Evaluation of the soil moisture content using GIS technique and SWAT model, (Wadi Al-Naft region: as a case study)

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Abstract. Soil moisture content is one of the basic parameters required to study the strategy of sustainable water management within urban and rural uses. Wadi Al-Nafat region was chosen as a study site within a total area of 8,820 km², which is located in the northeast of Diyala province in the country of Iraq. The net area of the main catchment planning was 4926 km² or about 56% of the total study area. The main catchment area was divided into 83 sub-catchments for the purpose of completing the application of the GIS technique and SWAT model. They were used to calculate the soil moisture content based on input data represented by the digital model of the elevation levels, meteorological data, uses of land and soil at the study site with the application of the SCS-CN mathematical model, and then determined water losses associated with average Annual Curve Number 73 during the period 2010 to 2016. The results of SWAT simulation showed that the annual rate of soil moisture content is 41.26 mm comparing with 46.74 mm from field works during the same period with a difference of about 11%. The study also explained the efficient use of SWAT model and GIS technique in predicting the soil moisture content values and compares them with field results. It is noted that the correlation coefficient between soil moisture content measured by field works and soil moisture content calculated according to SWAT model simulation is 97%. Study results are encouraging the use of these techniques in areas lacking hydrologic and topographic parameters and thereby reduce the need for human and economic sources.

Keyword: Soil moisture content, Land sat 8, SWAT, DEM, GIS.

1. Introduction

Precise knowledge of current and future spatial changes in soil moisture is critical to achieving sustainable land and water management, and to assess the optimal need for soil moisture suitable for agricultural production. United Nations data on agricultural production indicate that this activity needs about 70% of total global water consumption [1]. The quantity of water in the upper soil layer represents the rate of soil moisture that will interact with the climatic factors through the transpiration and evaporation processes [2]. The moisture of soil surface is determined by the rate of water in the top 10 cm of the soil layer, while the moisture in the root zone is the amount found in the 200 cm³ of the soil top layer despite it is small in a particular area, soil moisture has a significant impact on all types of hydrological, biological, biochemical, weather, runoff, corrosion and heat exchange models between the land surface and air [3] [4]. Traditionally, soil moisture measurements can be made at the site either directly or indirectly. The direct method uses volumetric or gravimetric measurements to
determine soil moisture, while indirect method measures the soil stresses generated by water using instruments such as Tensiometers, gypsum blocks, neutron probes and magnetite tracers [5]. The previous methods are expensive and consume a lot of resources and time. So, several researchers began working on modern and influential techniques for mapping and building simulation models, such as soil moisture simulations, rather than relying on the above methods to create a complete map of specific sites [6] [7]. The Soil and Water Assessment Tool (SWAT) is a semi-physical and semi-experimental modeling tool developed by the US Department of Agriculture (USDA). SWAT can be developed to simulate rain flow with different short and long-term objectives, for example, forecasting stream flow and sedimentation, identifying best management practices (BMP), and planning water resources for large and complex watersheds [8] [9]. In recent years, the SWAT system has been rapidly introduced as a modeling tool for various hydrological processes under different climatic conditions around the world. SWAT is expected to continue to evolve in response to the need for improvement in the status of major hydrological operations [10] [11]. Some studies have shown that SWAT performance is good for the watersheds and could be a potential tool for improving and assessing the effect of water and soil structures on sediment loads [12] [13]. Other studies have used a record of a long-term for soil moisture content as inputs to the SWAT model to estimate the relationship between soil moisture content and the standard rainfall index [14]. The Soil Conservation Service curve number (SCS-CN) is used by SWAT model in stream flow estimation. The SCS-CN uses soil separates, land uses and land cover information to predict runoff [15] [16]. This method separates actual rainfall from total precipitation using the concept of water balance [17]. The SCS-CN method is widely used to simulate a sequential flow to analyze surface runoff over the long term [18]. And also SWAT uses the SCS-CN method to predict stream flows in large and non-measured watersheds [19] [20]. Other technologies used in the field of irrigation work control and topographical details of land and soil are remote sensing technology. Currently, three major remote sensing applications are used to control the moisture content of soil: infrared, microwave, and electromagnetic radiation (visible infrared, near infrared, and shortwave). There is a significant correlation coefficient to surface temperature through thermal, infrared and energy (surface flux) with soil moisture content [6] [21] [22]. One of the studies has assessed the predictability of the predicted soil moisture content to indicate the water content of the soil in a short time and the space scale, by comparing with the daily soil content data specified at the site using an electrical insulating device [23]. Other studies did not use SWAT techniques and remote sensing, but the use of statistical models in estimating the content of soil moisture, by matching Gauss function inverted to a continuous series in the soil spectra. The Gaussian soil moisture model is used to estimate moisture content through a downward reflection in areas close to infrared and shortwave [24] [25]. The difficulty of determining soil moisture content in a poorly measured area, such as the oil valley area, the need to provide human and economic resources, and the time required to complete the work of laboratory analyzes and location are the main problems facing researchers to accomplish their research work. Therefore, in this research, SWAT model and GIS technique were used to determine the annual rate of soil moisture content, and explore the efficiency of these applications comparing with the field results.

