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Estimation of Surface Runoff for Al-Ghadaf Valley using the SWAT Model

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ABSTRACT

Hydrological studies have become more important in recent years to estimate flow discharges in the valleys. The study area of Al-Ghadaf Valley was chosen due to the absence of surface runoff information for this valley. This research studied the watershed of Al-Ghadaf (GW) by using the SWAT model. It wasn't possible to perform calibration and verification for the model due to the absence of actual discharges in the Al-Ghadaf valley. The area of the catchment was 8567.25 km^2 and the weather data used in this model was for three actual stations, Rutba, Ramadi, and Al-Nukhaib, for 13 years from 2009 to 2022. I wasn't able to choose a period larger than 13 years because some of them are missing. Despite this, one of the features of the period that was chosen is that the years 2019 and 2013 fall within the chosen period and are considered flood years by the Iraqi Ministry of Water Resources. The results show that the maximum daily flow discharge for Al-Ghadaf that outflows into Al-Razzaza Lake was 312.1 m^3/s, the maximum surface runoff depth (mm) for all watersheds was 6.62 mm, and the average curve number for the basin was 88.4. These results will help future researchers in this study area and decision-makers in the Ministry of Water Resources to know the amount of water coming from this basin and feeding Al-Razzaza Lake, especially since there are no previous studies about this basin showing the amount of water falling on the basin and coming to the lake.

Keywords: Al-Ghadaf catchment, GIS, SWAT, Hydrology, Runoff.

1. INTRODUCTION

Hydrological modeling is more important for studying the catchments because it gives all the information needed, such as flow discharges, and describes all the processes that convert precipitation into runoff in the watersheds. This research studies the hydrological modeling of the Al-Ghadaf catchment using the SWAT model due to the absence of information about the study area, such as runoff, discharges, soil type, and land cover.

(Sayl et al., 2021) They study the estimation of the dissertation risk, which is considered the most important problem in the western desert of Iraq. The case study is Al-Ghadaf Valley.

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The objective of the study was to find the most vulnerable rainwater-appropriate sites. The indicators LDI (Land Degradation Index) and NDVI (Normalised Differential Vegetation Index) were used. The results were that 65% of the land was considered more suitable for the harvesting of water, and 35% of the land lies in the large and small change of NDVI, respectively. **(Farhan and Al-Thamiry, 2020)** used the Climate Forecast System Reanalysis CFSR weather data in the Arc-SWAT model for a long-term period to estimate surface runoff for the Al-Mohammedi Valley. Calibration and then the validation were done for this model by using the average discharge. The (NS) and (R^2) coefficients for the calibration were 0.72 and 0.76 and 0.63 , 0.65 for validation. **(Muhaisen et al., 2022)** used the data of CFSR of the weather in Arc-SWAT to analyze the watershed of Mosul dam reservoir. It was concluded that the parameters (CN), (SOL_k), (ALPHA_BNK), (CH_K2), (GWQMN), (CH_N2), (Timp), and (GW_DELAY) were most sensitive. The accuracy for the period of calibration was very good , good , and very good. The results of average annual surface runoff were 2565. **(Al-Khafaji and Al-Sweiti, 2017)** depended on CFSR data to estimate the runoff of the Dokan , Duhok , and Adhaim huge watersheds in Iraq. The results were the delineation was affected by the DEM resolution. The best estimation of the runoffs was when the DEM equal to 90 m with LC equal to 1000 m, DEM 250 m with LC 1000 m, and DEM 30 m with LC 30 m.
(Manhi and Al-Kubaisi, 2021) depended on (SWAT) which was the tool of soil and water assessment to model the watershed of Galal Badra (GBW) in Iraq. Annual average of surface runoff was 244 million meter and average discharge was 7.8 m^3/s. **(Ezz-Aldeen et al., 2018)** Used the period 1959–2014 to estimate Dokan dam watershed. The results were 2100 million cubic for the volume of average annual runoff 72MCM for the sediment. (**Sulaiman et al., 2021)** used the period September 2020 - January 2023 to predict the runoff Arc-SWAT in Iraq's western desert. The results were NSE, RSR, and PBias were 0.71%, 0.85%, and 13% for calibration and 0.74%, 0.55%, and 0.11% for validation. **(Renganathan et al., 2015)** depended on Arc-SWAT to model Poondi subbasin in India. The results were in January to June, the precipitation and runoff were low and then increased. **(Aawar and Khare, 2020)** depended on SWAT model to predict the climate change impact and the streamflow in future on Kabul River sub-basin. The actual discharge was for the period 2003–2010 and validated for the period 2010–2018. **(Farhan and abed, 2021)** studied estimation of the runoff for Bahr Al-Najaf by using Arc-Swat model. The results after calibration and verification were worked, and the R2 coefficient, NSE coefficient, P-factor, and R-factor were 0.59–0.62 (0.51-0.59), 0.59–0.66 (0.60–0.62), 0.57–0.76 (0.62-0.76), and 0.58–0.74 (0.55-0.70) for these valleys, respectively. **(Al-Zubaidi and Abed, 2024)** studied the surface water assessment for the Shuwaija Marsh, in the eastern of Iraq. They used (WMS) which was the Watershed Modelling System. The results were the discharge was 8298 m^3/s at 100 years as a return period. **(AL-Thamiry and Hassani, 2015)** depended in their study on Al-Huweizah marsh inside Iraqi. They concluded that when the required water volume annually was 1384 million m^3, the restoration of the marsh couldn't be achieved. **(Al Zubaidy et al., 2008)** studied Assanna's marsh within hydrologic modeling. It was suggested that in the area surrounding the marsh, the dykes must be 11 m.a.s.l. There was some information about the western desert of Iraq, the Horan watershed, and the surrounding areas of Al-Ghadaf, but there haven't been hydrologic studies or research about it yet.
This research will help the researchers get enough information about this study area. The objectives of the study are to estimate the surface runoff discharge and the surface runoff

depth (mm) of the Al-Ghadaf watershed and calculate the peak discharge compared with the results of the Iraqi Ministry of Water Resources for the period 2009–2022.

