Assessing the Hydrological and Sedimentary Reality of Amman/Zarqa Basin using the Soil and Water Assessment Tool

Taran, A.,[1*] Al-Ghumaid, A.[2] and Al-Mayouf, F.[3]
[1]Department of Applied Geography, Al al-Bayt University, Al-Mafraq, Jordan, E-mail: Taran@aabu.edu.jo
[2]Ministry of Education, Al-Mafraq, Jordan, E-mail: atef05969@gmail.com
[3]Department of Applied Geography, Al al-Bayt University, Al-Mafraq, Jordan
E-mail: drfaisal_almayouf@aabu.edu.jo

Abstract
This study aims at analyzing and simulating the hydrological and sedimentary reality of Amman/Zarqa Basin using the Soil and Water Assessment Tool (SWAT) in order to support hydrological management plans for the basin; make the most of the available water resources in the basin; and build a hydrological database for the basin using climatic and hydrological data rendered by Jordan Meteorological Department. The study found that Amman/Zarqa Basin receives an average rainfall of 293.2 mm/year, the greater part of which is being lost by evaporation as 69.9% of the total precipitation is lost as a result of the actual evaporation process. On the other hand, the surface runoff receives 10.1% of the total precipitation on Amman/Zarqa Basin. The study concluded the need to intensify the reliance on the (SWAT) in the hydrological and sedimentary modeling processes of basins, as its results proved to be effective and efficient in the hydrological management of water basins and in the determination of the quantities of sediments produced by the runoff in the basin. Thus, it helps in determining the extent of feasibility of established hydrological projects such as the King Talal dam and determining the period taken by sediments to fill it.

1. Introduction

Water is the backbone of daily life. It is indispensable due to its multiple uses. It is the main component of any development process. The issue of providing water cannot only be linked to natural factors and conditions. The country's ability to provide its water resources reflects the extent to which it uses and manages water efficiently and effectively. Perhaps the global interest in climate change is primarily due to its impact on water resources, as the surface temperature of the Earth increased in the late nineteenth century between 0.3° and 0.6° and the Earth surface temperature continued to rise over the past forty years in the twentieth century between 0.2° and 0.3° (Houghton et al., 1996). It is noted that this rise in surface temperature varies from one region to another, and this difference is not only limited to temperature, but also includes precipitation amounts (Jaber, 2012).

Jordan is considered one of the poorest countries in water resources, as it is one of the four countries in the world that suffer from weak capacity to provide water resources. The volume of water resources available in Jordan is currently about 800 million m^3, while the demand for water is about 1100 million m^3 and it is expected to reach 1400 million m^3 by the year 2020 (Al-Omari, 2017). This increase in demand for water resources is primarily due to the natural as well as the non-natural population increase resulting from refugees fleeing to a country that suffers from difficulty in providing water resources to its citizens in the first place. This is due to its location within a zone prevailed by arid and semi-arid climate, which is characterized by low and fluctuating rainfall. Perhaps what climate models indicate that the Middle East region will witness a decrease in the amount of precipitation due to an increase in the ratio of carbon dioxide in the atmosphere; the resulting decrease in soil moisture and surface runoff; and the fact that Jordan is one of the world's poorest countries in water resources, are the reasons for choosing this area for study. As well as being one of the tourist areas in Jordan that are visited by tourists and hikers due to its geomorphological and topographical diversity. Therefore, the status of surface and ground water resources in the basin will be simulated using the ArcSWAT extension within the ArcGIS10.5 software environment.

This study came to tackle the hydrological and sedimentary reality in an area suffering from lack of water resources by virtue of its location in a dry region that suffers from high temperatures and lack of rain. And thus, this study puts decision-makers in the current situation, which contributes to establishing effective hydrological management to preserve the scarce water resources in the basin through real-time water projects, whether earth or concrete dams, or the afforestation projects that contribute to increasing the retention of moisture in the soil and reducing its losses in the long run. The main objective of this study is to build a hydrological sedimentary model for the lands of the Amman/Zarqa basin during the period 1985-2020, based on the water budget data, and by using the Soil and Water Assessment Tool (SWAT) in order to simulate and understand the hydrological processes in the basin and estimate the values of the water and sedimentary budget. Since most of the agricultural activities prevailing in the basin lands are rain-fed at times of sufficient quantities of soil moisture, any shortage of irrigation water will lead to low agricultural yield or whole season failure. This makes studying the water budget, identifying, and evaluating its components, an urgent necessity in order to identify the approach taken in similar circumstances. Such approach is usually liked to the formation of a water resources management in ways that guarantee maximizing the returns of water harvesting, and raising the storage capacity of water constructions, on top of which is the King Talal Dam. Not to mention following the best methods for exploiting the basin lands, providing additional water quantities for the irrigation of agricultural units and watering livestock, raising the capacity of pastoral lands, developing the reality of mountain reserves and recharging groundwater for use at times of water demand peak on the one hand and to ward off the risks of flash floods on the other hand. This represents a new environmental reality in which all components take part and contributes to creating multiple developmental investments that benefit the local and thus the national economy.

2. Literature Review

The interest in water resources at the global, regional, and local levels was evident in the diversity and abundance of studies and research that paid the topic special attention. Kusangaya (2015) showed the Intergovernmental Panel on Climate Change that there is a consensus that the increase in greenhouse gases in the atmosphere will lead to climate change that will lead to a rise in sea levels, an increase in the frequency of extreme weather events including severe storms and drought. These effects in turn will increase the frequency of climate-related hazards, causing loss of lives, social disruption, and economic hardship. The study also reviewed the potential impacts of climate change on water resources in southern Africa. Jaber (2012) assessed the effects of climate change on water resources in the Mujib Basin using the Soil and Water Assessment Tool, and the method of cumulative climate change scenarios. The dry scenarios indicate a decrease in surface runoff at a rate of 10% - 30% when the temperature rises by 2 to 4 °C, while the wet scenarios indicate an increase in surface runoff by more than three times the amount.

These include flooding, drought, sea-level rise in estuaries, drying up of rivers, poor water quality in surface and groundwater systems, precipitation and water vapour pattern distortions, and snow and land ice mal-distribution These include flooding, drought, sea-level rise in estuaries, drying up of rivers, poor water quality in surface and groundwater systems, precipitation and water vapour pattern distortions, and snow and land ice mal-distribution. Hallouz et al., (2018) attempted to quantify the drainage and erosion using the Soil and Water Assessment Tool in the Wadi Shalif Basin and concluded that the annual sediment volume increased in the basin due to the increase in the amount of runoff in it than it was in the past. Al-Hassani (2018) studied the potential impacts of climate change on surface water sources in the Amman/Zarqa Basin using the reduced Regional Circulation Model and the Soil and Water Assessment Tool. The study concluded that a decrease is expected in each of the amounts of rainfall between 3.7% and 20.7%; surface runoff between 25% and 47%; water yield between 21.5% and 41.4%. Al-Ghumaid (2019) also studied the impact of expected climate change on the surface and ground water resources within four water basins in Jordan, using Geographic Information Systems and Remote Sensing. The study showed that the surface runoff in the selected water basins is expected to decrease.

