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Received on: 16/05/2016
Accepted on: 23/02/2017

Effect of DEM and Land Cover Resolutions on Simulated Runoff of Adhaim Watershed by SWAT Model

Abstract- *Accurate estimation of surface runoff by using Soil and Water Assessment Tool (SWAT) model is highly depends on the accuracy of the Digital Elevation Model (DEM), Land Cove and Land Use (LC/LU), soil and weather data as input variables. The interactive and complementary effects of the DEM and LC/LU resolutions on the estimated runoff were not taken into consideration in previous studies. This research aims to study these effects on the accuracy of runoff estimation of Adhaim Watershed by using SWAT Model. Twenty surface runoff estimation SWAT models of Adhaim Watershed were implemented using five DEMs with spatial resolution of 30, 50, 90, 250 and 1000m in conjunction with four LC/LUs with spatial resolution of 30, 300, 500 and 1000 m. These models were calibrated and verified on daily time step with the adoption of maximizing Nash and Sutcliffe Efficiency (NS) as an objective function. The results of SWAT models show that specifying the watershed boundary and the total area is highly affected by the DEM resolution without considerable trend. Also, the estimated minimum altitude is inversely related to the DEM resolution, whereas the maximum altitude has a direct relationship. Furthermore, LC/LU resolution is highly affected the number and area of classes that can be distinguished in the LC/LU image. Although, the number of hydrologic response units (HRUs) depends on LC/LU resolution, it was found that this number increases with the increase in LC/LU resolution to a maximum number of HRUs and then it gradually decreases. Whereas, the HRUs has a direct relationship with the DEM resolution and the number of subbasins irregularly changed with the increase of DEM resolution. Results of runoff estimation by using SWAT models show that the estimated runoff is not directly or inversely related to the DEM and LC/LU resolutions. Moreover, the most accurate runoff was not estimated with the highest DEM and LC/LU resolutions, where it is obtained with DEM and LC/LU resolutions of 250 m and 1000 m respectively with NS of 0.74. Accordingly, it is recommended to use these resolutions for estimating the surface runoff of Adhaim Watershed. The relationship between the HRUs and estimated runoff is very complex therefore; more extensive studies are required to comprehend this relationship.*

Keywords- *Adhaim Watershed, DEM, surface runoff, SWAT model.*

How to cite this article: M.S. Al-Khafaji and F.H. Saeed, "Effect of DEM and Land Cover Resolutions on Simulated Runoff of Adhaim Watershed by SWAT Model," *Engineering and Technology Journal*, Vol. 36, Part A, No. 4, pp. 439-448, 2018.

1. Introduction

Adhaim Watershed is one of the most important water supplier of the Tigris River through the Adhaim River that originate in Iraq. Because of lack information about land management and hydrology, especially in the far parts, the remote sensing and hydrologic model are the optimum solution for study and evaluate the water resources of Adhaim. The Soil and Water Assessment Tool (SWAT) employ the DEM and LC/LU data to simulate the runoff. The model discretize the watershed into smaller parts called subbasins based on DEM and the spatial input data processed as hydrologic response units (HRUs) of uniform slope, LC/LU, and soil [1]. The DEM has large effects on the simulated stream flow [2,3]. Many studies have demonstrated that the outputs of hydrological models are influenced by input DEM resolution, DEM source, and DEM resampling technique [4,5,6,7].The DEMs such as ASTER 30m and SRTM 90m examined by SWAT model In the Xiekengxi River Watershed in China, [8]. The study indicated that the SRTM of 90m resolution simulate the runoff better than the ASTER 30m. Other study [9] evaluated the sensitivity of simulated runoff in Thyle Catchment in Belgium by SWAT hydrologic model to the LC/LU data. The results suggested that the SWAT model is still sensitive to the quality of the LC/LU input

https://doi.org/10.30684/etj.36.4A.11
2412-0758/University of Technology-Iraq, Baghdad, Iraq

data. The DEM resolution also strongly effects on watershed delineation [10], the study evaluated the effect of DEM resolution on the accuracy of delineate the stream network by use DEM with 30 to 3000m resolutions to compare the extracted streams network with that obtained from DEMs based on topographic surveying on 1000 km^2 study area in the Adirondac State Park New York. Results showed that with the decreasing of DEM resolution from 150 to 3000 m the accuracy of extracted streams network and the number of streams also decreased. However, interfering effects of the DEM and LC/LU resolution were not taken into consideration in the previous studies.

The main aim of this study is to evaluate the interactive and complementary effects of the DEM and LC/LU resolution on the estimated runoff of Adhaim Watershed. Moreover, it aims at specify the optimal resolutions of the DEM and LC/LU to maximize the accuracy of the estimated runoff of this watershed.