2. MATERIALS AND METHODS

2.1 The Study Area

The Al-Ghadaf basin is one of the most important catchments in the western desert of Iraq. This basin feeds Al-Razzaza Lake, so it is important to study it to know the amount of recharge and the time of its peak. It's located in the western part of Iraq between the latitude ($32^o52'57''$- $32^o18'21''$) North and longitude ($40^o5'50''$ - $43^o32'18''$) east, according to **Fig. 1.** It outflows into Al-Razzaza Lake and is surrounded by Wadi Horan from the north and Wadi Al-Obayidh from the south. In this study area, the relative humidity, temperature, and precipitation is 44^oC, begins in October, and between 13 to 45% in winter season. **(Farhan and Al-Thamiry, 2020; Al-Ansari, 2021; Mohammed et al., 2022).**

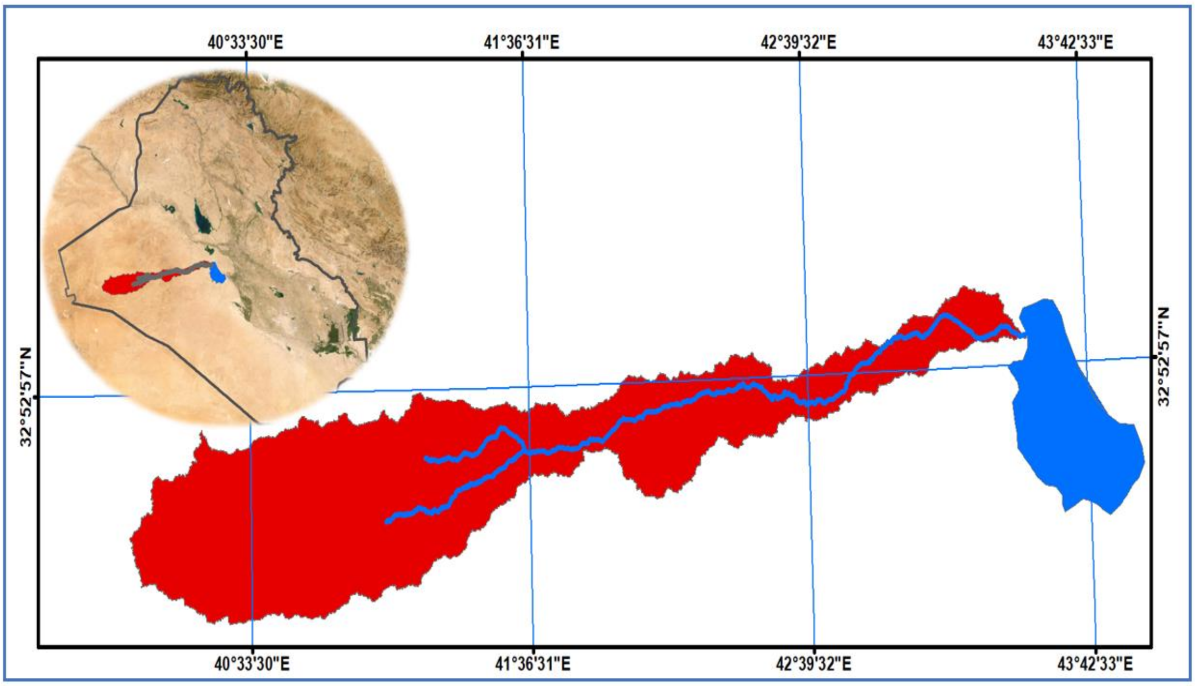

Figure 1. Study area.

2.2 Soil and Water Assessment Tool (Swat)

The Service of Agriculture Research (ARS) developed the tool of soil and water assessment as a modeling tool. The software used for estimating the surface runoff, sedimentation and management of land **(Neitsch et al., 2011).** The tool is called Arc-SWAT. This tool needs input data such as vegetation, soil type, topography, and weather data **(Farhan and Al-Thamiry, 2020).** The plan of Arc-SWAT model divides any watershed into several subbasins, then divides into sveral numbers of Hydrologic Response Units (HRU) **(Neitsch et al., 2011; Douglas-Mankin et al., 2010)**.

The equation of the water balance, which is developed by **(Neitsch et al., 2011)** is the main equation that the software depends on, according to Eq. (1).

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \quad (1)$$

The terms of the equation can be expressed in the nomenclature.

2.3 Input Data

This item shows the data that has been inserted in the ArcSWAT model, such as the digital elevation model (DEM), soil type, land cover, and weather data.

2.3.1 Digital Elevation Model (DEM)

The digital elevation model (DEM) of Al-Ghadaf Valley, west of Iraq, was prepared from the USGS website at 30 meters, which is considered one of the most important factors in preparing any hydrological model **(Warner and Conley, 2015; Lettenmaier et al., 2000)**. **Fig. 2** shows the satellite (SRTM 1 Arc-Second Global), which gives DEM data for any study area.

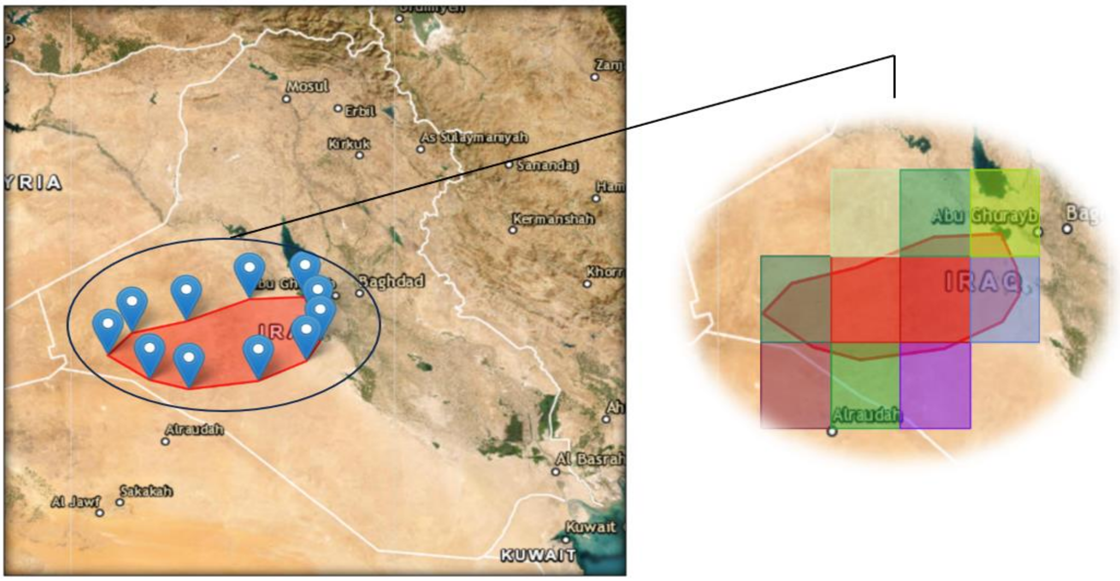

Figure 2. Bands of DEM and location of the study area.

