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Using SWAT Model to Estimate the Water Balance of Wadi Al-Mohammadi Basin, Western Iraq

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Abstract

Water balance as a technique is considered one of the means that is relied upon in solving significant hydrological problems. The soil and water assessment tool (SWAT) model was used in this study to assess the water balance in the Wadi Al-Mohammadi basin located at the eastern edge of the Western Desert. Digital elevation model, soil data, Land use - Land cover, and climate data represent the most important requirements for the SWAT model's input as a database. The Wadi Al-Mohammadi basin delineation results show the overall drainage area was 2286.8 km^2 with seven sub-basins. The trend line of climate data indicates a clear increase in the total rainfall, relative humidity, temperature, and solar radiation from 1990-2020, while the wind speed decreased during the observed period. The average monthly hydrological components (precipitation, actual evapotranspiration, surface runoff, lateral flow, and deep aquifer recharge) representing the basin's water balance are 68.8 mm, 67 mm, 2.03 mm, 0.02 mm, and 0 mm, respectively.

Keywords: SWAT, Water Balance, Wadi Al-Mohammadi, Hydrological Components, Western Desert.

استخدام نموذج SWAT لتقدير الموازنة المائية لحوض وادي المحمدي، غربي العراق

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الخلاصة

الموازنة المائية كتقنية هي واحدة من اهم الوسائل التي يتم الاعتماد عليها في حل المشاكل الهيدرولوجية الهامة. تم استخدام موديل أداة تقييم التربة والمياه في هذه الدراسة لتقييم الموازنة المائية في حوض وادي المحمدي، على الحافة الشرقية للصحراء الغربية. يمثل نموذج الارتفاع الرقمي وبيانات التربة واستخدام الأراضي/ الغطاء الأرضي وبيانات المناخ أهم متطلبات نموذج SWAT كمدخلات. أظهرت نتائج تحديد حوض وادي المحمدي أن مساحة الصرف الإجمالية بلغت 2286.8 كيلومتر مربع مع وأحواض فرعية. يشير خط الاتجاه لبيانات المناخ إلى زيادة واضحة في إجمالي هطول الأمطار والرطوبة النسبية ودرجة الحرارة

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والإشعاع الشمسي خلال الفترة 1990–2020، بينما انخفضت سرعة الرياح خلال الفترة المرصودة. المتوسط الشهري للمكونات الهيدرولوجية (هطول الأمطار والتبخر الفعلي والجريان السطحي والتدفق الجانبي والتغذية العميقة للخزان الجوفي) والتي تمثل التوازن المائي للحوض هي 68.8 ملم، 67 ملم، 2.03 ملم، 0.02 ملم، وصفر ملم على التوالي.

1. Introduction

Since the last century, climate change has been one of the key concerns confronting the Middle East. It greatly impacted agriculture, the environment, economics, social issues, and health [1]. It directly affects the abundance of water as a natural resource in rural and urban environments [2]. Iraq's climate is continental, subtropical, and semi-arid except for the hilly region in the north and northeast of the country, which has a Mediterranean climate [3].

The climate has considered an important factor affecting the water balance 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. Studying climate change in a region is important because it is closely related to quantities and water quality [4]. 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 [5].
One of the mathematical models that simulate hydrological processes in general and water balance, in particular, is the Soil and Water Assessment Tool (SWAT) model, which can describe the water balance of watersheds. The water balance was calculated by other methods, e.g., [6] using Lerner's methods for calculating water balance in the Ishaqi area within the Salah Al-Din Governorate. Also, meteorological parameters methods were used by [7] to calculate groundwater recharge and water balance in Khan Al-Baghdadi, and an analysis of climate parameters to calculate water balance was used by ([8] and [9]). The SWAT model is one of the most effective and vital tools in watershed assessment and simulation. A SWAT model has been used by researchers at different watershed scales worldwide under different conditions. 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 [10].

The presence of several outcrop formations characterized the study area are configured from the oldest to the youngest. It is the Ms'ad Formation (Late Cretaceous, Cenomanian – Turonian) with an area of about 96 km^2, 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, Zahra Formation (Pliocene – Pleistocene?) with an area of about 594.8 km^2 and in addition to Quaternary sediments with an area of about 10 km^2 [11].

The water balance estimation is particularly a study objective and the assessment of the hydrological conditions in general of the watersheds in the Wadi Al-Mohammadi basin. It was 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 condition in the Wadi Al-Mohammadi basin.

2. Study Area

Wadi Al-Mohammadi is located in the eastern part of the Iraqi Western Desert. It is an ephemeral valley drains into the Euphrates River, 35 km west of Ramadi city. The basin is bordered from the east by the Euphrates River, from the south by the Abu-Jir depression.

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 following coordinates bound the basin; Latitudes 33˚ 34′ 18.1″ N–33˚ 4′ 44.4″ N and longitudes 41˚ 55′ 3.8″ E – 42˚ 56′ 31.6″ E (Figure 1). The total area of the basin is 2286.82 km^2. Its elevation above sea level ranges from 52 to 367 m. Wadi Al-Mohammadi basin is characterized by an uncomplicated topography of varying elevations and a decrease towards the Euphrates River.