Al-Ghonmieen (2018) pointed out the inefficiency of constructing a water dam on the northern Wadi Araba basin. This is due to the formation of large quantities of sediments in that basin, which were verified through the use of the Soil and Water Assessment Tool (SWAT). The main reason for the formation of these sediments was the severe erosion processes associated with low percentage of vegetation cover and soil degradation resulting from precipitation at a rate of up to 300 mm/year in the eastern highlands of the basin, which is characterized by its severe ruggedness and steep cliffs. Saha et al., (2019) assessed the potential impacts of land use change and climate change on the Murrumbidgee Stream in southeastern Australia using the Soil and Water Assessment Tool (SWAT) and by applying three different change scenarios for climate and for land use. The study found that the effect of change in precipitation and temperature was greater than the effect of change in land use. A 10% decrease in the rainfall rate reduced the water flow by 18%, while a 10% decrease in the rate of conversion of pastures to forests reduced the flow by only 1.5%. Francesconi et al., (2016) aimed in this study to provide an overview of the efforts made using SWAT to define ecosystem services, determine the model's ability to examine different types of services, and describe how SWAT is used by many researchers.

The Soil and Water Assessment Tool (SWAT) has been applied because of its multiple components and functions that are useful in constructing and simulating the water and sediment budget and its processes in water basins lands in line with the impact of climate change, the growth of different agricultural crops, and land management practices. In addition to what has been achieved to confirm the efficiency and reliability of (SWAT) results in many regions around the world (Abdelhamid et al., (2011), Ashagre (2009), Cambien et al., (2020) Schuol et al., (2008) and Shimelis et al., (2008)), including the arid and semi-arid environments to which the Jordanian lands in general belong (Farhan and Althamiry, 2020, Al-Rawashada, 2004, Ananza 1996, Ayad et al., 2016 and Iwan et al., 2017).

3. Study Area

The Amman-Zarqa Basin is located in the northwestern side of Jordan between latitudes 31° 54′, 32° 24′ N and longitudes 35° 42′, 36° 36′ E. The area of the basin is about 4123.9 km^2. With its wide extension, (7%) of its total area enters the Syrian lands from the northern sides. the majority of the basin area (93%) is located in Jordan which represents 3835.3 km^2. The Amman-Zarqa Basin is bordered by Al-Azraq basin on the east, Al-Azraq and Al-Mojib basins on the south, the basins of the Al-Ghor eastern valleys on the west, and Al-Yarmouk basin on the north (Zghoul, 2016). Figure (1A) shows the location of the study area.

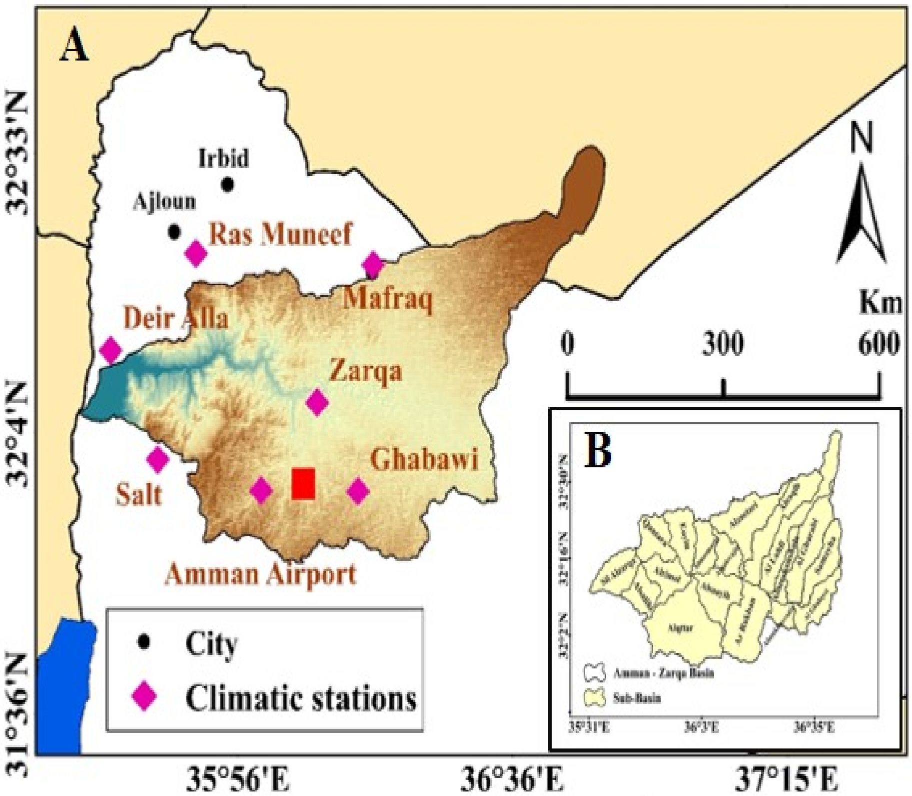

Figure 1: Amman/Zarqa Basin. (A) The location of the study area and climatic stations located, (B) The subsidiary basins in the Amman/Zarqa Basin

The Amman-Zarqa Basin is one of the important tributaries of the Jordan River in terms of area and amount of river discharge (Abu Samour, 1998). Heights levels vary in the Amman-Zarqa Basin where the highest level is about 1577 m. in the Syrian territories, and the lowest level is about -366 below sea level at the downstream region of the Jordan River. This indicates that the basin has a sharp rugged topography with ruggedness index reaching 1943 m. Moreover, there is a clear climatic variation in the basin areas. The dry climate prevails in the Jordan Valley and the eastern regions which are represented by the Jordanian Badia, while the highlands regions have semi-humid climate. In general, the climatic conditions in the Amman-Zarqa Basin are naturally an integral part of the climatic conditions of Jordan, where winter is the season of rainfall in the basin. This is because the basin is located within the temperate zone in winter, and within the tropical zone in summer (Shehadeh, 1991). Figure 3(A) shows a gradual decrease in the amount of precipitation in the basin from west to east. This could be attributed to the variation in the topography of the basin, the land cover and its uses, in addition to the fact that the eastern regions of the basin fall within what is known as the rain shadow regions.

As for temperatures in the basin, they are naturally a reflection of the climatic regions in the basin. The eastern regions and the Jordan Valley witness a remarkable rise in the annual average temperature of more than 20°C. This is because they are located in the dry region. On the other hand, the highlands regions with the semi-humid climate witness moderate annual average temperature of less than 17°C. These highlands are represented by the regions of Ajloun and Jerash (Zghoul, 2016). There is a great diversity in soil types in the basin regions. The results of the National Soil Map and Land Use Project carried out by Hunting Technical Services Ltd in cooperation with the Jordanian Ministry of Agriculture in 1993 showed that the basin region includes 12 soil textures. This variation is due to the different geological structures, the morphology and topography of the basin and the prevailing climatic conditions. This resulted in a difference in the hydrological and physical properties of the soil in terms of its impact on the runoff values in the basin, such as the field capacity and the wilting point in the soil, which affect the extent of soil moisture retention. The more moisture the soil can retain, the higher the runoff (Abed, 2009).

Accordingly, the soil in the basin area is classified into three categories: 1. The sandy soil spread in the southern and eastern regions, which constitutes (13.4%) of the lands of the basin. 2. Clay soil, located in four main areas: the far western part, the area adjacent to the central area, and some spatial spots on the eastern and southern sides of the basin. These areas represent (19.8%) of the total area of the basin. 3. Alluvial soil which is the most prevalent in the basin, as it is present in its various regions, constituting (66.8%) of the total area of the basin (Ministry of Water Agriculture, 1993). Figure 3(I) shows the types of soil in the Amman-Zarqa Basin region.