From **Fig. 2** the left photo shows the borders of DEM for the study area, and the right photo explains the bands of the SRTM satellite that have been used in ArcGIS to merge it. **Fig. 3** shows the elevations of Al-Ghadaf Valley from DEM after clipping it in ArcGIS. Elevations range from 27m to 818m.

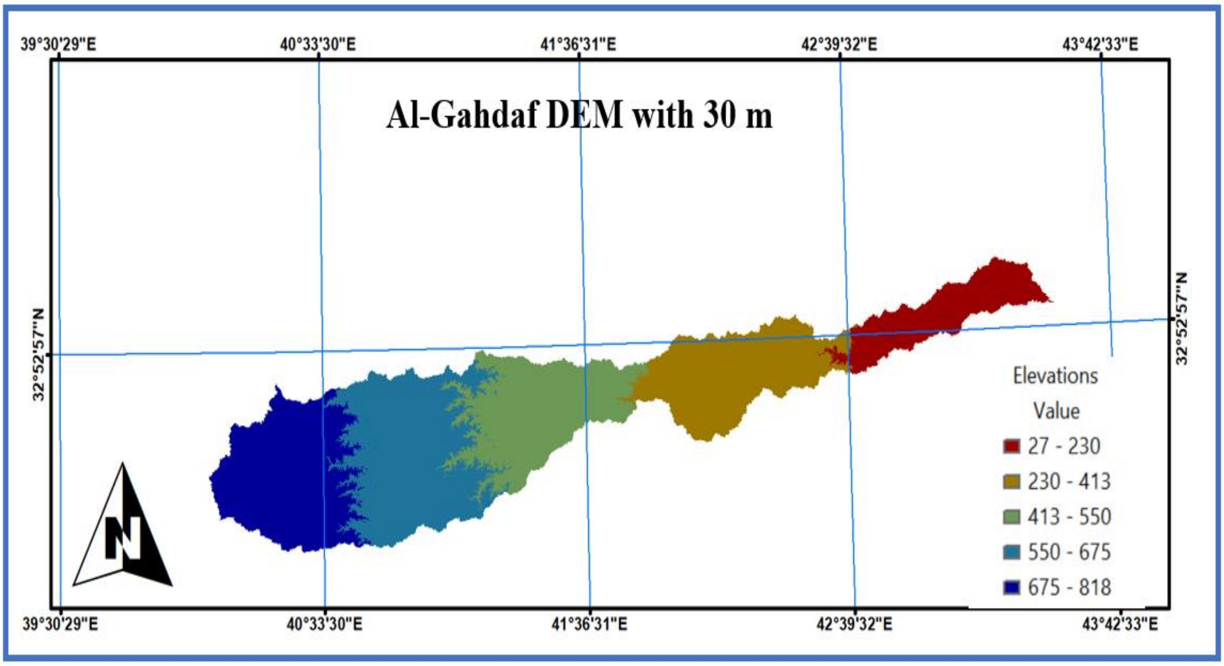

Figure 3. Al-Ghadaf elevations.

2.3.2 Creation Subbasins

Creation of subbasins is the next step after importing all information about the digital elevation model. **Fig. 4** shows the Al-Ghadaf subbasins. It was concluded that subbasin 1 is the largest area, which is equal to 3275.7 km^2, and the areas of subbasins 2, 3, 4, and 5 are equal to 2171.1km^2, 1094.9km^2, 1333.6km^2, and 1062.4km^2, respectively **(Mekonnen and Manderson, 2023)**.

2.3.3 Creation Land Cover

The land cover map used in this research was a global map of the European Space Agency Glob Cover Portal; download it, insert it in ArcGIS, and extract it to the study area, as shown in **Fig. 5**, **(Carlson and Arthur, 2000; Schoonover et al., 2006).**

2.3.4 Soil Type

The soil type map used in this research was from the Food and Agriculture Organisation at scale 1:5000 000. This world map was clipped to the study area of Al-Ghadaf Valley as shown in **Fig. 6.** This figure contains some polygons; each polygon has FAO soil type, area of the polygon, value as SNUM, soil texture, hydraulic conductivity, and hydrological soil group. The data for Al-Ghadaf soil type is shown in **Table 3.**
The catchment of Al-Ghadaf contains a river, which is considered a natural river, and it is possible to build a dam in the future for rainwater harvesting **(Amelung et al., 2022).**

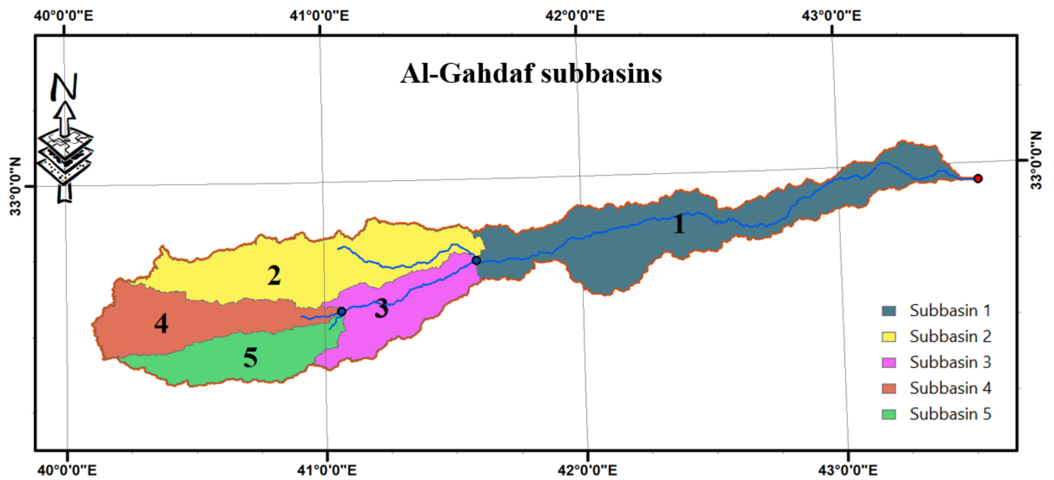

Figure 4. Subbasins of Al-Ghadaf watershed.