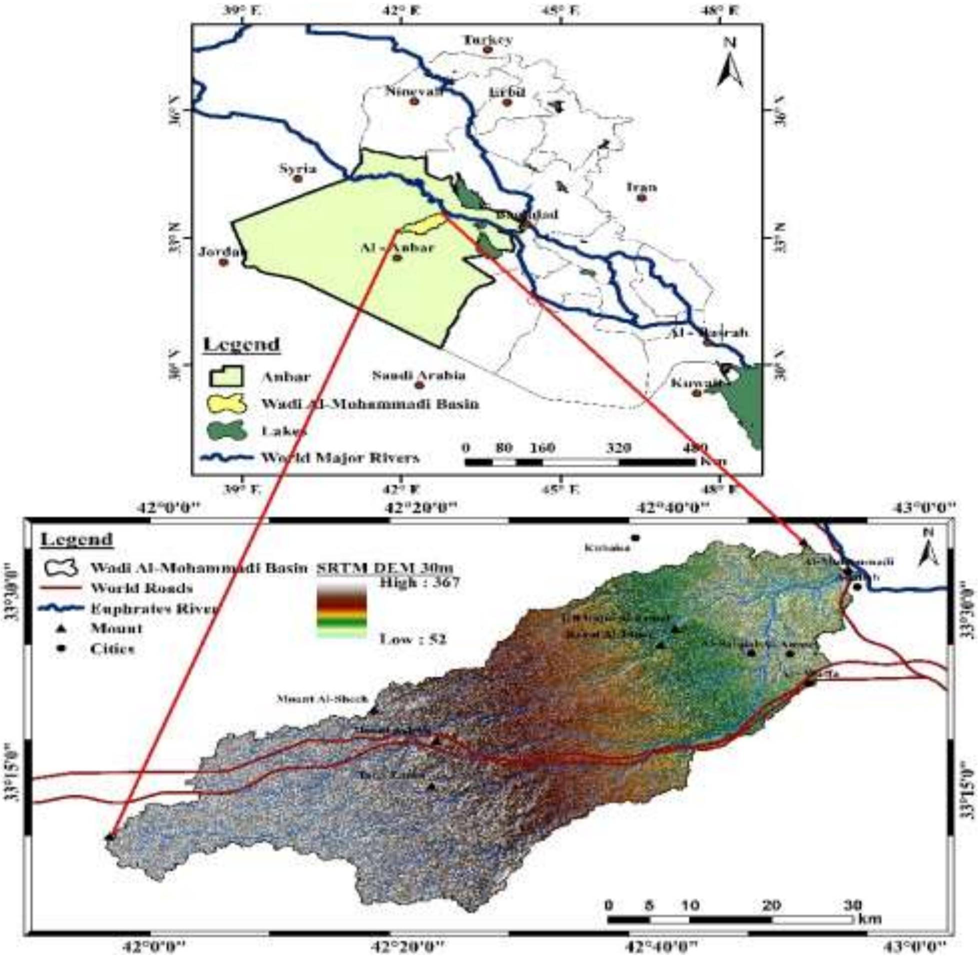


Figure 1: Location map of the study area

3. Materials and Methods

3.1 Data Set

Remote sensing (RS) can provide important data and can be used to draw many maps in the field of water resources [12]. The SWAT model requires the main database that can be included in four groups: First group; the DEM (Digital Elevation Model) was obtained from Shuttle Radar Topography Mission (SRTM), with 30 m spatial resolution, and the USGS website was used to download it (Figure 1). Second group obtained soil data from the Food and Agricultural Organization of the United Nations (FAO) (http://www.fao.org/home/en/). The map of soil is shown in (Figure 2), where it is cut off from the DSMW (Digital Soil Map of the World), version (V. 3.6) [13]. This data includes about 7000 soil types found in the world and comes with an accuracy of 10 km, and its database is for two layers of soil: the upper layer is at a depth of 30 cm, and the lower is from 30 to 100 cm. The third group; land use/ land over (LULC) was produced by utilizing the landsat 8 satellite image, free of cloud, acquired on December 21, 2021. The LULC result of the Wadi Al-Mohammadi basin contains four classes which are Wetlands-Mixed (WETL), Agricultural Land-Generic (AGRL), Pasture (PAST), and Barren (BARR), as seen in (Figure 3 and Table 1). The Pasture and barren lands are the two main classes of the LULC map of the Wadi Al-Mohammadi basin. Fourth group; the climate data were collected from the Langley Research Center (LaRC) Prediction of Worldwide Energy Resource (POWER) project funded by the NASA Earth Science/Applied Science Program for three stations (Figure 4) and 31 years starting from January 1, 1990, to December 31, 2020. The POWER project provides the meteorological and solar parameters in the near time with 0.5*0.5 degrees and for the entire globe. The power data can obtain as a point or polygon and layers data through the POWER website (https://power.larc.nasa.gov/). In one step, the SWAT weather database-v01803 generator model was used to calculate the WGEN statistics required by the SWAT project for many climate stations.