4. Materials and Methods

4.1 Data Resources

In analyzing and assessing the hydrological and sedimentary conditions in the Amman/Zarqa Basin using (SWAT), the study relied on the following resources:

1. Maps of all kinds, shapes, and scales, including:
   a. Topographic Maps (1997), namely: the plates of Umm Al-Quttain, Umm Al-Jimal, Amman, Jerash, Qasr Al-Manshiah, Sweileh, Al-Mafraq, Qasr Al-Hallabat, Qusair Amra, Al-Hamidiyah, Sabha and Salt, within a scale of (1: 50000) (Royal Geographical Center, 1997).
   b. Soil Map (1993), namely: the plates of Umm Al-Quttain, Umm Al-Jimal, Amman, Jerash, Qasr Al-Manshiah, Sweileh, Al-Mafraq, Qasr Al-Hallabat, Qusair Amra, Al-Hamidiyah, Sabha and Salt, within a scale of (1: 50000) (Ministry of Water Agriculture, 1993).
   c. Geological Maps (1997), namely: the plates of Umm Al-Quttain, Umm Al-Jimal, Amman, Jerash, Qasr Al-Manshiah, Sweileh, Al-Mafraq, Qasr Al-Hallabat, Qusair Amra, Al-Hamidiyah, Sabha and Salt, within a scale of (1: 25000) (Natural Resources Authority, 1997).
2. Digital Elevation Model (DEM) with 30m discrimination capacity, provided by the US Geological Survey with the aim of deriving the water basins selected in this study, and the degrees of surface slope. (https://earthexplorer.usgs.gov/).

3. Satellite imagery provided by the Sentinel 2 satellite with a discrimination capacity of 10m with the aim of classifying or identifying the land cover and its usage patterns. The land cover and its uses for the Amman/Zarqa basin were extracted according to Table 1.

Table 1: Classification of the land cover and its uses in the Amman/Zarqa Basin

NO	Class	Description
1	Urban Areas	Includes residential, commercial, industrial and commercial areas.
2	Vegetation	It includes all agricultural lands, whether rainfed or irrigated, in addition to the natural vegetation cover
3	Pasture	It includes the lands that contain grazing plants, which are designated for grazing animals.
4	Barren Lands	Lands that lack any semblance of plant life.
5	Basalt Land	It includes volcanic regions, and lands with bare rocks.
6	Dams	Representing reservoirs and water harvesting projects.

4. Climatic data that include daily rainfall amounts, daily maximum and minimum temperatures, and solar radiation for stations located in the Amman/Zarqa basin, for the period from 1985 to 2020. These climatic stations are divided with their general characteristics, and they belong to the Meteorological Department (Jordan Meteorological Department, 2020).

4.2 Software Used

The study used the following software to address its topic:

1. Geographic Information Systems (GIS), especially the ArcGIS 10.5 software was used in performing geo-corrections for paper maps and converting them into digital maps; determining the selected water basins and their role in the process of cartographic output.
2. The ArcSWAT 2012 for basin simulation and modeling. The Soil and Water Assessment Tool is both a climatic and hydrological model in terms of its reliance on daily climatic data for several elements, namely temperature, rain, relative humidity, solar radiation, wind speed and direction, in assessing the current hydrological situation of the water basin. This model also enables users to make future predictions of climate elements and employ them in the water basin modeling process, with the aim of conducting projects and implementing future water plans and strategies in light of these forecasts. The Soil and Water Assessment Tool was developed by the Department of Agricultural Research and Research Center at the University of Texas in the United States of America in the early 1990s (Bell, 2015). They aimed to develop a model capable of assessing the long-term impact of land management and use on the amount of water contained in both large and small water basins.
3. ERDAS IMAGINE 2016 software for classification of land covers and their use.
4. Microsoft Excel 2016 software for creating graphs of hydrological and climatic variables.

4.3 Study Procedures

4.3.1 Data collection

The modeling process for the current and future hydrological reality in light of the cumulative climate change scenarios includes a number of stages, namely: reviewing the previous studies; then preparing and arranging the study data obtained from various sources before processing them with SWAT, through engineering and radiological correction of space images; converting data and paper maps into digital and classifying them, so that they can be easily dealt with using a computer, such as geological maps and some climatic elements. The study also dealt with the missing data, whether climatic data or runoff, by filling it with the number -99 so that the tool recognizes that these data are missing.

4.3.2 Weathered delineation and HRU definition

After that, the basin determining stage comes in the following two ways: 1. Analyzing topographic maps using geographic information systems (GIS) software or using the digital elevation model (DEM) directly through the Hydrology tool within Spatial Analysis. After determining the external boundaries of the basin, the tributaries, the outlet, and the sub basins are extracted; then the spatial and topographic variables are calculated. This stage and the following one were carried out using the ArcSWAT 2012 extension. 2. Determining the hydrologic response units (HRUs), which refer to the lands within the basin that consist of vegetation cover, lands, soil and a homogeneous management group (Al- Ghonmieen, 2018). These units are determined by dealing with three main variables, namely: the classification of land cover and its uses, according to a custom classification used by the Soil and Water Assessment Tool (SWAT Land-use Classification). After obtaining the satellite images representing the study area, they were combined into a single image in what is known as the (Mosaicking) process. Then, the image enhancement and classification processes were carried out using ERDAS IMAGINE 2016 software, based on the supervised classification method, according to the Maximum Likelihood Classification, which is characterized by higher cell classification accuracy. Whereby each of the cells is assigned to the class that it has the highest probability of belonging to, based on the reflection values of these cells (Ghaith, 2010). The lands of the Amman/Zarqa basin were classified according to the SWAT Land Use Classification system, with some modifications made to suit the conditions of the study area. Training areas, which represent the types of land covers and their uses in the Amman/Zarqa basin were used in order to classify the basin lands according to them through their reflective values. Then comes the second variable which is related to soil classification according to texture, based on several models, such as the International Food and Agriculture Organization (FAO) classification which is adopted by this study; as the soil maps in Jordan depend on this type of classification. Or the American classification on which the model is based. The (FAO) classification is entered to the SWAT model database in order for the model to recognize it and be easy to deal with in terms of the physical properties of the soil types in the Amman/Zarqa basin. The third variable is related to the slope classification. After introducing the requirements and the variables of determining the (HRUs) to SWAT, an overlay is made between the three maps resulting from the determination of those variables, and a map showing the (HRUs) is produced.

After the previous stages comes the important stage, which is making the climatic stations of the water basin and making them be recognized by the SWAT model extension through the Access software. The SWAT model was built based on that the water basin includes at least two climatic stations, so the readings of the stations of the Meteorological Department were relied upon. Figure (1A) shows the climatic stations located within the lands of the Amman/Zarqa basin.