2. Material and Methods

2.1. Study Area

Wadi Al-Naft is an Iraqi city located in the province of Diyala on the Iraqi-Iranian border, located between the areas of Khanaqin and Mandali, 40 km south of Khanaqin. The region is characterized by the presence of many oil wells in its territory, in addition to the uniqueness of the city from the fertile soil for agricultural production, which encouraged the development of the city and increased investment by the global oil, industrial and commercial companies. It's within the geographic coordinates N 34° 00' 00'' to 33° 00' 00'' E 46° 00' 00'' to 45° 00' 00''. The region area is about 8820 km². Figure 1 illustrated study area.
2.2. Soil and Water Assessment Tool (SWAT)
The Soil and Water Assessment Tool (SWAT) was used as a simulation model for hydrological variables in the Wadi Al-Naft region. The study area is represented as the main catchment, and its behavior is determined as the final and the net result of a group of small catchments or secondary basins. Maps of land use and soil were applied within each secondary catchment to generate a special combination of regular and uniform physical characteristics, which is a unit of hydrological response (HRU) [8]. The SWAT model will divide the main catchment area into several hydrological response units with homogeneous characteristics in the land cover and soil within each secondary catchment. The water balance of all response units is evaluated and calculated within the time unit (day). The Swat model splits the rainfall system into a range of influencing variables such as surface runoff, evaporation, infiltration, lateral flow, groundwater recharge, etc. Surface runoff is estimated daily by adopting the modified SCS curve number method (USDA -SCS), and maximal runoff rates using the rationalized method [8] [12].

2.3. Hydrological Modeling

2.3.1. Ground Water: The simulation of the hydrological cycle is based on the use of the water balance equation, as shown below: [26]:

\[
SW_T = SW_I + \sum (R_D - Q_{SUR} - E_V - W_{SEP} - Q_{DR})
\]

Where:
- \(SW_T\): the amount of soil moisture content after a period of time during the day (mm).
- \(SW_I\): the amount of initial moisture content of the soil per day (mm).
- \(T\): the time (day).
- \(R_D\): the rate of precipitation expected per day (mm).
- \(Q_{SUR}\): the rate of surface runoff expected per day (mm).
- \(E_V\): the rate of evaporation per day (mm).
- \(W_{SEP}\): the rate of water entering the unsaturated soil profile (mm).
- \(Q_{DR}\): the rate of drainage flow to the surface runoff (mm).

2.3.2. The Surface Water: The main basin of surface runoff is divided into a set of secondary basins for the purpose of determining the flow path. The secondary basin includes two types of channels
(primary and secondary) that direct the flow path from the secondary basins towards the main basin [27].

2.4 Field and Laboratory Works of Soil Investigations

One hundred forty-four soil samples were selected at the rate of six samples per each month, randomly and sporadically from the study area during the two-year research period starting in 2016. The disturbed samples were obtained, according to (BS: 5930). The samples that were secured by the Standard Split Spoon Sampler were also used as disturbed samples. All disturbed samples were sent to the Laboratory for further examination and testing to determine the natural moisture of soil in the study area by using the standard methods (BS:1377-Part 2-Class 3).

2.5. SCS Curve Number Method

Curve Number SCS is an estimated method of predicting the expected response to the magnitude and intensity of the rainstorm. This method is easily applied and suitable for use and response to the characteristics of catchments represented by land uses, soil type, surface and antecedent conditions. It is a model for loss of an infiltration, and this does not mean calculating the amount of evaporation over long ranges [28] [29]. Watersheds include a specific set of soil and land cover that can be classified in different numbers of the curve. These curves represent the logical relationship between precipitation and surface runoff, such that [27]:

\[
\frac{P_R - Q_A}{S_P} = \frac{Q_A}{P_R}
\]  

Where:

\( P_R \) - the actual of surface runoff retention (mm).

\( Q_A \) - the actual surface runoff (mm).