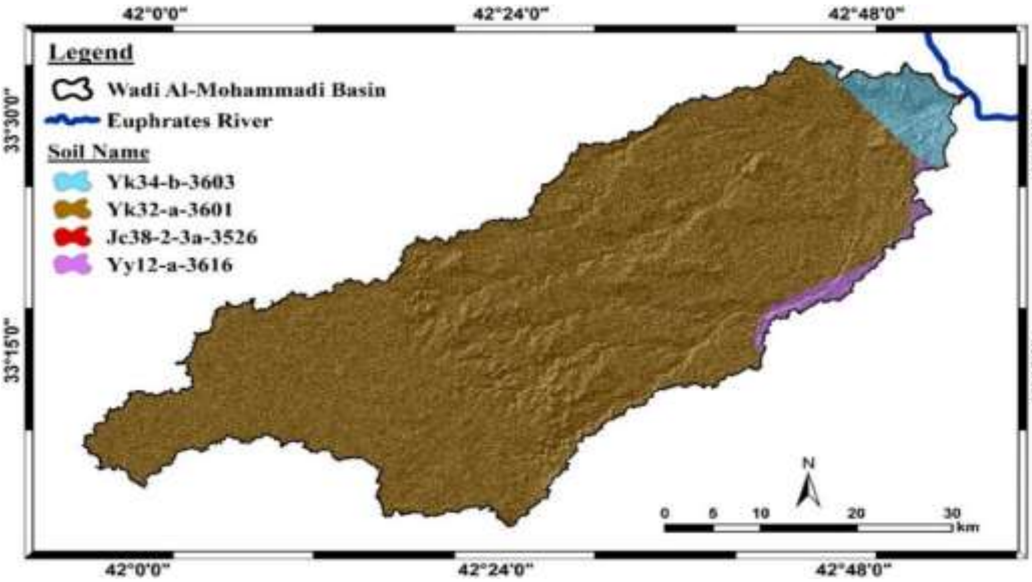


Figure 2: Soils map of the Wadi Al-Mohammadi basin

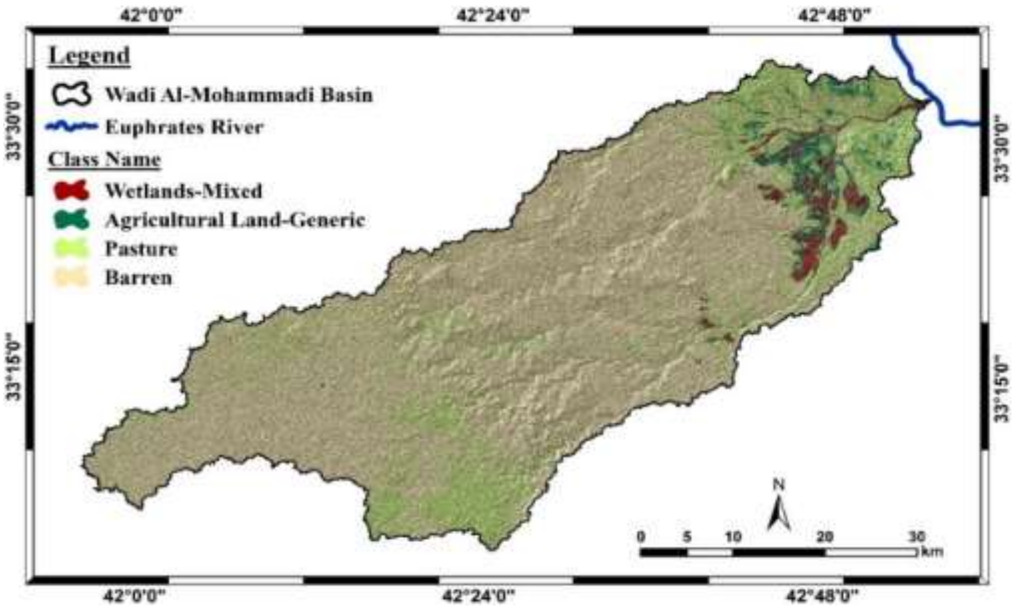


Figure 3: LULC map of the Wadi Al-Mohammadi basin

Table 1: The LULC classification of the Wadi Al-Mohammadi basin

Class Name	ArcSWAT Code	Area km^2	Area%
Wetlands-Mixed	WETL	43.10	1.88
Agricultural Land-Generic	AGRL	77.29	3.38
Pasture	PAST	510.99	22.35
Barren	BARR	1655.44	72.39
		∑= 2286.82	100

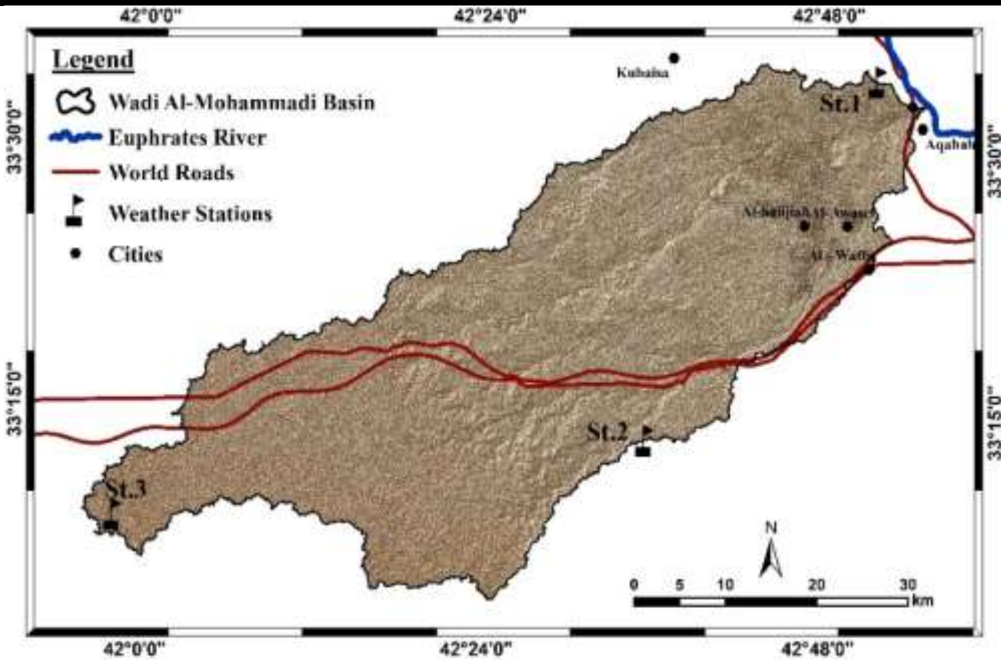


Figure 4: Locations of weather stations in the Wadi Al-Mohammadi basin

3.2 Setup of SWAT Model

After collecting and pre-processing all data required for the SWAT model as the first stage, these required data included the layers of DEM, Land Use/ Land Cover (LULC), soils, and weather data. There are four main inputs for the SWAT model setup. These essential inputs are depicted in a schematic diagram (Figure 5). 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 [14].