4.3.3 Create SWAT database

After performing this step, the SWAT database is created according to the previous variables, and then potential evapotranspiration (PET) calculating method is determined according to the Hargreaves method. Given the importance of this element, the SWAT model contains three computational methods for calculating the (PET), which allows the user to choose the appropriate method in light of the available climatic elements, in addition to the ability to add a file containing calculated values of evaporation. These methods are the Penman-Monteith, the Priestly-Taylor, and the Hargreaves method which is mainly based on air temperature and will be relied upon in this study due to the availability of all its climatic inputs. Hargreaves method is represented in the following equation (Weib and Menzel, 2008):

$$Erc = 0.002 * Ra * \boldsymbol{\delta}\, \mathrm{T}^{0.5} * (T + 17.8)$$

Equation 1

Where ***Erc*** represents potential evaporation based on the Hargreaves equation mm/day; ***Ra*** is the average daily solar radiance (MJ/day); ***δ*** is the difference in temperature C (monthly average maximum temperature - average minimum temperature); and ***T*** is the average air temperature. The SWAT simulates the volume of runoff and the maximum runoff rates for each HRU using daily rainfall quantities according to the Soil Conservation Service Curve Number (SCS-CN) method, which can be mathematically represented as follows (Mosbahi et al., 2013):

$$\mathrm{Q} = \frac{(\mathrm{R}-0.2\mathrm{s})^2}{(\mathrm{R}+0.8\mathrm{s})} \qquad \mathrm{R} > 0.2\mathrm{s}$$
$$\mathrm{Q} = 0.0 \qquad \mathrm{R} \leq 0.2\mathrm{s}$$

Equation 2

Where ***Q*** represents the daily runoff (mm); ***R*** is the daily precipitation (mm); and ***S*** is the water storage of the basin. The water storage varies among the basins due to the combination of several factors: soil, land use and management, and slopes. The water storage of the basin is related to the curve number (CN) by the SCS equation which can be represented mathematically as follows (Mosbahi et al., 2013):

$$S = 254\left(\frac{100}{CN} - 1\right)$$

Equation 3

4.3.4 Run SWAT

After all the previous stages, the model is executed (run) in order to make maps that illustrate each of the elements of the surface water budget and the groundwater budget, as well as tables and charts that represent the statistical properties of these variables. The water cycle can be represented using the SWAT model depending on the water budget equation, as shown below (Hallouz et al., 2018):

$$SWt = sw0 + \sum_{i=1}^{i=t}(Rday - Qsurf - Ea - Wperc - Qgw)$$

Equation 4

Where ***SWt*** and ***SW0*** represent the initial and final water content in the soil, respectively. The initial soil moisture source was obtained through digital soil maps prepared by the Ministry of Agriculture, in the form of digital files (Shapefile). Those files include the physical characteristics of each soil type in Amman/Zarqa Basin, such as the field capacity and the wilting point.

The ***Rday*** symbol refers to the daily amounts of precipitation, while the surface runoff in the equation is represented by the symbol ***Qsurf***. The equation also included the evaporation component, which is the main element in the water budget, represented by the symbol ***Ea***; the percolation represented by the symbol ***Wperc***; and the symbol ***Qgw*** refers to the return of the flow. All elements are measured or recorded in mm/day. The ***t*** symbol represents the time period in days. The steps of the SWAT model can be represented as in Figure 2.

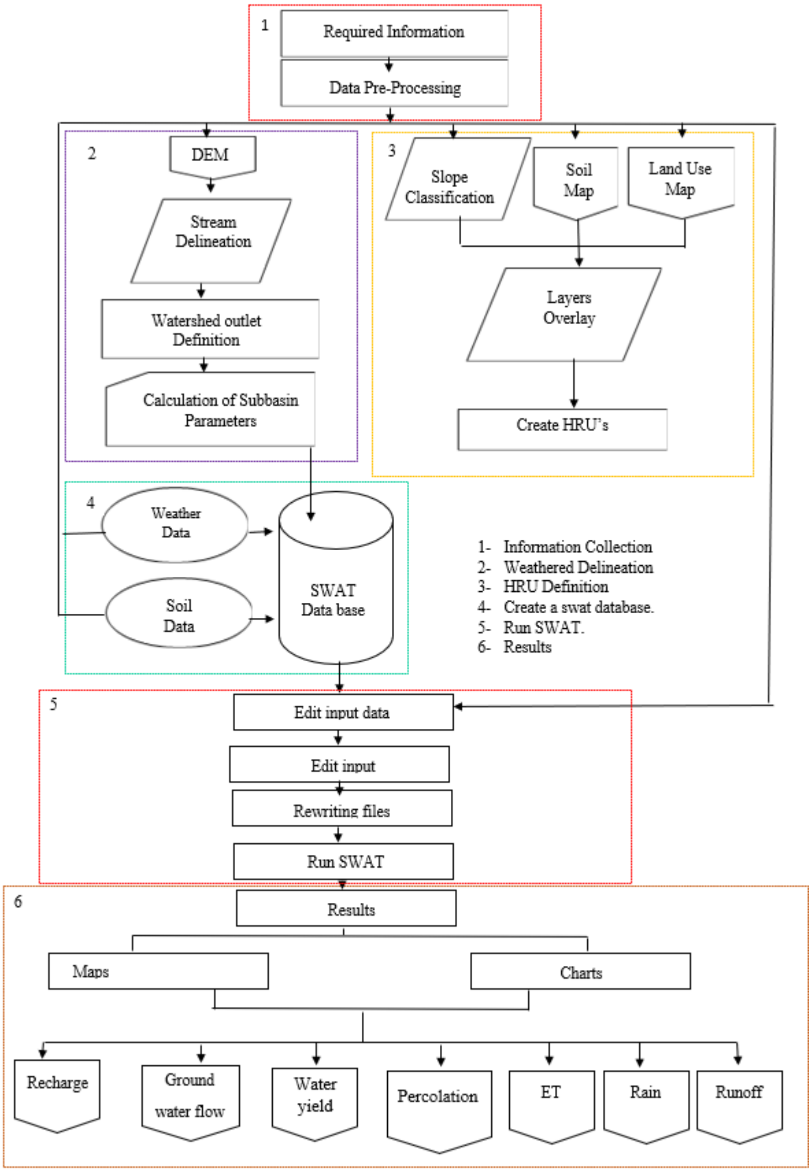

Figure 2: Representation of the steps of the Soil and Water Assessment Tool (SWAT)

ISSN 2673-0014 (Online) / © Geoinformatics International

5. Results and Discussion

The current simulation of Amman/Zarqa Basin includes simulating the hydrological reality in the basin, whether the water budget is surficial such as the amounts of precipitation, the actual and latent evaporation, and the surface runoff; or underground such as percolation and underground runoff. The current simulation also includes simulating the sedimentary status in the basin. There are some shared results between the surface and underground water budget represented by the subsidiary basins and the hydrologic response units (HRUs). The water basin was divided into several subsidiary basins and into (HRUs). Through the application of the SWAT, it was found that the Amma/Zarqa basin contains 18 sub-basins and 230 hydrologic response units at the 5% threshold level for soil, slope, and land use. Figure 1(B) shows the subsidiary basins in the study area.

5.1 Simulation of the Surface Water Budget

The surface water budget includes several variables that control the amount of water deficit or surplus, as it is a dynamic equilibrium process between what is gained through precipitation and what is lost through evaporation and transpiration (Zagul, 2016). This simulation includes the following elements:

5.1.1 Precipitation

Precipitation is the main element of the water budget in any water basin due to the dependence of the rest of the budget elements on it, especially the actual evaporation and runoff. Moreover, some riverine processes depend mainly on the amounts and intensity of precipitation, such as river erosion of all kinds, soil erosion and landslides. The SWAT revealed that the average amount of precipitation during the study period was about 293.2 mm. The model also showed a temporal variation during the months of the year within the study period, as the basin received the most rainfall in January with a value of 63.3 mm, while the summer months during the study period lacked any amounts of rain. Figure 4(A) shows the temporal variation of the rainfall rate in the Amman/Zarqa Basin during the study period. The SWAT results also showed that twelve of the eighteen sub-basins in the Amman/Zarqa Basin have an average annual precipitation of less than 194.4 mm, for the year 2020. Those sub-basins are located in the southern, southeastern, eastern, and northeastern sections of the Amman/Zarqa Basin. As for the remaining six sub-basins, the average annual precipitation was more than 194.4 mm. Two of them are located in the western part of the main basin, and the last sub-basin is located in the north and northwestern sides of the main basin. Figure 3(B) shows the spatial variation of the average areal precipitation among the sub-basins in Amman/Zarqa Basin for the year 2020.