\( S_P \) - the potential surface runoff representing total precipitation (mm).

\( I_A \) - all losses of flow before surface runoff begins. It includes the retention of water in the depressions and their interception through evaporation, vegetation and infiltration as shown in Figure 2. 

\( I_A \) is subtracted from the potential total precipitation \( P_R \) in equation (2) as follows:

\[
\frac{(P_R - I_A - Q_A)}{S_P} = \frac{Q_A}{(P_R - I_A)}
\]  

Solving for \( Q_A \) as described below:

\[
Q_A = \frac{(P_R - 0.25 S_P)}{(P_R - I_A Q_A + S_P)}
\]

\[\text{Figure 2. SCS Curve Number Method [7]}\]
3. Input Data

3.1 Climate Variables
The climate variables of the Iraq Meteorological Organization for the city of Khanaqin were adopted during the period 2010-2016 for the purpose of the research application. Rainfall data, relative humidity, minimum and maximum temperature, wind speed and data of ref. [30] are among the most important variables. The climatic information about the city of Khanaqin shows that it has a dry and warm climate during the summer; the average temperature is about 31.0 °C while it is subjected to cold winds and rainstorms during the winter season, with an average temperature of about 8.0 °C. The relative humidity in summer and winter is about 25.0% and 65.0%, respectively, while the average evaporation is about 330.0 mm in summer and 55.0 mm in winter. The average wind speed is about 1.25 m/s in winter and 1.85 m/s in summer, and the duration of sunshine is about 11.0 and 5.0 hours in summer and winter, respectively.

3.2 Digital maps of land use, land cover and soil properties.
The land use, land cover (LU, LC) and Soil properties of the study area can be obtained from satellite imagery; Land sat. 8 and the ref. [31]. Three satellite images of the study area were obtained during the month of March of 2015, and these images were processed from all aspects of geometry, atmospherically and digital programs within GIS software, Figure 3. The study area was covered with the resulting mosaic images, and the GIS technique was used in achieving the various thematic mapping (LU, LC) and soil layers. According to the exploratory soil map of Iraq 1960 and Land-use map at scale 1,000,000, [31]. The Soil, Water Properties Program (SPAW) was used to analyze soil texture components according to land uses and soil maps during 1960 at a scale of 1: 1,000,000. The program is characterized by its ability to demonstrate the soil characteristics in terms of water tension, salinity, conductivity, sand and gravel content, and organic matter. The digital elevation model map for the study area was obtained from the downloaded website of Land sat. 8 [32], as shown in Figure 4. The construction of the Swat model depends on the determination of elevation levels, such as the altitude of the study area above sea level, the sides and slopes of the area, the network of flow channels, and the distance of the area from the nearest waterway. The construction of the model requires the division of the study area (main catchment) into a number of secondary catchments. The determination of the secondary catchment area is usually based on the nature of the topography specifications of the study area, where there is little need for detail in the case of flat land, while many details are required in the case of mountainous and lowland areas. So the area of the main catchment was then divided into 83 sub-catchment, as shown in Figure 5.

![Figure 3. Satellite Imagery; Land sat 8 of the study area](image-url)
3.3. Hydrological Response Unit (HRU) Analysis

The rainfall has a monsoonal seasonal pattern, with using commands from the HRU Analysis menu on the Arc SWAT Tool bar. Tools help users to download land uses and soil data, as well as to assess the topographical specifications of the study area. Data sets can be a shape file, an ESRI grid, or a Geo-database class format. The user can define the required standards for HRU distributing by linking the land uses and soil data collection with SWAT databases. One or more unique combinations (hydrological response units or HRUs) can be built for each sub-basin. The classification of land uses and soil helps to download the previously mentioned utilization data, determine their sets and distribute them to sub-catchments. The spatial analyzer calculates cross-tabulated areas in land uses and soil data by taking advantage of automatic data transfer to the grid. Taking into consideration the use of the same projection of such data as the use of the digital elevation model in the delineation of watersheds and determining the extent of (DEM) used in the demarcation process of the catchments [32].