2. Methods and Materials

I. Soil and Water Assessment Tool (SWAT)

Soil and Water Assessment Tool made by the United States Department of Agriculture, (USDA). SWAT developed to predict the effects of land management processes on simulated flow, sediment, and agriculture chemical yields in large and complex watersheds with numerous types of soils, LC/LU and management conditions for long period of simulation [11]. SWAT is a physically (deterministic) based model and the watershed discretize into a numerous of subbasins based on the input DEM data. Within each subbasin, slope, LC/LU and soil maps are overplayed to create a number of uniform hydrological response units (HRUs) [12]. SWAT processes the surface and subsurface water flow, take in accounting for the processes such as Infiltration, evapotranspiration, plant up take, lateral flow, and percolation to the aquifers. SWAT is based on the water balance equation, Eq. (1):

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - ET_i - W_{seep\,i} - Q_{gw} \quad (1)$$

where, SW_t is the final soil water content (mm), SW_0 is the initial soil water content on day i (mm), t is the time (days), R_{day} is the precipitation on day i(mm), Q_{surf} is the surface runoff on day i (mm), ET_i is the evapotranspiration on day i(mm), W_{seepi} is the amount of water entering the vadose zone from the soil profile on day (Soil interflow) i (mm) and Q_{gw} is the amount of return flow on day i (mm) [12].

The Soil Conservation Service Curve Number (SCS-CN) method, which is an option provided by SWAT, was used to estimate the direct runoff volume. In addition, SWAT provides optional flow routing, the Muskingum routing method or variable storage method using in daily time discretize. The variable storage method was selected for this study. Besides transmission loss, channel also loosed the water through evapotranspiration, which is a function of water surface area in the channels.

II. Study Area

1 Location

Adhaim Dam Watershed is located in the northern region of Iraq between the latitude 35° 42' 24"-34° 33' 8" N and the longitudinal 43° 41' 9"- 45° 27' 31" E, (Figure 1). It has an area of about 11600km^2 and it is bounded from the north by the Lesser Zab River while on the south it is adjoined by the Diyala Rivers Watersheds [13].

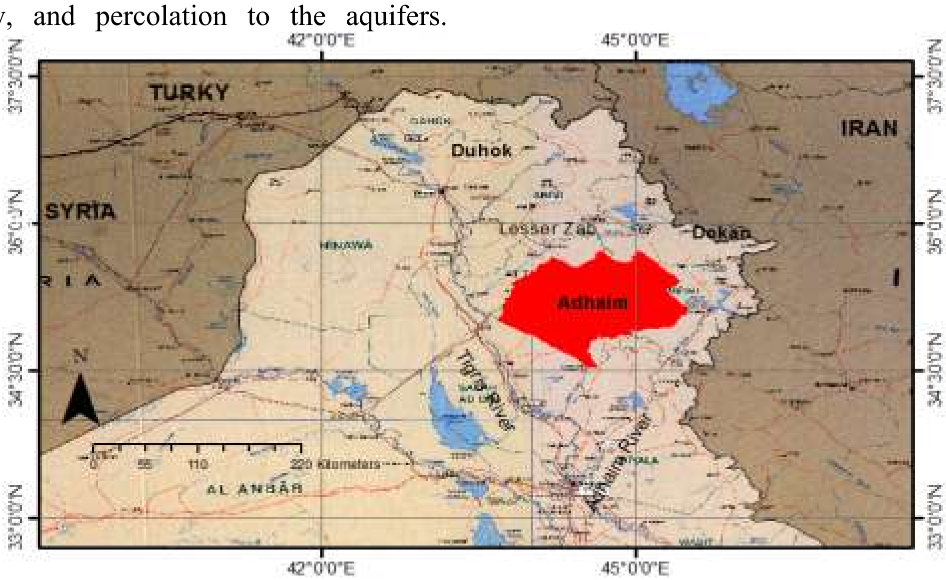


Figure 1: Location map of Adhaim Watershed

2. Topography

Adhaim River is origins in the Kurdistan Mountains of 1400m a.s.l., in the high elevation region of the Sulaymaniyah Province and flow out through the Kirkuk City towards the downstream plain. The ground slope decreased from north to south with an average of 1.5 m/km, the main water courses are the Kaurr Ders, Khassa Chai, Tuzz Chai and Touq Chai, all joining together as they cross the Hemmrin Mountain to form the Adhaim River determined by the alignments of the major mountain chain that make up the Zagros. Most tributaries join the Lesser Zab upstream from Adhaim, with the largest being the Beneh River and the Qelaa Chulane [14].