5.1.2 Evaporation

Evaporation is defined as the transformation of water from liquid state to gaseous state. It is an important and basic process in the thermal equilibrium between the Earth's surface and the atmosphere (Oruod, 2002). Evaporation is divided into two main types: Actual Evaporation and Potential Evaporation. The SWAT showed that the rate of the actual and potential evaporation in the Amman/Zarqa Basin was 205 mm and 1521.2 mm respectively, during the period between 1985 and 2020. However, these values vary temporally (during the months of the year) and spatially (within the sub-basins). Moreover, the temporal and spatial distribution values of the actual and potential evaporation are described as varying. The highest value of the actual evaporation rate was in June (66.3 mm), while the highest value of the potential evaporation rate was in July (215.2 mm). As for the lowest value of the actual evaporation rate, it was 1.01 mm, while the lowest value of potential evaporation rate was 42.94 mm during December. Figure 4(B) shows the values of the actual and potential evaporation rate in the Amman/Zarqa basin during the study period. As for the spatial variation in the actual evaporation values for the year 2020 among the sub-basins of Amman/Zarqa Basin, it became clear that the northern basins especially the northwestern, the western, and the southwestern basins have higher actual evaporation values than the eastern, the north-eastern, and the south-eastern basins. This is due to the fact that the northern basins especially the northwestern, the western, and the southwestern basins have a higher average rainfall than the eastern, the northeastern and southeastern basins. Figure 3(C) shows the spatial variation in the actual evaporation values for the year 2020 in the Amman/Zarqa Basin.

5.1.3 Runoff

Runoff is the final process after rain reaches the surface of the earth and is lost by evaporation, percolation, and absorption by the vegetation. The surface runoff rate reached 29.47 mm over the study period extending from 1985 to 2020. However, the value of surface runoff varies during the months of the year, as it reached its highest value in February of 7.65 mm, while its lowest value was during the summer months.

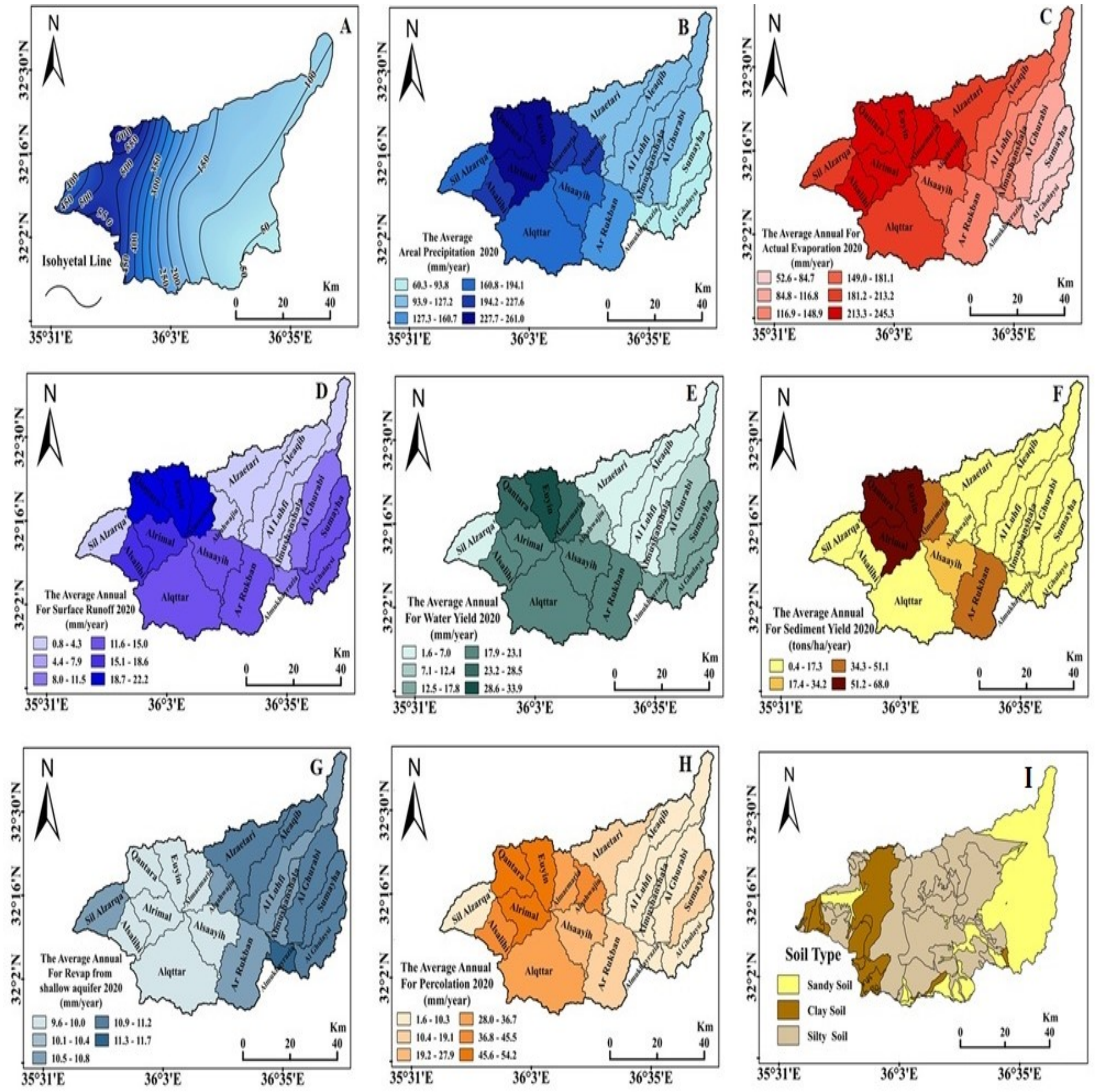

Figure 3: (A) Spatial distribution of rainfall. (B) Spatial variation of the average areal precipitation among sub-basins. (C) Spatial variation in the actual evaporation rate among the sub-basins. (D) Spatial variation in runoff rate among sub-basins. (E) Spatial variation in the water yield rate among the sub-basins. (F) Spatial variation in the sediment yield rate among the sub-basins. (G) Spatial variation of the average amount of water returned to the surface among the sub-basins. (H) Spatial variation in the water percolation rate among the sub-basins. (I) Types of Soils in the Amman/Zarqa Basin

Figure 4(C) shows the temporal variation of the runoff rate in the Amman/Zarqa Basin during the study period. As for the spatial variation in the runoff values among the sub-basins of the Amman/Zarqa Basin for the year 2020 AD, it became clear that the southern and eastern basins have lower surface runoff values than the northern and northwestern basins. This is due to the fact that the northern and northwestern basins have a higher rainfall rate than the southern and the eastern basins. Figure 3(D) shows the spatial variation of the surface runoff rate among the sub-basins of the Amman/Zarqa Basin.

