water reaches the mainstream, or it ends in secondary valleys or collects in pits, and therefore the surface runoff is higher than the discharge.

4.4. Rainfall-Runoff Relationship in the Wadi Al-Mohammadi Basin

The relationship between rainfall and runoff is strong and correlated as shown in Fig. 7. Peak runoff is observed in the Wadi Al-Mohammadi basin mostly during the winter season, from November to March of the year. Fig. 7a shows a presentation of the rainfall during the year of the Wadi Al-Mohammadi basin. The precipitation peak, as well as runoff peak, occurs in February, this indicates that runoff is highest when the maximum precipitation occurs during the year. Although the rainy season begins in November, the peak runoff does not occur until February, and this is because the first months of the rainy season are characterized by intermittent rains in addition to the dryness of the soil after the summer season, which makes most of the rainwater contribute to soil moisture and loses as evapotranspiration.

Generally, the climatic factor controls the hydrograph shape and thus controls the characteristics of the basin. This study found that about 3% of rainwater, which has an annual average of 68.8 mm, is discharged as surface runoff, while the remaining 97% is lost as evaporation. The relationship between the rainfall and runoff can be represented by regression analysis based on the monthly observed rainfall from climate data and runoff simulated in the SWAT model, then the best model was selected depending on the value of R^2 (the coefficient of determination). Fig. 7b shows the monthly relationship between rainfall versus surface runoff. The polynomial regression (nonlinear model) was the best model to explain the rainfall-runoff relationship with an R^2 value of about 0.69 which indicated a good correlation between both data, the closer R^2 to 1 is the better the fit. The non-linear relationship shows that there are factors other than the rainfall that influence the amount of runoff.

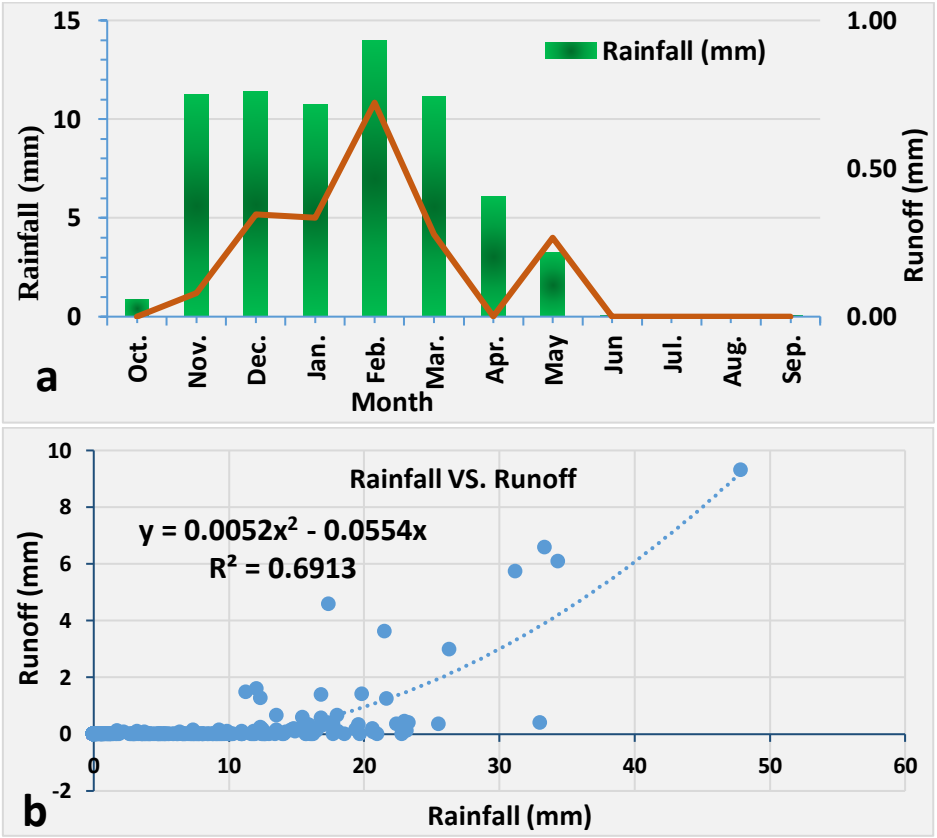


Fig. 7. The relationship between Rainfall-Runoff of the Wadi Al-Mohammadi basin: (a) The rainfall during the year of the Wadi Al-Mohammadi basin; (b) The scatter plot shows the monthly relationship between rainfall and runoff for the period 1992-2020.

5. Conclusions

SWAT proved to be effective as a working platform in the hydrological cycle and to clarify its components and factors affecting the hydrological situation in a region, especially in the area of the current study. The preliminary results of the quantities of water resulting from the simulation are results that can be used in the development of plans, and through effective methods, these quantities of water can be invested. When implementing these plans, they will achieve relative stability in the water supply to the region, and thus will have a positive impact on the population and the environment. The results of the Wadi Al-Mohammadi basin delineation show that the overall drainage area was 2286.8 km^2 with 7 outlets and 7 sub-basins named sub-basin1 to sub-basin 7. The annual average flow discharge was 0.138 m^3/s with the average annual water volume being about 4.366 Mm^3, while the average annual water volume calculated from runoff was about 4.651 Mm^3. There is a difference in the average annual volume of water calculated from surface runoff and discharge, this is because the Wadi Al-Mohammadi basin is of a little slope, and not all the surface runoff water reaches the mainstream, or it ends in secondary valleys or collects in pits, and therefore the surface runoff is higher than the discharge. Peak runoff is observed in the Wadi Al-Mohammadi basin mostly during the winter season, from November to March of the year.

Accordingly, proper management is very necessary for such areas, as it will provide scientific and practical methods for storing the largest amount of water in periods of water available and using it in periods of drought. The installation of gauge stations on the main streams is one of the priorities in water investment, and thus the establishment of a database for these stations recorders. Through this realistic data, it is possible to conduct assessments by authorities and researchers interested in this field, which are considered more accurate and give more acceptable future expectations.

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