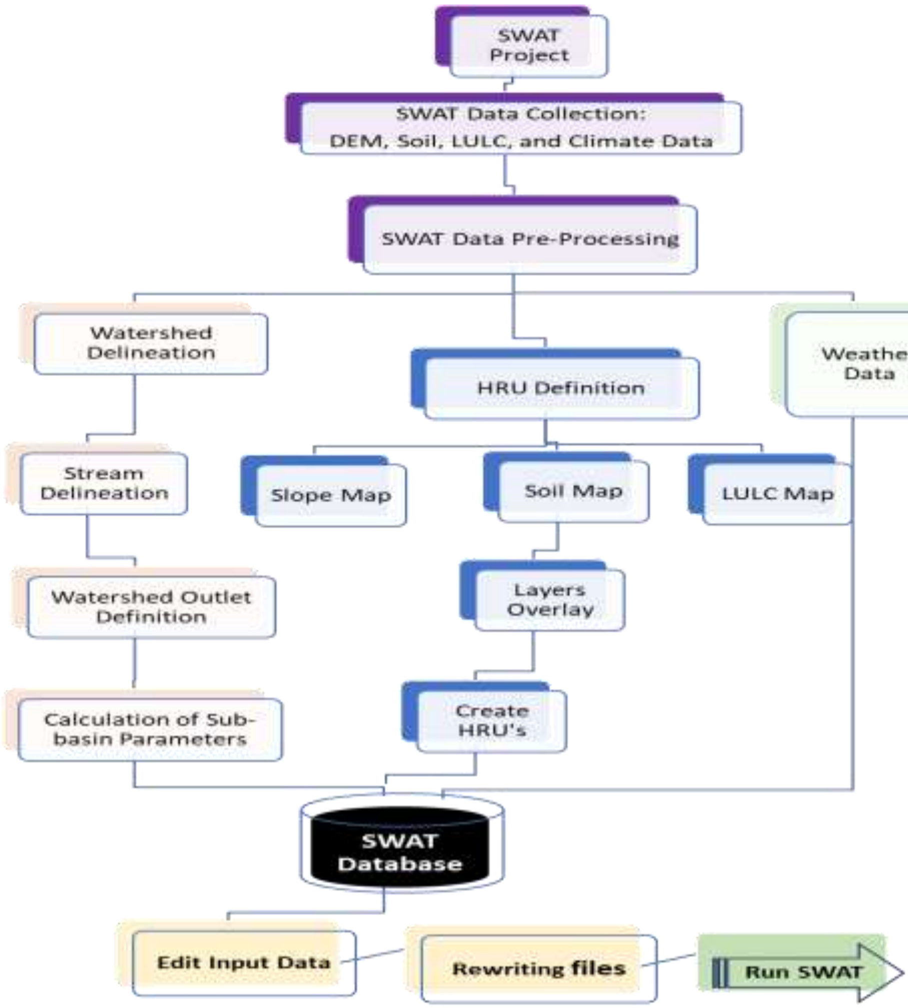


Figure 5: A schematic diagram of the SWAT model's setup

3.3 SWAT Model Run

The SWAT model was running daily after its set up, and the overall pre-processing of the inputs required data for it. The simulation was carried out from 1990 to 2020 (31 years); the first two years were utilized as a warm-up period and for best simulation rendering [15]. The simulation results were applied to analyse the sensitivity of hydrological parameters to evaluate their ability to predict surface runoff [16].

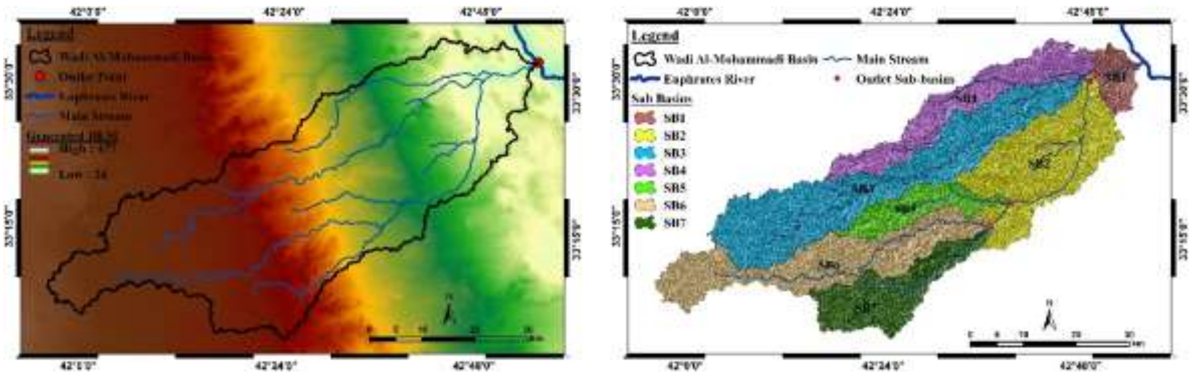
4. Results and Discussions

After executing the SWAT model, the results of the water balance estimation are presented and discussed in the following:

4.1 Watershed Delineation

The first stage in creating a SWAT model automatically delineates the entire basin and each sub-basin's catchment. The Wadi Al-Mohammadi basin was delineated using the major outlet point, which is located near the basin's confluence with the Euphrates River. This increased model dependability and reliability (Figure 6 (a)). In contrast, sub-basins have been delineated based on the area threshold of 4712 ha (47.12 km^2) and manual adjustment of the sub-basins outlet sites (Figure 6 (b)). The Wadi Al-Mohammadi basin delineation results show the overall drainage area was 2286.8 km^2 with seven sub-basins named sub-basin1 to sub-basin 7. The sub-basin-3 (SB3) is the largest sub-basins of the Wadi Al-Mohammadi basin, which has an area of 636.12 km^2 and represents 27.82% of the total area of the Wadi

Al-Mohammadi basin. In comparison, 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, with 84.52 m high, and a drainage area of 2286.8 km^2. The sub-basin -2 (SB2) receives water from the SB5, SB6, and SB7 and from its area as well. Therefore, the drainage basin is covering these four basins (1280.89 km^2).



(a) **(b)**

Figure 6: The delineation of the Wadi Al-Mohammadi basin. (a) Depended on the main outlet point (b) Depended on the sub-basins.

4.2 Climate Data

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) play an important role in determining the variables related to the water balance. Thus, it is among the essential criteria for the SWAT regarding climatic data. In addition, several datasets can be used as SWAT inputs.

The highest annual rainfall was 6.7 mm in 2018, while 2000 was the lowest rainy year, with a total of just 1.2 mm (Figure 7). The highest average annual relative humidity was 41.9 % in 2019, while 2008 was the lowest average annual relative humidity (31.7 %) (Figure 8). The highest average annual temperature was 23.7 °C in 2010, while 1992 was the lowest average annual temperature at 19.8 °C (Figure 9). The highest average annual wind speed was 3.1 m/s in 2001, while in 1995, the lowest average wind speed was 2.7 m/s (Figure 10). The highest average annual solar radiation was 20.4 MJ/m^2/day in 2004, while 1991 was the lowest average at 17.4 MJ/m^2/day (Figure 11).

Figures (7, 8, 9 and 11) also show that the trend line indicates a clear increase in the total rainfall, relative humidity, temperature, and solar radiation during the observed period. At the same time, Figure 10 shows that the trend line indicates a decrease in the wind speed during the observed period.