5.1.4 Water yield

Water yield is the final outcome of the water falling on the basin and utilized for various uses (Al-Ghumaid, 2019).

ISSN 2673-0014 (Online) / © Geoinformatics International

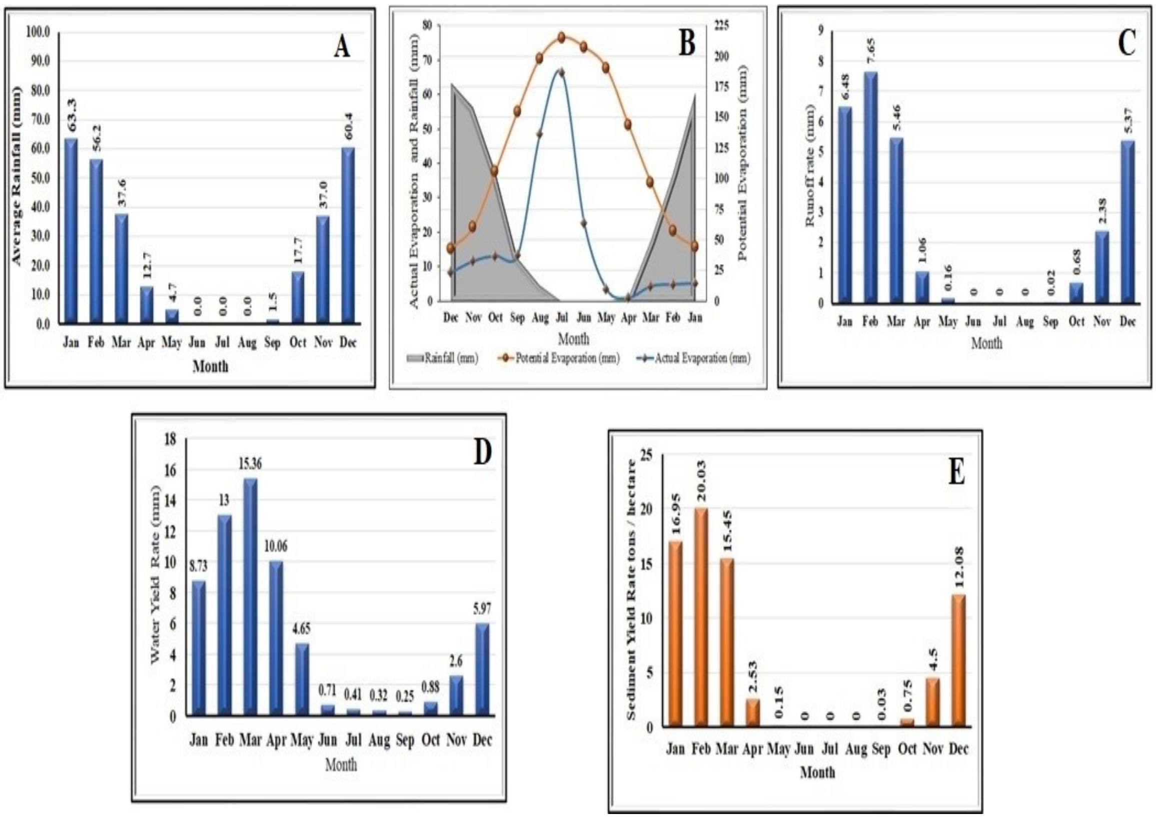

Figure 4: (A) Temporal variation of the average rainfall. (B) The values of actual and potential evaporation and precipitation rates. (C) Temporal variation in the runoff rate. (D) Temporal variation in the water yield rate. (E) Temporal variation in the sediment yield rate in the Amman/Zarqa basin during the study period.

The water yield is affected by several climatic conditions that have contributed to a clear variation among the water basins. Some of these conditions include temperatures and amounts of annual precipitation, as well as the nature of the land cover and its uses, and the quality of soil and rocks. The SWAT showed that the rate of water yield in the Amman/Zarqa Basin during the study period was 63.55 mm. However, this value varies throughout the months of the year within the study period, as its highest value was in March 15.36 mm, while the lowest value was in September 0.25 mm. Figure 4(D) shows the temporal variation of the water yield rate in the Amman/Zarqa Basin during the study period. As for the spatial variation among the sub-basins of the Amman/Zarqa Basin in terms of water yield values for the year 2020, it became clear that the eastern and southeastern basins have lower values than the northern and northwestern basins, and this is due to the fact that the northern and northwestern basins have a higher rainfall rate than the southern and eastern basins. Figure 3(E) shows the spatial variation in the water yield rate among the sub-basins of Amman/Zarqa Basin.

5.1.5 Sediment yield

Sediment yield is considered one of the important variables and processes in water basins. This is due to its contribution to the process of sedimentation along the course of the river valley, especially if a water dam was constructed across its course. Thus, the sediment load shown by the results of the SWAT is considered a very important finding, especially for the decision-making processes. The SWAT results showed that the sediment load rate in the Amman/Zarqa Basin was 73.06 tons/hectare. This value varied throughout the months of the year, as the highest value was 20.03 tons/hectare in February, while it was absent during the summer months. Figure 4(E) shows the temporal variation in the sediment yield rate in the Amman/Zarqa basin during the study period. As for the spatial variation in the sedimentary yield values among the sub-basins of the Amman/Zarqa Basin for the year 2020, it became clear that the eastern, northeastern, southeastern, western, and southwestern basins have lower values than the northern and northwestern basins. This is due to the fact that the northern and northwestern basins have a higher surface runoff rate than the other basins. Figure 3(F) shows the spatial variation in the sediment yield rate among the sub-basins of the Amman Zarqa Basin.

5.2 Simulation of the Groundwater Budget

The groundwater budget refers to a number of variables that are included in its calculation and can be summarized in the following variables:

5.2.1 Revamp from shallow aquifer

It is the water returned to the earth surface (Evaporated water from the subsurface layer) due to the osmotic process, which accounts for the movement of water through the membranes from areas of high water density to areas of low water density (Al-Ghumaid, 2019). The results obtained from the SWAT show that the average amount of water returning to the surface was 28.41 mm during the study period. The variation among the sub-basins of the Amman/Zarqa Basin in terms of the re-surfaced waters in 2020 is clear. This is due to the fact that the eastern, northeastern, and southeastern basins have higher evaporation rates from the subsurface layer compared to the central, northern, northwestern, and southwestern basins due to the lack of rainfall in them. Figure 3(G) shows the spatial variation of the average amount of water returning to the surface among the subsidiary basins of Amman/Zarqa Basin.

5.2.2 Water percolation

Percolation refers to water penetration from shallow aquifers into deep aquifers other than the infiltration, which refers to water filtration into shallow aquifers (Al-Ghumaid, 2019). In other words, the infiltration does not go beyond the root zone, while the percolation goes beyond the roots zone and reaches the shallow aquifer. Water percolation is affected by several climatic conditions that have contributed to creating a clear variation among the studied basins. Some of these conditions include temperatures and amounts of annual precipitation, as well as the nature of the land cover and its uses, and the quality of soil and rocks. It was found that the rate of water percolation during the study period in the Amman/Zarqa Basin was 55.22 mm. However, this value varies among the sub-basins. We note that in most of the basins located in the eastern, northeastern, southern, and southeastern regions (11 basins), the percolation rate varied between 1.6 and 27.9 mm during the year 2020. Whereas the maximum value of water percolation in the sub-basins located in the northwestern parts of the Amman/Zarqa Basin ranged between 45.6 and 54.2 mm. The reason for this is the significantly higher rates of precipitation in the northwestern basins than in the rest of the other basins. Figure 3(H) shows the spatial variation in the water percolation rate among the sub-basins of the Amman/Zarqa Basin.