3. Geology

The mountain parts of Adhaim Watershed consist lime stones fold and rocks whereas, the hilly parts consist sandy soil, rough and often derived from the same rocks, and a few content of organic materials. The loamy surface soil predominate most of Adhaim Watershed.

4. Climate

Adhaim region can be considered as an arid area, practically no snowfall, and even rainfall is very limited. Practical runoff occurs during the rainy seasons only. Major rainfall storm occurs from October to May, the other months of the year are drier. The temperatures limits from, minimum -4 in winter to maximum 49 °C in summer and the annual rainfall of the region is about 610 mm, major rainfall storm occur from October to May [17].

III. Input Data

1.DEM

Five available global DEMs of free cost were used in this study. Which are, the ASTER 30m, resampled 50m from ASTER 30m, SRTM v-4.1 of 90 and 250m, GTOPO 1000m. These DEMs are shown in Figure 2 and the names of DEMs, resolutions, and sources are listed in Table 1.

– NASA and Japan′s Ministry of Economy Trade and Industry (METI) extracted the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM, by made grids of 30m size. GDEM2 was obtained in October 2011 with some improvements in absolute vertical accuracy of approximately 17 m and the absolute horizontal accuracy is about ±30 m [18].

– The ASTER DEM of 30m spatial resolution resampled to produce DEM with 50m resolution by majority resampling techniques [19].

– Shuttle Radar Topography Mission, (SRTM) produced global coverage of DEM of the Earth surface with a horizontal spatial resolution of 90m and absolute vertical height accuracy of 16m. The SRTM DEM produced by the C-band-SIR-C-5.6 cm of NASA radar, the Italian Space Agency (ASI) and German Aerospace Agency (DLR) X-band-3.1 cm-Synthetic Aperture Radar (X-SAR) collected global surface models by using the single pass techniques [20].

– The SRTM DEM of 90m spatial resolution resampled to produce DEM with 250m resolution by majority resampling techniques [19].

– GTOPO30, developed in 1996, over three years period by the U.S. Geological Survey's (USGS) Center for Earth Resources Observation and Science, (EROS). GTOPO30 is a global DEM with a horizontal spatial resolution of 1000 m.

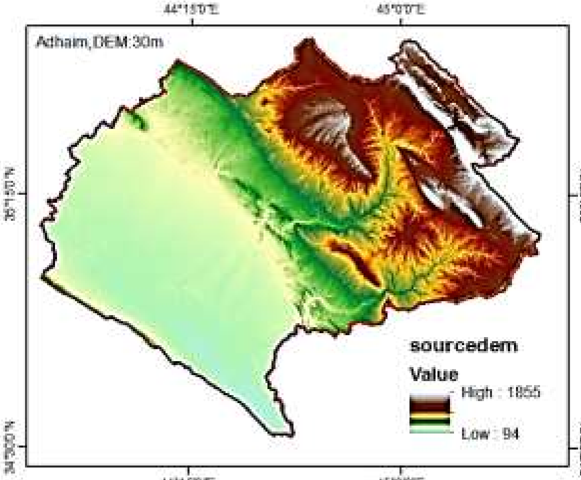
2.LC/LU

Four free cost global LC/LU of different resolution were used in this research which are the Landsat 30m, ESA 300m, and MODIS 500 and 1000m. Figure 3 shows the LC/LU classes applied on SWAT for Adhaim Watershed.

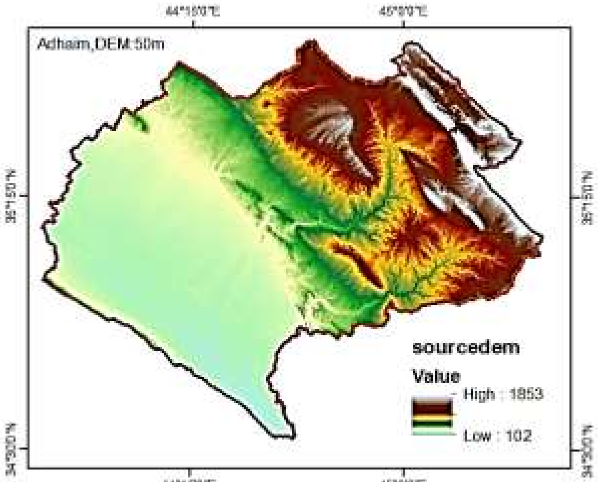
The National Geomatic Center of China produce global land cover of 30m resolution. The data produced by classification images of Landsat TM and ETM+ and multispectral images of Chinese Environmental Disasters Alleviations Satellite HJ-1.Cloud less images obtained in vegetation growing seasons with in 2009, 2010, and 2011. The average accuracy of global LC/LU for all the types is 83.51% the minimum is 72.5% for shrub land and maximum 92% for water bodies [21].