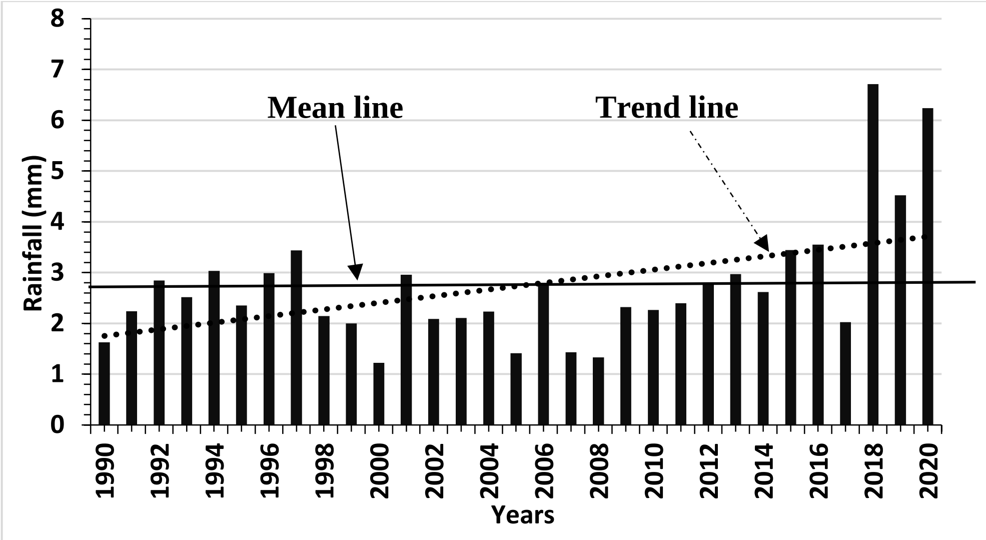


Figure 7: Total annual rainfall recorded in the three stations (St.1, St.2, and St.3) for the period 1990-2020

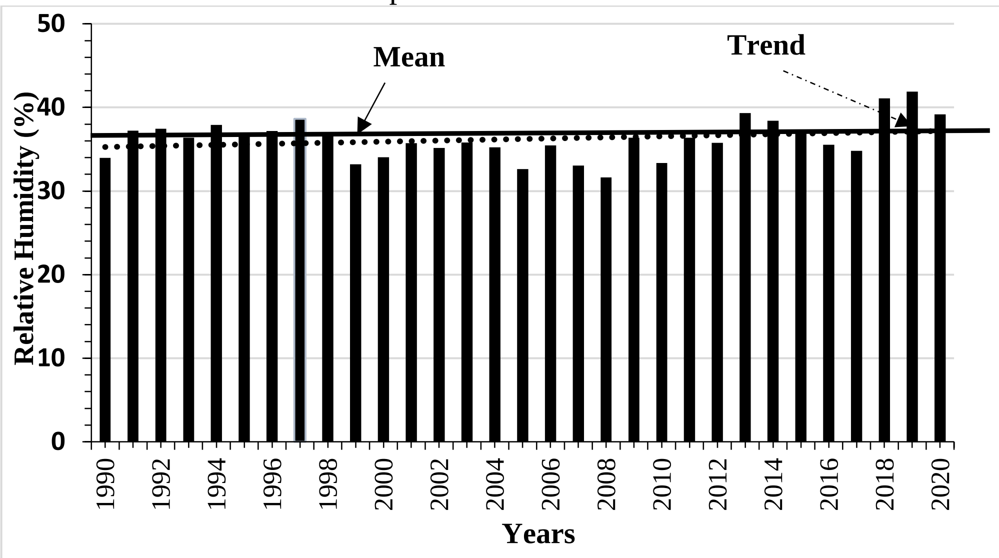


Figure 8: Average annual relative humidity recorded in the three stations (St.1, St.2, and St.3) for the period 1990-2020

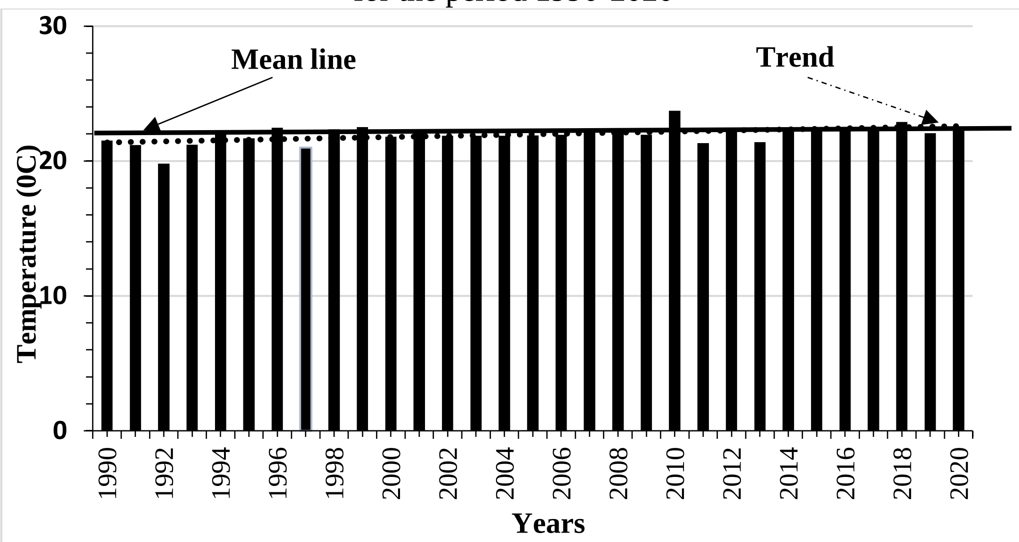


Figure 9: Average annual temperature recorded in the three stations (St.1, St.2, and St.3) for the period 1990-2020