5.2.3 Groundwater flow

Groundwater flow is the flow of water within the sub-surface layer extending from the root zone to the deep groundwater. The groundwater flow is controlled by the presence of impermeable layers or the presence of saturated layers, which allow the underground water to flow through layers, faults, and rock joints. The groundwater flow is divided into two main parts: the lateral flow which occurs within the roots zone due to the presence of a layer saturated with water preventing water from being absorbed or leaking towards the interior; thus, causing ground flow. The second part is the return flow, which is the flow of fresh groundwater towards the surface water. The reason for this flow is the interception of the water vertical flow by an impermeable layer known as the Confining Layer, which is a layer separating the shallow groundwater and deep groundwater layers. The lateral flow and the return flow rates in the Amman/Zarqa Basin during the study period were 2.37 mm and 28.96 mm, respectively.

5.2.4 Groundwater recharge

Groundwater recharge is the quantities of water leaked into the ground and supplying the aquifers. It is affected by several natural factors, including climatic conditions, the type of geological formations in terms of porosity, permeability, gravity, capillary characteristic, and vegetation cover. Moreover, Groundwater recharge is affected by several human factors such as the expansion of drilling wells and other activities such as urban expansion and constructing dams (Abu Samour and Al-Khatib, 1999). The average amount of ground recharge in the Amman/Zarqa Basin was 2.76 mm.

All the previous results can be summarized in the figures produced by the SWAT through its ArcSWAT appendix within the ArcGIS environment. Those figures provide a realistic representation of the nature of the hydrological cycle in the water basins. Moreover, they present the nature of the sedimentary reality in those basins during the study period. Figure (5) shows the modeling of the hydrological and sedimentary reality in the Amman/Zarqa Basin during the study period. Table (2) shows the water budget items in the Amman/Zarqa Basin.

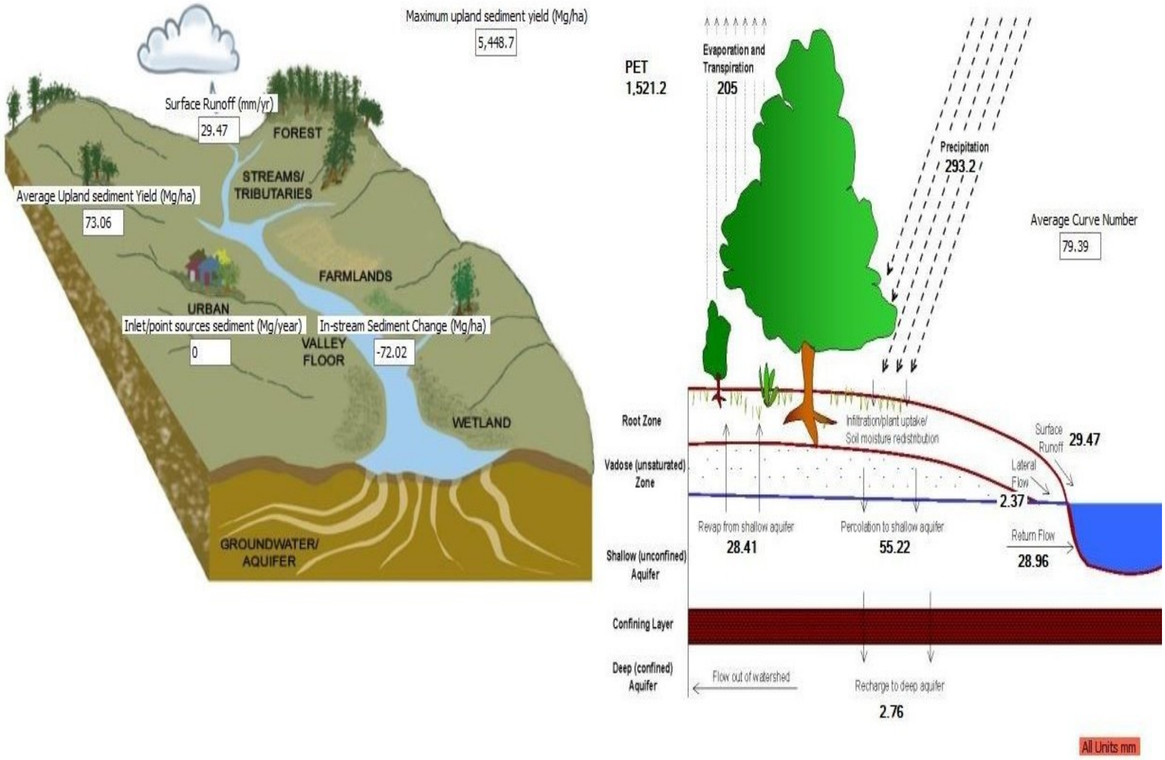

Figure 5: Values of the hydrological and sedimentary modeling in the Amman/Zarqa basin during the study period. Source: Prepared by the researchers based on SWAT results

Table 2: Water budget items in the Amma/Zarqa Basin

No	**Surface Water Budget**		
1	Rain (mm/year)		293.2
2	Evaporation	Actual (mm)	1521.2
		Potential (mm)	205
3	Runoff (mm)		29.47
4	Water Yield (mm)		63.55
Underground water Budget			
5	Revap		28.41
6	percolation		55.22
7	Groundwater Flow	Lateral Flow (Mm)	2.37
		Return Flow (Mm)	28.96
8	Recharge		2.76

6. Conclusion

The study showed the effectiveness of the SWAT in simulating the surface and groundwater hydrological reality, and the sedimentary reality with high efficiency. This contributed to building a hydrological and sedimentary database for the Amman/Zarqa Basin through the ability of the SWAT to produce accurate hydrological information and data. which in turn contributes to achieving optimal hydrological and soil resources management. Where an accurate simulation of the hydrological and sedimentary reality assesses the risks of soil erosion by determining the most appropriate land use and adopting the most appropriate measures of soil conservation. It also contributes to increasing the utilization of the available water resources.

The results of the study also revealed that the northwestern and western sub-basins have higher rainfall rate than the eastern basins. And that the highest rate of the actual evaporation was during the month of June, while the highest rate of the potential evaporation was during the month of July. It was also found that the northern basins have higher Actual Evaporation rates than the southern and eastern basins. The results showed that the highest water yield was in March. Furthermore, the spatial variation of the water yield corresponds with the spatial variation of the two elements of evaporation and precipitation, as the northern sub-basins of the Amman/Zarqa Basin had a greater water yield than the southern and eastern basins due to the high rates of precipitation in them. As for the sedimentary reality, the results showed that the volume of sediments in the Amman/Zarqa Basin according to the results of the SWAT was about 73.06 tons/hectare. Its maximum value was during the winter period, especially in February, due to the long period of rainfall in Jordan, which results in soil erosion by various kinds of surface runoff. Moreover, the spatial distribution of the sediment yields also coincided with the spatial distribution of the surface runoff, as the northern and central basins had greater sediment yield compared to other basins.

The study recommends intensifying the reliance on the SWAT in the hydrological and sedimentary modeling processes of water basins because of the effectiveness and efficiency of its results in the hydrological management of the water basins. It also provides crucial data for determining the quantities of sediments produced by the runoff in the basin, which helps in determining the feasibility of establishing water projects such as dams and determining the period it takes to be buried with sediments.