The European Space Agency, (ESA) Climate Change Initiative Land Cover (CCI-LC) products contain LC/LU data in approximately five years of period of centered in 2000, 2005, and 2010 respectively of spatial resolution of 300 m. This set of global land cover data extracted from the MERIS satellite earth surface reflectance archives between 2003 and 2012. The data processed to correct for the radiometric, geometric, and atmospheric impacts, also the checking for clouds effects. Supervised and unsupervised classification technics were used in an automated procedure to extract the LC/LU classes, 22 major and 16 minor land cover/use classes were classified based on the United Nations Land Cover Classification System (UN-LCCS) [22].

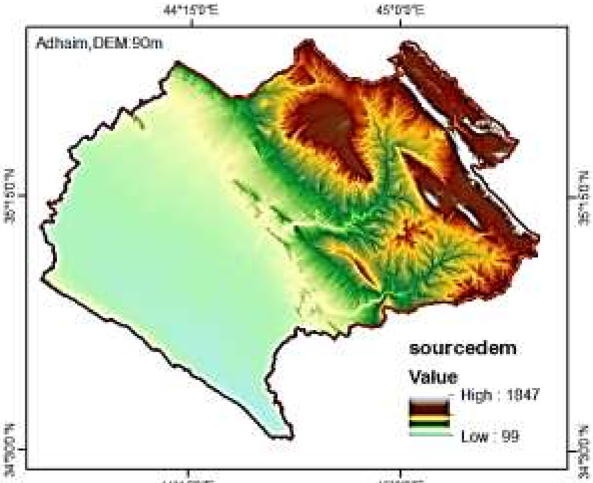
MODIS LC/LU of 500 and 1000m spatial resolution were used in this research, The MODIS is instrument aboard Aqua of NASA EOS- PM and Terra EOS-AM satellites. The MODIS Land Cover type product is produced using a supervised classification technics, International Geosphere-Biosphere Programmer (IG-BP) classification, which is predicted by using good quality database of LC/LU training sites and the training site database selected using high resolution images in coupling with other auxiliary data [23]. The selected site database is living database that requires continuous maintenance to improve the training data and detect mistakes on sites or sites that have unstable over time. Table 2 shows the names, resolutions, and sources of LC/LU.



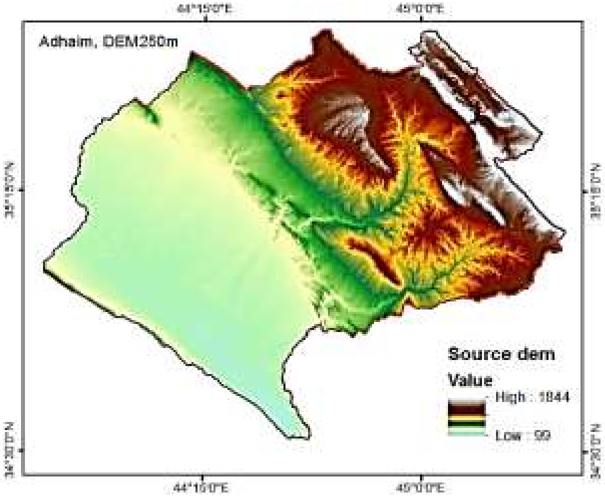
a-Adhaim DEM 30 m.



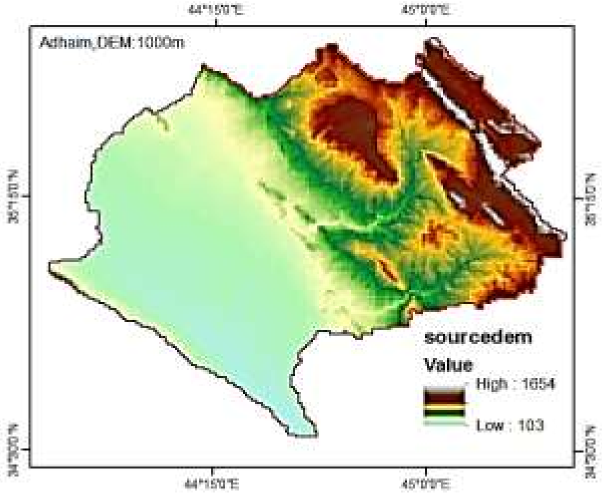
b- Adhaim DEM 50m.



c- Adhaim DEM 90m.



d- Adhaim DEM 250m.