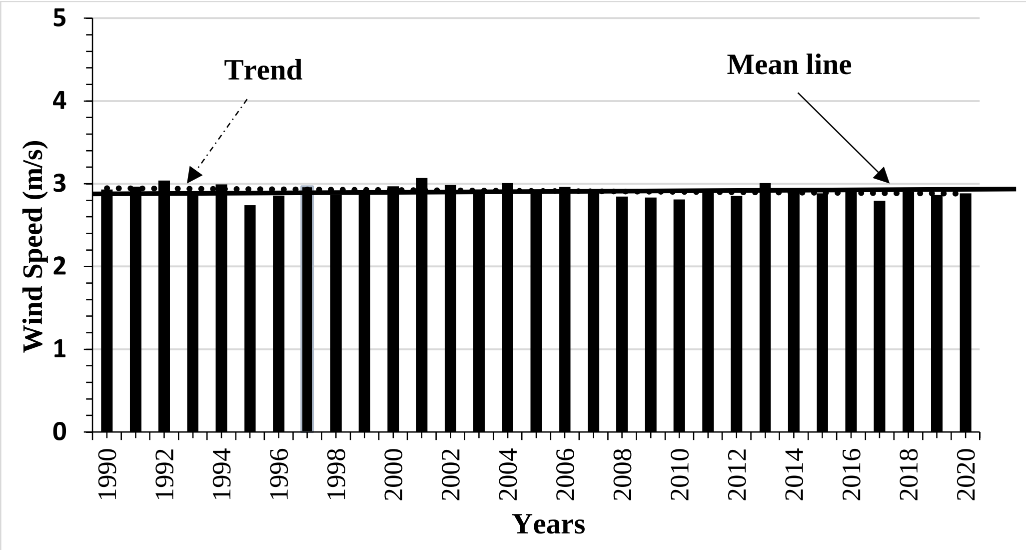


Figure 10: Average annual wind speed recorded in the three stations (St.1, St.2, and St.3) for the period 1990-2020

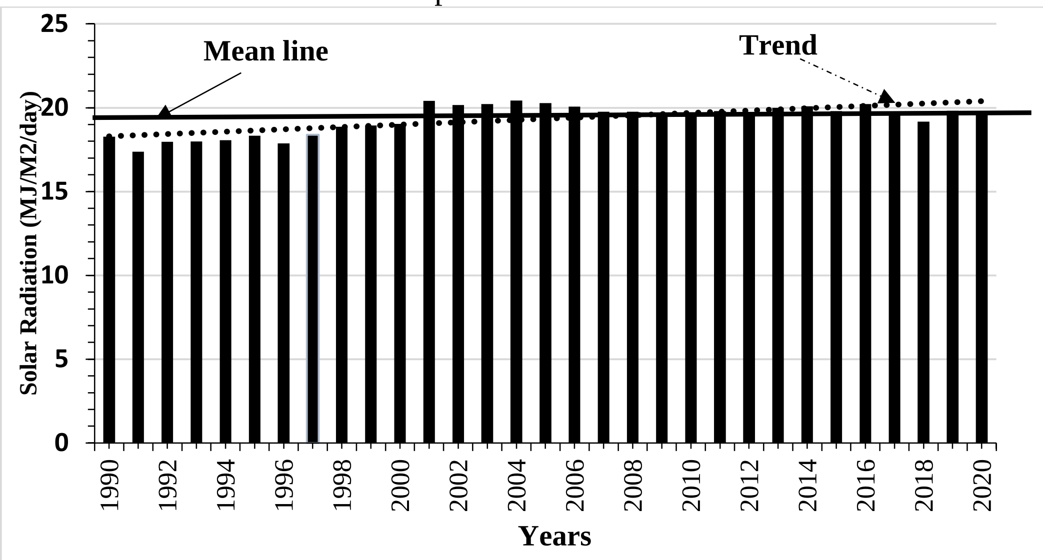


Figure 11: Average annual solar radiation recorded in the three stations (St.1, St.2, and St.3) for the period 1990-2020

4.3 Quantification of Hydrological Components

The availability of water resources was computed as an annual average for sub-basins of the Wadi Al-Mohammadi basin from 1992 to 2020. Figure 12a, b, c, d, and e shows the interesting hydrological components for the period 1992-2020, including the annual average of potential evapotranspiration (PET), actual evapotranspiration (ET), soil water content (SWC), surface runoff (SURQ), and water-yield (WYLD) (i.e., the water amount which leaves the sub-basin and contributes to the flow of the stream during the period).