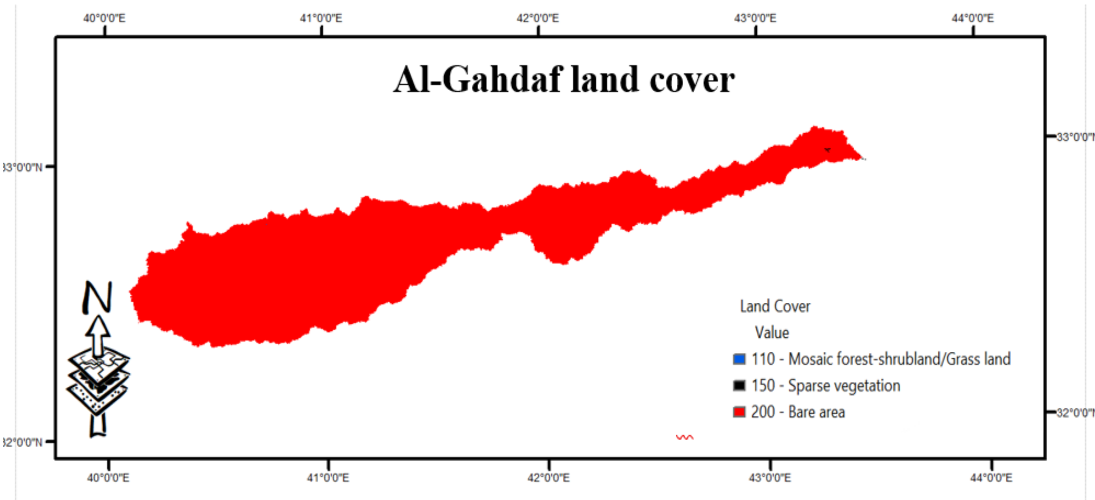

Figure 5. Land cover of Al-Ghadaf valley.

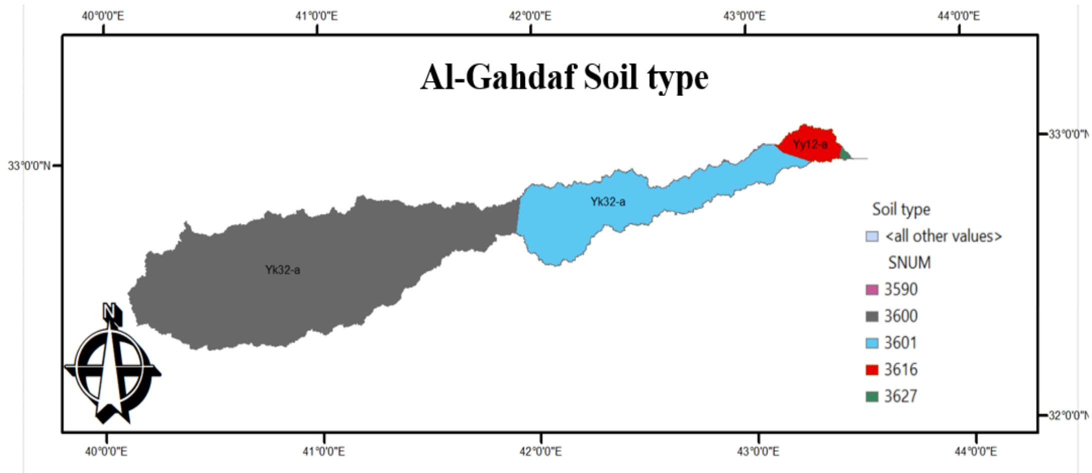

Figure 6. Al-Ghadaf soil type

2.3.5 Weather Data

The data of the weather, such as rainfall, temperature, solar radiation, wind speed, and relative humidity, are necessary to run any Arc-SWAT model. The weather stations used in this model were three, Rutba, Ramadi, and Al-Nukhaib, for a period of 13 years from 2009 to 2022. It wasn't able to choose a period larger than 13 years because some of them are missing, and contain monthly data recordings, while the program requires daily or sub-daily data that is incomplete or difficult to record because of the country's conditions in recent years in the areas located west of Iraq. The database of actual rainfall stations, such as latitude, longitude, elevation, and rain years, was entered into the model by using WEGAN-USER. The station locations of the weather data are shown in **Fig. 7.**