4. Results and Discussion

SWAT model was simulated for the study region (Wadi Al-Naft) for the period 2010 to 2016 for the purpose of predicting the annual rate of soil moisture content. The area of the main catchment was divided into 83 sub-catchments for the purpose of completing the application of the model. The net area of the main catchment planning was 4926 square kilometers, or about 56% of the total area of the study region. Figs (6 & 7) showed the hydrologic response unit (HRU) of land use and soil reclassified.
respectively. Also, Figure 8 illustrated the hydrologic cycle considered by SWAT Simulation - DEM14m with the value of average Annual Curve Number Curve Number which was equal to 73. According to SWAT Simulation, the water balance for the period 2010-2016 was calculated as shown in Table 1. The monthly rate of the soil moisture content (SWM) in the study area for the period 2015-2016 was illustrated in Table 2. Field tests in the study area showed that the soil moisture content (SWM) ranged between 45.55 - 55.78 mm during the period 2015-2016, Table 3. It showed that the annual rate of soil moisture content in the north of the research area for the period 2004-2011 was 49.47 mm [33]. While the advisory technical studies for Diyala province showed that the annual rate of the soil moisture content in the west of the study area was about 38.71 mm [34]. The results of SWAT simulation showed that the annual rate of soil moisture content (SWT) is 41.26 mm, while the results of the field tests indicate an annual rate of 46.74 mm during the period 2010-2016, with a difference of about 11%, as shown in Table 3.

![Figure 6. Land use Reclassified.](image1)

![Figure 7. Soil Reclassified.](image2)

![Figure 8. Hydrologic Cycle Considered by SWAT Simulation - DEM 14m.](image3)
Table 1. Annual water balance terms (mm).

| Year | SW_T | R_D  | Q_SUR | E_V  | Later Flow |
|------|------|------|-------|------|------------|
| 2010 | 22.35| 98.69| 5.35  | 70.40| 0.09       |
| 2011 | 85.22| 110.63| 12.63 | 95.50| 0.08       |
| 2012 | 28.86| 96.77| 16.19 | 104.0| 0.08       |
| 2013 | 27.1 | 93.45| 8.71  | 77.90| 0.08       |
| 2014 | 38.0 | 118.36| 23.46 | 106.7| 0.07       |
| 2015 | 40.07| 137.52| 21.44 | 113.0| 0.08       |
| 2016 | 47.57| 90.90| 35.6  | 87.0 | 0.09       |

Table 2. The monthly rate of the soil moisture content in the study area (mm), at field tests.

| Month | Jan. | Feb. | Mar | Apr. | May | Jun | Jul. | Aug | Sep. | Oct. | Nov | Dec |
|-------|------|------|-----|------|-----|-----|------|-----|------|------|-----|-----|
| Year  | 2015 | 70.4 | 141.8 | 113.3 | 91.7 | 91.4 | 3.7 | 0.0 | 0.0 | 4.8 | 12.8 | 16.7 |
|       | 2016 | 79.0 | 160.4 | 136.6 | 109.4 | 116.6 | 9.8 | 0.0 | 0.0 | 11.4 | 19.6 | 26.5 |

Table 3. Annual rate of soil moisture content in the study area (mm).

| Year  | Value of soil moisture content (SW), mm. |
|-------|-----------------------------------------|
|       | SWAT Model (SW_T) | Field Test (SW_M) |
| 2010  | 22.35 | 26.49 | Ref. [33] |
| 2011  | 85.22 | 91.67 |
| 2012  | 28.86 | 30.27 |
| 2013  | 27.10 | 33.65 | Ref. [34] |
| 2014  | 38.00 | 43.78 |
| 2015  | 40.07 | 45.55 | Field Tests |
| 2016  | 47.57 | 55.78 |
| Av. Value | 41.26 | 46.74 |

SPSS program was used for the statistical analysis. It is noticed that the correlation coefficient between soil moisture content measured by field works (SW_M) and soil moisture content calculated according to SWAT model simulation (SW_T) is 97%, which gives high confidence in the result of the following equation for the purpose of calculating SW_M in terms of SW_T, Fig. 9.

\[
SW_M = 1.044 \times SW_T + 3.599
\]
Figure 9. Showed the relationship between SW\textsubscript{M} and SW\textsubscript{T}

5. Conclusions

Wadi Al-Nafat region was chosen as a study site because it is a poorly gauged area to determine the soil moisture content. The objectives of this study are exploring the efficiency of SWAT model and GIS technique in predicting the soil moisture content values and compare them with field results. The results of SWAT Simulation showed that the annual rate of soil moisture content is 41.26 mm comparing with the 46.74 mm from field works during the same period with a difference of about 11%. It is noted that the correlation coefficient between soil moisture content measured by field works (SW\textsubscript{M}) and soil moisture content calculated according to SWAT model simulation (SW\textsubscript{T}) is 97%. Study results recommend the use of these techniques in areas that lack hydrological and topographical parameters and thereby reduce the need for human and economic resources.

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