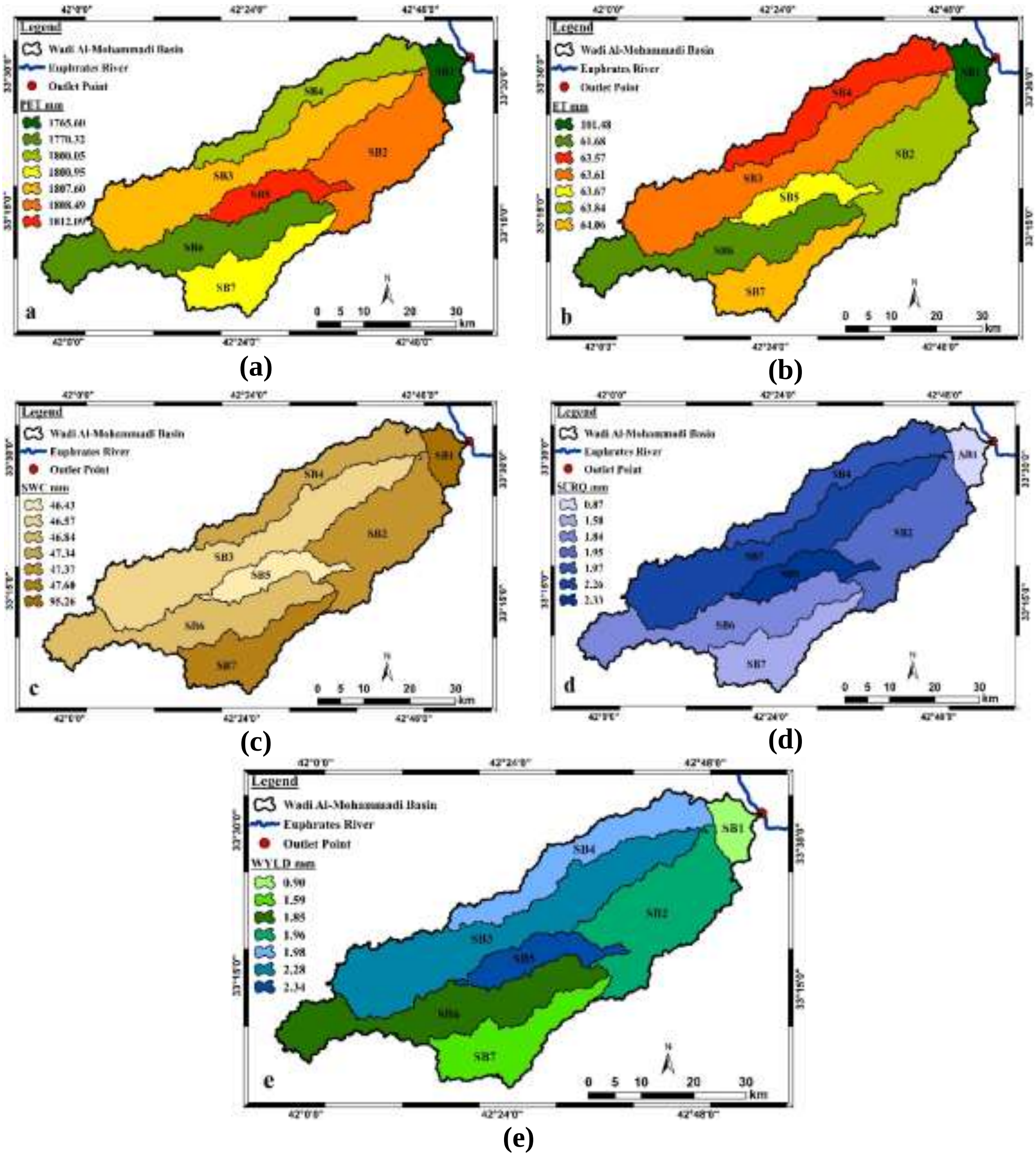


Figure 12: Spatial distribution of annual averages of hydrological components in Wadi Al-Mohammadi basin for 1992-2020. (a) PET (b) ET (c) SWC (d) SURQ (e) WYLD.

Although all sub-basins of the Wadi Al-Mohammadi basin have a close amount of precipitation, the average annual precipitation varies from 63.49 to 102.33 mm/year. However, there is a spatial difference in the distribution of other hydrological components through the Wadi Al-Mohammadi basin.

Figure 12a shows the high value of PET in the center of the Wadi Al-Mohammadi basin (SB5), where it is the evaporation from a large area of short green vegetation that completely shadows the ground, water flows through it with little or no resistance, and it is always well supplied with water. Under the same meteorological conditions, potential evapotranspiration cannot surpass free water evaporation. Figure 12 (b) showed the high value of ET in the southern Wadi Al-Mohammadi basin (SB7), as the actual evapotranspiration values are much lower than the potential evapotranspiration values. Figure 12 (c) shows the high value of

SWC in the eastern and southwestern Wadi Al-Mohammadi basin (SB1 and SB7), respectively. The amount of water in the soil is measured by soil water content (SWC) or soil moisture. It impacts plant development, soil temperature, chemical transport, and groundwater recharge. Figure 12 (d) showed the high value of SURQ in the center and north of the Wadi Al-Mohammadi basin (SB5, SB3, and SB4), respectively. This can occur when the rain arrives more quickly than the soil can absorb it. Surface runoff often occurs because impervious areas (such as roofs and pavement) do not allow water to soak into the ground. Figure 12e shows the high value of WYLD in the center of the Wadi Al-Mohammadi basin (SB5), where the water amount that leaves the sub-basin and contributes to the flow of the stream during the period.

4.4 Water Balance of the Wadi Al-Mohammadi Basin

One of the SWAT model's components is the hydrologic component. The model uses precipitation, surface runoff, evapotranspiration, percolation, and flow variables to solve the water balance equation. The SWAT model can identify water movement for each basin's sub-basin, reservoir, pond, and river [14]. The assessment of the basin's water balance and the determination of hydrological characteristics such as runoff are crucial steps in determining the availability of water resources. Three main hydrological parameters that leave the sub-basin and contribute to the streamflow are the surface runoff, lateral flow, and groundwater flow minus the transport losses (the water lost as re-evapotranspiration from the shallow aquifer and deep percolation). These three parameters form the water yield of the basin. Groundwater flow is one of the water yield parameters and, simultaneously, one of the percolation parameters. Figures 13 and 14 and Table 2 summarize the annual water balance components for the period 1992 to 2020 monthly at the Wadi Al-Mohammadi basin outlet, which revealed that about 46% of the annual rainfall was lost by ET, while the value of percolation is zero and did not affect the amount of rainfall.

The simulation result of the hydrologic components indicates that the main contributor to the Wadi Al-Mohammadi basin's total flow was about 99% of total streamflow, while the contribution of the base flow (lateral flow plus groundwater flow) with the percent of 1% of total streamflow. The results of the annual average show that the groundwater flow does not contribute any amount of that water. Figure 14 displays rainfall, WYLD, percolation, and ET relationships. The highest value of rainfall occurs during the months from November to March. The average monthly of ET is very high, peaking from Febreuary to April. Table 2 indicates that Feb. has the highest runoff value with an average of about 0.72 mm/month. It is followed by Dec. and Jan. This result is a normal, given that the land has become saturated after the rainy months from Nov. to Mar., even though the amount of rain that falls during Nov. and Dec. is very close to the amount of rainfall during Jan. and Feb., the difference in soil moisture. By comparing the previous studies that used the SWAT model, a convergence among these results was found in [17] and [18]).