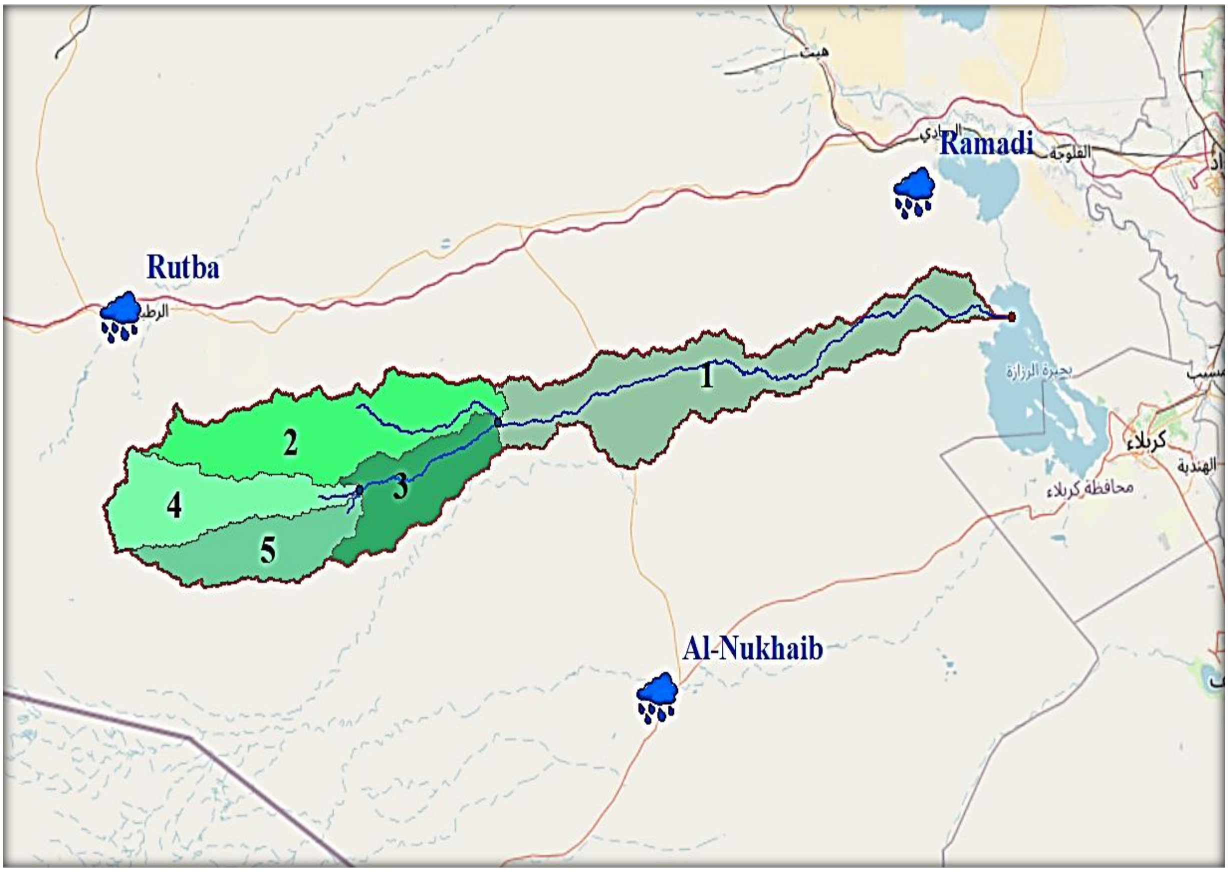

Figure 7. Locations of actual weather stations.

3 . METHODOLOGY

This section explains the steps to prepare the Arc-SWAT model, as shown in **Fig. 8.**

3.1 Hydrologic Response Unit (HRU)

It is the most important step in the model, which merges the layers of soil type, land cover, and topography together **(Flügel, 1997; Her et al., 2015; Pignotti et al., 2017; Femeena et al., 2022; Poblete et al., 2020)**. As shown in **Fig. 9**.

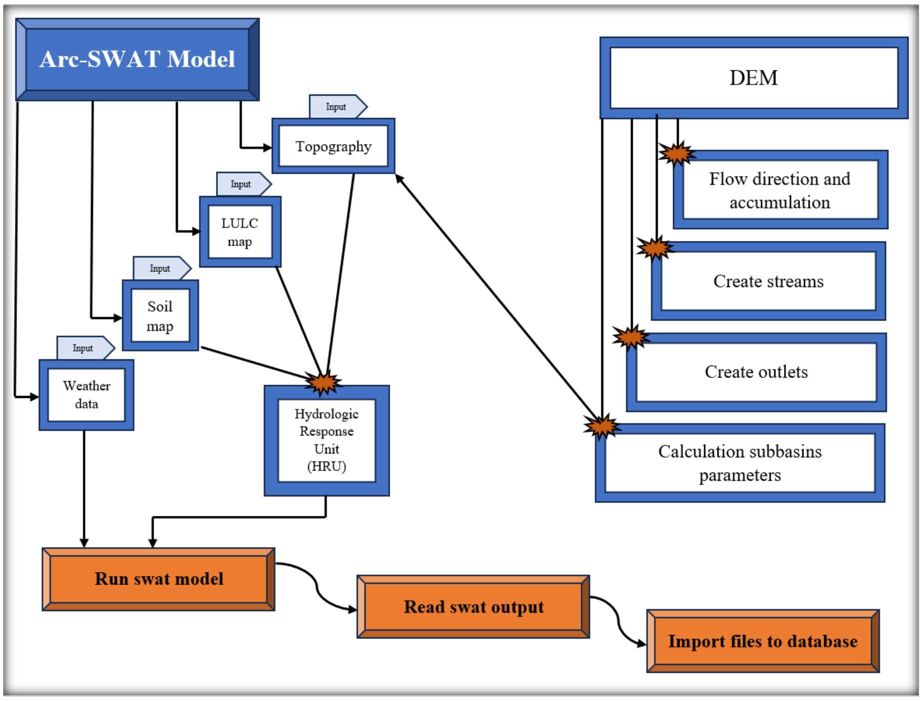

Figure 8. Flow chart of the Arc-SWAT model.