References

Abdelhamid, F., Hassan, R., Abdelhadi, K., Youness, K. and Omar, A., 2011, Hydrologic Modeling of the Bouregreg Watershed (Morocco) using GIS and SWAT Model, *Journal of Geographic Information System*, Vol. 3, 279-289. doi:10.4236/jgis. 2011.34024.

Abed, A., 2009, *Jordan's Geology, Environment and Water*. 2nd Ed, Jordan Geologists Syndicate, Scientific Book Series, Amman.

Abu Samour, H., 1998, Water Drainage in Zarqa River. *Damascus University Journal for Arts and Humanities*, Vol. 13(4). 185-213.

Abu Samour, H. and Al-Khatib, H., 1999, Geography of Water Resources, Dar Safa: Amman.

Al-Ghumaid, A., 2019, *The Impact of Climate Change on Water Resources within Four Water Basins in Jordan using GIS and Remote Sensing*. Ph.D Thesis, University of Jordan, Amman, Jordan.

Al-Ghonmieen, T., 2018, *Water Resources Assessment in Northern Wadi Araba Basin using Geographic Information System and Soil and Water Assessment Tools*. Ph.D Thesis, University of Jordan, Amman, Jordan.

Al-Hassani, I., 2018, *Potential Impacts of Climate Change on Surface Water Resources of Amman-Zarqa Basin using Downscaled Regional Circulation Model and Soil Water Assessment Tool*. M.A Thesis, Hashemite University. Zarqa- Jordan.

Al-Omari, A., 2017, *Assessment of Water Resources in the Wadi Shoaib Basin using Hydrological Models, Remote Sensing Techniques and Geographic Information Systems*. M.A Thesis, Yarmouk University, Irbid, Jordan.

Al-Rawashada, Sh., 2004, *Efficiency of Irrigation Water use in the Central Karak Valley Basin.* M.A Thesis, Muta University, Karak, Jordan.

Ananza, A., 1996, Water Balance Based on Rainfall Rates and Potential Evapotranspiration in the Karak Valley Basin. *Muta Research and Studies,* Vol. 11(5), 149-169.

Ashagre, B., 2009, *SWAT to Identify Watershed Manage- ment Options: Anjeni Watershed, Blue Nile Basin, Ethiopia*. M.A Thesis, Cornell University, New York.

Ayad, S., Mustafa, S., Oleiwi, S. and Omar, M., 2016, Application of SWAT Model for Sediment Loads from Valleys Transmitted to Haditha Reservoir. *Journal of Engineering*; Vol. 22(1), 184-197.

Bell, S., 2015, *Implementing the Soil and Water Assessment Tool for the Puyallup River Watershed of Washington State: A Feasibility Assessment*. M.A Thesis, The Evergreen State College.

Cambien, N., Gobeyn, S., Nolivos, I., Forio, M. A. E., Arias-Hidalgo, M., Dominguez Granda, L., Witing, F., Volk , M. and Goethals, P. L. M., 2020, Using the Soil and Water Assessment Tool to Simulate the Pesticide Dynamics in the Data Scarce Guayas River Basin, Ecuador. Water 2020, Vol. 12(696),1-21. https://doi.org/10.3390/w12030696.

Farhan, A. and Althamiry, H., 2020, Estimation of the Surface Runoff Volume of Al-Mohammedi Valley for Long-Term Period using SWAT Model. *IRAQI Journal of Civil Engineering*, Vol. 014–001, 7-12. https://www.iasj.net/iasj/-download/4361fce17db3764a.

Francesconi, W., Srinivasan, R., Minana, E., Willcock, S. and Quintero, M., 2016, Using the Soil and Water Assessment Tool (SWAT) to Model Ecosystem Services: A Systematic Review. *Hydrology Journal,* Vol. 535, 625-636.

Ghaith, D., 2010, *Land Degradation Assessment in the area Send Dhuliel Using Satellite.* M.A Thesis, University of Jordan, Amman, Jordan.

Hallouz, F., Meddi, M., Maha, G., Alirahmani, S. and Keddar, A., 2018, *Modeling of Discharge and Sediment Transport Through the SWAT Model in the Basin of Harraza (Northwest of Algeria).* Water Science, Vol. 32(1), 79-88.

Houghton, J., Meira Filho, L., Callander, B., Katenberg, A. and Markell, K., 1996, *Climate Change 1995: the Science of Climate Change*. Cambridge University Press, Cambridge, UK, 904-905.

Iwan, R., Fakhrudin, M., Hendro, W. and Meti, Y., 2017, Application of the Soil and Water Assessment Tool (SWAT) to Predict the Impact of Best Management Practices in Jatigede Catchment Area. Global Colloquium on GeoSciences and Engineering. *IOP Conf. Series: Earth and Environmental Science*, Vol. 118, doi :10.1088/1755-1315/118/1/012030.

Jaber, M., 2012, *Assessment of Climate Change Impacts on Water Resources in Mujib Basin (Central Jordan)*. M.A Thesis, Zarqa- Jordan.

Jordan Meteorological Department, 2020, *Climate Data*, Amman, Jordan.

Kusangaya, E., 2015, Climate Change Impact on Water Resources in the Desert Area Considering Irregularity in Rainfall Intensity and Distribution: A Case Study in Wadi Mujib basin Jordan, *Journal of Environment and Earth science*, Vol. 5(5), 34-44.

Ministry of Water Agriculture, 1993, Soil Map and Land Use Project for Jordan, Hunting Technical Service LTD in Associated with Soil Survey and Land Research Center, UK, Vol. 1(3).

Mosbahi, M., Bendabdallah, S. and Boussema, M., 2013, Assessment of Soil Erosion Risk using Swat Model. *Arabian Journal of Geosciences*, Vol. 6(10), 4011-4019.

Natural Resources Authority, 1997, Geological maps, (50000:1) Amman, Jordan.

Oruod, I., 2002, Principles of Natural Geography, Dar Al Shorouk: Amman.

Royal Geographical Center, 1997, Topographic Maps Scale 1:50000, Amman.

Saha, P., Zeleke, K. and Hafeez, M., 2019, Impacts of Land Use and Climate Change on Streamflow and Water Balance of Two Sub-Catchments of the Murrumbidgee River in South Eastern Australia. *Extreme Hydrology and Climate Variability*, (1st ed., 279-299). Elsevier

Schuol, J., Abbaspour, K., Srinivasan, R. and Yang, H., 2008, Modelling Blue and Green Water Availability in Africa. *Water Resources Research*, Vol, 44,1-18.

Shehadeh, N., 1991, The Climate of Jordan, Dar Al-Bashir: Amman.

Shimelis, G., Srinivasan, R. and Dargahi, B., 2008, Hydro-logical Modelling in the Lake Tana Basin, Ethiopia Using SWAT Model, *The Open Hydrology Journal*, Vol, 2(1), 49-62. doi:10.2174/1874378100802010049,

Weib, M. and Menzel, L., 2008, A Global Comparison of Four Potential Evapotranspiration Equations and their Relevance to Stream Flow Modelling in Semi-Arid Environments. *Advances in Geosciences*, Vol. 18(1),15-23.

Zghoul, M., 2016, *Water Resources and Harvest Potential in the Zarqa Basin using Remote Sensing Techniques and Geographic Information Systems.* Ph.D Thesis, University of Jordan, Amman, Jordan.