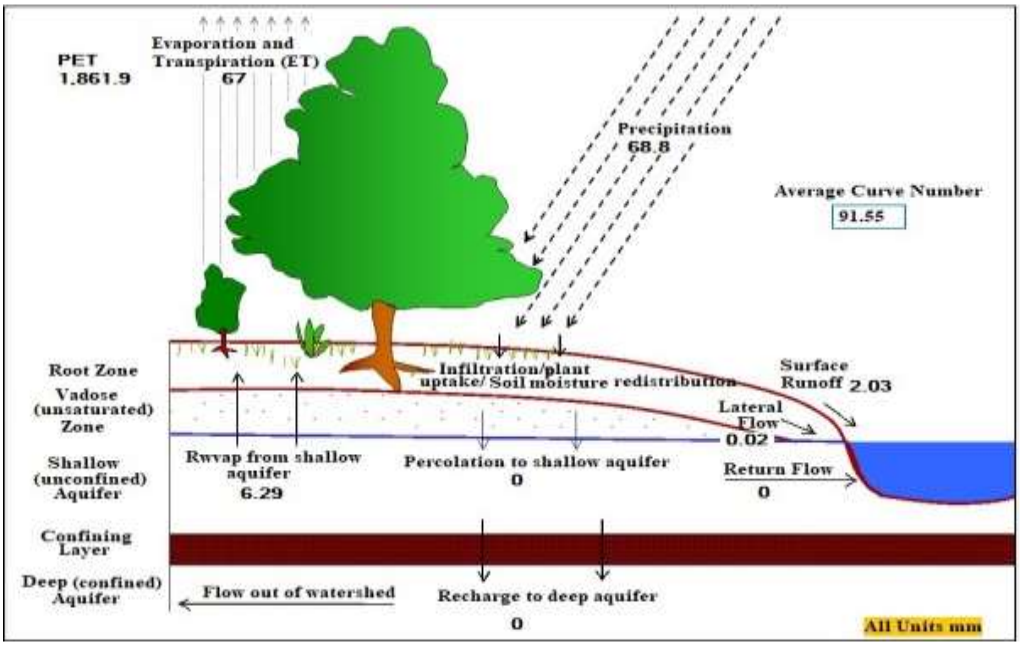


Figure 13: Schema shows the water balance of the Wadi Al-Mohammadi basin

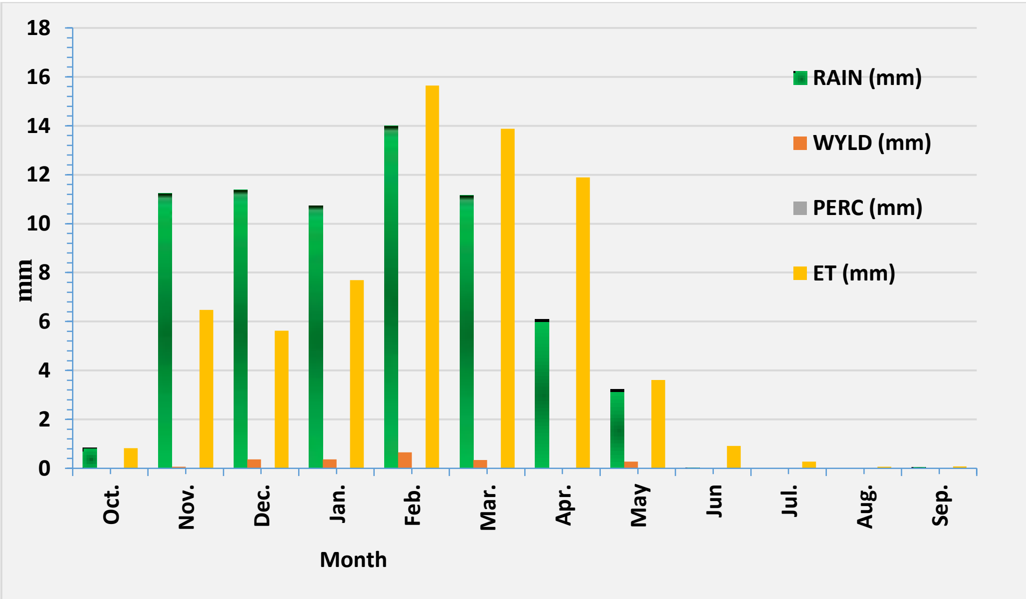


Figure 14: Histogram of the Wadi Al-Mohammadi basin water balanced

Table 2: Average monthly hydrological components which represent the water balance of the Wadi Al-Mohammadi basin for the period 1992-2020.

Month	*RAIN (mm)*	*SURF-Q (mm)*	*LAT-Q (mm)*	*GW-Q (mm)*	*REVAP (mm)*	*D-RCHG (mm)*	*ET (mm)*	*WYLD (mm)*	*PERC (mm)*
Oct.	0.85	0.00	0.001	0.00	0.33	0.00	0.82	0.00	0.00
Nov.	11.25	0.08	0.001	0.00	0.18	0.00	6.48	0.06	0.00
Dec.	11.38	0.34	0.001	0.00	0.06	0.00	5.62	0.36	0.00
Jan.	10.74	0.33	0.001	0.00	0.09	0.00	7.69	0.36	0.00
Feb.	14.00	0.72	0.001	0.00	0.20	0.00	15.64	0.66	0.00
Mar.	11.16	0.28	0.002	0.00	0.31	0.00	13.88	0.34	0.00
Apr.	6.10	0.00	0.002	0.00	0.71	0.00	11.89	0.00	0.00
May	3.23	0.27	0.002	0.00	0.59	0.00	3.61	0.27	0.00
Jun	0.02	0.00	0.001	0.00	1.06	0.00	0.92	0.00	0.00
Jul.	0.01	0.00	0.001	0.00	1.26	0.00	0.27	0.00	0.00
Aug.	0.01	0.00	0.001	0.00	0.93	0.00	0.07	0.00	0.00
Sep.	0.05	0.00	0.001	0.00	0.57	0.00	0.08	0.00	0.00
Total	68.79	2.03	0.02	0.00	6.29	0.00	66.96	2.05	0.00

SURF-Q represents surface-runoff; LAT-Q represents lateral flow; GW-Q represents groundwater flow; REVAP represents the water in the shallow aquifer returning to the root zone; D-RCHG represents Deep aquifer recharge; ET represents actual evapotranspiration; WYLD represents water yield; PERC represents water that percolates past the root zone during the time step.

5. Conclusions

Simulating water behavior and estimating the water balance for the Wadi Al-Mohammadi basin for a period of 31 years (1990 - 2020) is one of the objectives of this work. For this simulation, a SWAT model was used within the GIS environment (ArcGIS, V. 10.5). The SWAT model's efficiency is one of the most critical conclusions reached, as it has proven its worth in simulating the water behavior of basins. The data covered a relatively long period and was challenging to process. Ultimately, the SWAT model was adopted in this study to calculate the water balance results, as it provided an adequate visual representation of the behavior of the elements of the hydrological cycle. The SWAT model proved through the results that soil categories, LULC, and topography, in addition to climatic factors, are factors that have a clear impact on surface runoff and thus on the water balance in general.

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