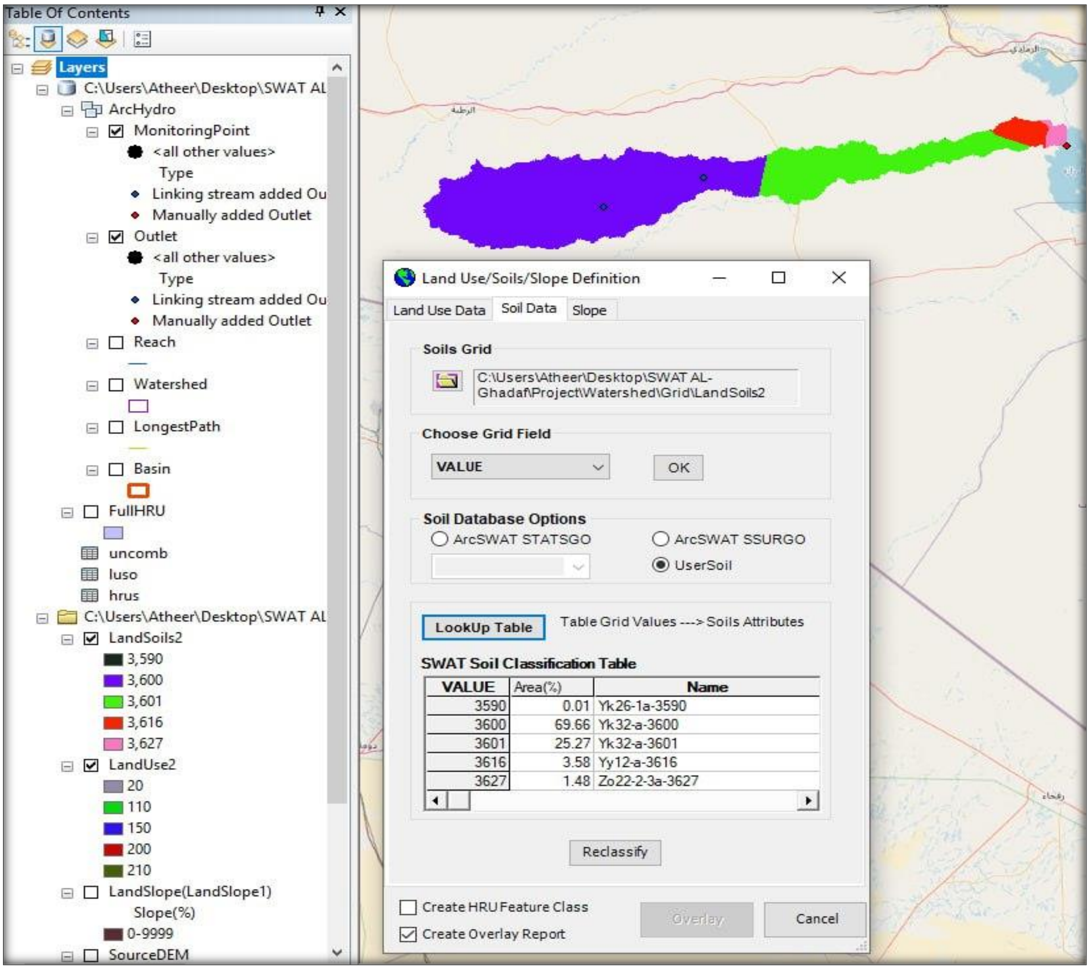

Figure 9. HRU step.

3.2 Methods Used in the Model

There are some methods used in the Arc-SWAT model for the Al-Ghadaf watershed, such as:

A- Rainfall-runoff method for estimating surface runoff, which depends on (Daily Rain / CN (curve number) / Daily Route). The value of CN refers to the losses that have been calculated according to the values of the curve number **(Amutha and Porchelvan, 2009; Al-Ghobari et al., 2020).**

B- For the channel routing, the Muskingum method was used with the coefficients (CO1 = 0.75, CO2 = 0.25, and X = 0.2) **(Das, 2004; Gill, 1978; Wang et al., 2023)**. It is mentioned that the Muskingum equation is used for calculating channel routing in hydrological modeling, and CO1, CO2, and X are the parameters of this equation.

4. RESULTS AND DISCUSSION

The data on Al-Ghadaf land cover that has been extracted from ArcGIS is shown in **Table 2.**

Table 2. Data of Al-Ghadaf land cover.

Grid code	Land cover	Area (km^2)	The total area of the basin (km^2)
200	Bare area	8565.197	8567.25
150	Sparse vegetation	1.997513	
110	Mosaic forest-shrubland/Grassland	0.05506	

It was concluded that most of Al-Ghadaf's land cover was bare area, which equals 8565.197 km^2. The data for Al-Ghadaf soil type is shown in **Table 3.** The results of **Table 3** show that the large type of soil in the catchment of Al-Ghadaf was Yk32-a, which has an area equal to 8276.491 km^2. **Fig. 10** shows the results of soil type

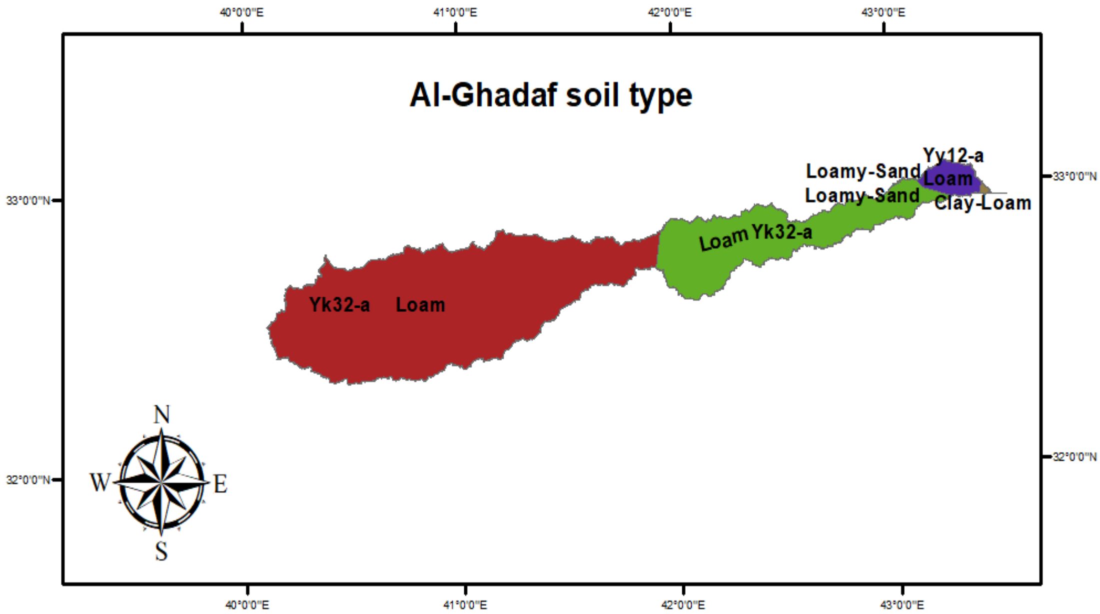

Figure 10. Results of soil type.

The results of HRU for five subbasins in the Al-Ghadaf basin are shown in **Table 4.** Average annual values of precipitations and discharges for a simulated period are shown in **Fig.11.**

Table 4. HRU results of the study area.

Subbasin: Area (ha)	HRU Classification		Area (ha)
	Land cover	Soil Type	
1	Agricultural Land-Row Crops	Zo22-2-3a-3627	38.7988
	Agricultural Land-Generic	Yy12-a-3616	167.6911
	Agricultural Land-Generic	Zo22-2-3a-3627	278.4947
	Barren	Yk26-1a-3590	79.3452
	Barren	Yk32-a-3600	56337.1166
	Barren	Yk32-a-3601	225518.6915
	Barren	Yy12-a-3616	31726.2914
	Barren	Zo22-2-3a-3627	7508.4347
	Water	Zo22-2-3a-3627	5325.7421
2	Range-Brush	Yk32-a-3600	8.1268
3	Barren	Yk32-a-3600	217258.8366
	Barren	Yk32-a-3600	109571.6428
4	Barren	Yk32-a-3600	133680.2687
5	Barren	Yk32-a-3600	106280.9133

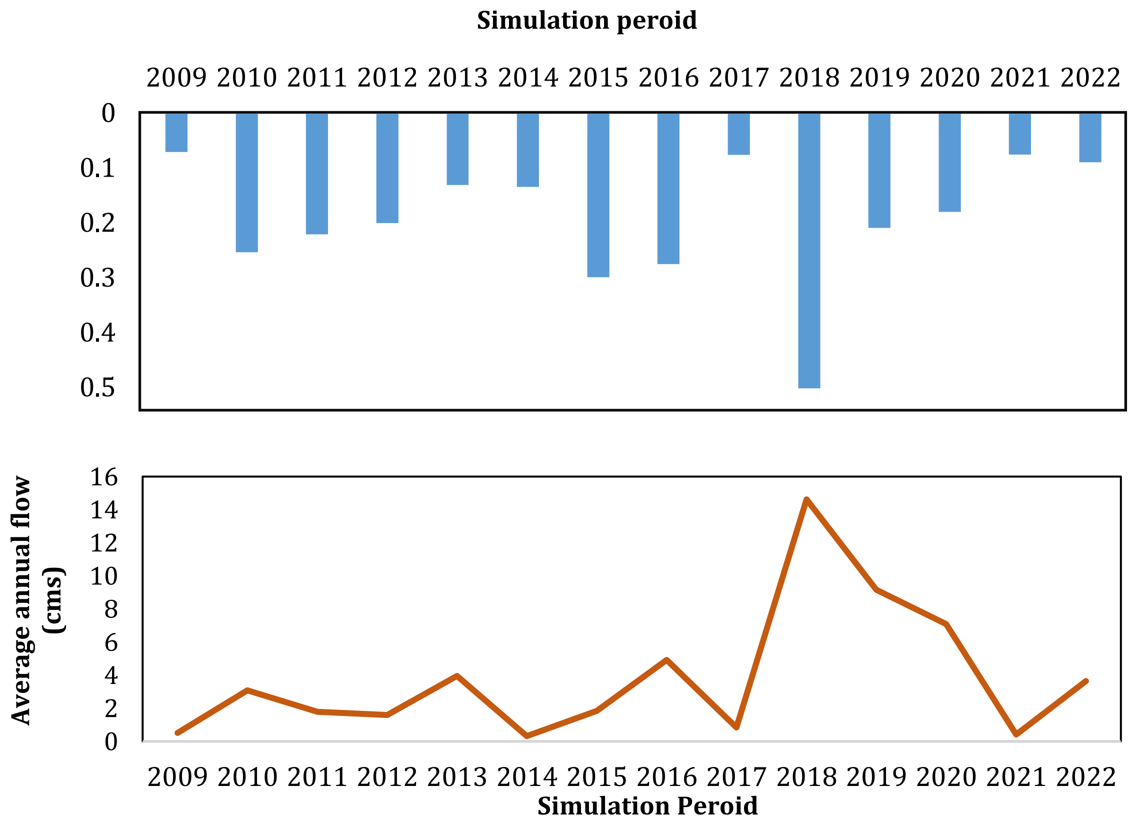

Figure 11. Results of discharges and precipitations during the simulation period.

The maximum and minimum daily flow discharges for the Al-Ghadaf watershed that outflow into Al-Razzaza Lake for the period (2018-2020) were 312.1 m^3/sat 25/2/2020 and zero on 31/12/2020, which considered the flood period, while in the drought period (2009-2017), the maximum and minimum discharges were 228.3 m^3/s at 25/3/2010 and zero discharge at 01/01/2012, respectively. The average runoff volume for the simulation period was 0.37

million m^3. The maximum ET for all watersheds was 4.18 mm, and the rainfall-runoff coefficient was 0.19 **(Suleimany, 2020)**. The longest flow path, subbasin slope, hydrology statistics of land cover, average monthly rainfall, and surface runoff are shown in **Tables 5 to 7**, respectively.

Table 5. Longest flow path and the slope of the subbasins.

Subbasin	Longest flow path (km)	Slope %
1	255.2748	3.373658
2	180.0437	5.379304
3	86.15736	6.6887
4	127.6063	5.395255
5	110.8936	5.641151

Fig. 12 shows the result of the longest flow paths for all the subbasins of the study area. It was noticed that

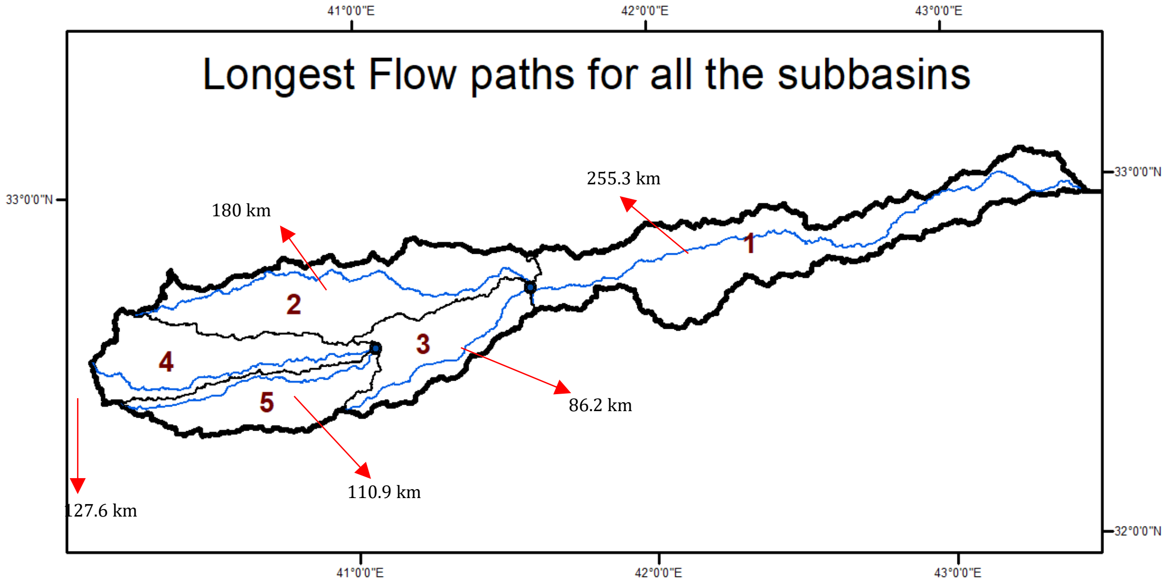

Figure 12. Results of the longest flow paths of the subbasins.

It was concluded that subbasin 1 has the largest flow path, which is equal to 239.9 km, while subbasin 3 has the little one, which is equal to 85.3 km. It was concluded that the surface runoff for the water cover is equal to zero, the curve number of the bare area is the largest one of the others, and the largest area is the bare area.

Table 6. Hydrology Statistic for land cover types by Arc-SWAT.

No.	Land cover	Area km^2	CN	Precipitation mm	Surface runoff depth mm
1	Agricultural Land-Generic	4.47	87	68.8	2.81
2	Agricultural Land-Row Crops	0.39	89	68.8	1.95
3	Bare area	8565.197	94	79.55	15.96
4	Range-Brush	0.08	80	89.71	3.15
5	Water	53.30	92	68.8	0.00

Table 7. Average monthly values of the Al-Ghadaf basin for the simulated period.

Month	Rain mm	Surface runoff mm
1	10.01	1.92
2	14.47	3.83
3	14.42	3.23
4	7.93	1.03
5	3.36	0.36
6	0.06	0.00
7	0.00	0.00
8	0.00	0.00
9	0.20	0.00
10	4.34	0.24
11	12.76	2.14
12	11.82	3.08

Table 7 shows the average monthly rain and average monthly surface runoff for the simulated area. The results proved that the rainfall for June, July, August, and September was too little and equal to zero, and this is due to Iraq's weather conditions, which has very little rain in the summer season. It wasn't possible to perform calibration and verification for the model due to the absence of actual discharges of Al-Ghadaf Valley.

4. CONCLUSIONS

In this study, the Arc-SWAT model was used to estimate maximum discharge and average annual precipitation for the Al-Ghadaf catchment.

1. The maximum daily flow discharge for the Al-Ghadaf catchment was 312.1 m^3/s for the period 2009–2022.
2. The largest area of land cover was for the bare area type, which equaled 8,885.89 km^2.
3. The largest area of soil type was the bare area, which equaled 491 km^2.
4. The maximum surface runoff depth of land cover was for bare area type, which equaled 15.96 mm.
5. There were 14 types of HRU. Subbasins 1, 2, 3, 4, and 5 contain 9, 1, 2, 1, and 1 type of HRU, respectively.
6. It wasn't possible to perform calibration and verification for the model due to the absence of actual discharges in the Al-Ghadaf valley.

NOMENCLATURE

Symbol	Description	Symbol	Description
SW_t	Final water content, mm	Q_{surf}	The amount of the surface runoff per day, mm
SW_o	The initial moisture content of the soil on a day, mm	E_a	Evapotranspiration amount per day, mm
t	The time, days	W_{seep}	Amount of percolation, mm
R_{day}	Precipitation amounts per day, mm	Q_{gw}	Amount of return flow per day, mm

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تخمين السيح السطحي لحوض الغدف باستخدام نموذج Arc-SWAT

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الخلاصة

اصبحت الدراسات الهيدرولوجية أكثر أهمية في السنوات الأخيرة في تخمين تصاريف الاودية والجابيات. تم اختيار حوض الغدف كمنطقة دراسة نظراً لغياب معلومات السيح السطحي لهذا الوادي. يتناول هذا البحث دراسة جابية حوض الغدف باستخدام برنامج Arc-SWAT والتي تعتبر من ضمن برنامج ArcGIS. لم يكن بالإمكان إجراء المعايرة والتحقق للنموذج لعدم وجود التصاريف الفعلية للوادي. بلغت مساحة جابية الغدف 8567.25 كم2 وكانت البيانات المناخية المستخدمة في هذا النموذج عبارة عن ثلاث محطات فعلية وهي الرطبة والرمادي والنخيب ولمدة 13 سنة للفترة من 2009 إلى 2022 ولم يكن بالامكان اختيار فترة أكبر من 13 سنة لأن البعض منها مفقودة او غير مكتملة او يصعب تسجيلها بسبب ظروف البلاد في السنوات الاخيرة في المناطق الواقعة غرب العراق او انها تحتوي على تسجيلات لبيانات شهرية فقط بينما يتطلب البرنامج بيانات يومية أو لساعات معينة خلال اليوم. أظهرت النتائج أن الحد الأقصى لتصريف الجريان اليومي لحوض الغدف الذي يصب في بحيرة الرزازة 312.1 م3/ثا، وكان الحد الأقصى لعمق الجريان السطحي (ملم) لجميع مستجمعات المياه 6.62 ملم، وكان متوسط رقم المنحنى للحوض 88.4.

الكلمات المفتاحية: حوض الغدف، SWAT, GIS, هيدرولوجي، سيح سطحي.