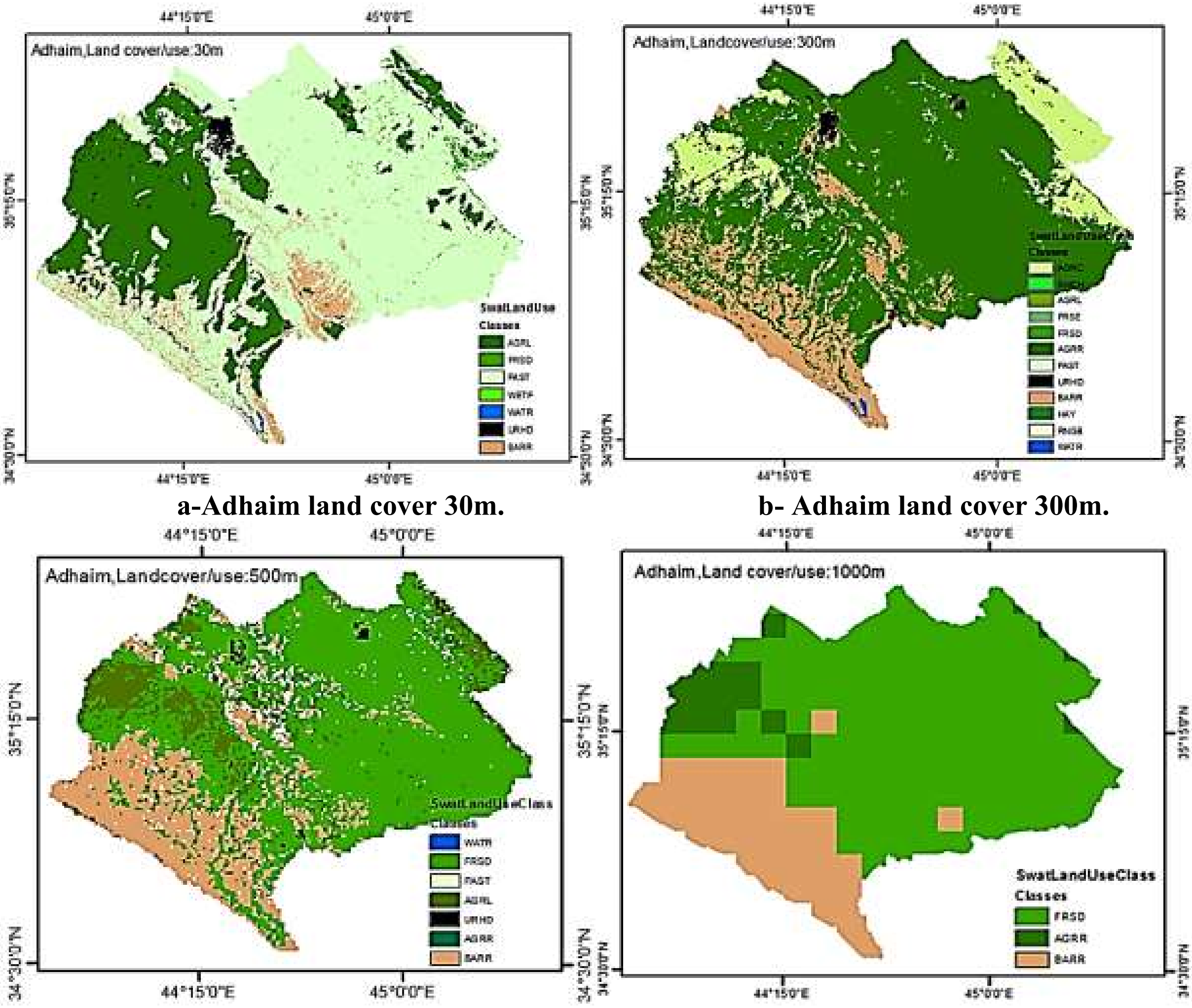


e- Adhaim DEM 1000m.

Figure 2: Utilized DEMs in SWAT models of Adhaim Watershed; a-Adhaim DEM 30m, b- Adhaim DEM 50m, c- Adhaim DEM 90m, d- Adhaim DEM 250m and e- Adhaim DEM 1000m.

Table 1: Utilized DEMs in SWAT models of Adhaim Watershed

No	Name	Spatial resolution	Source
1	ASTER GDEM2	30m	http://gdex.cr. usgs.gov/gdex/
2	Resampled from ASTER	50m	http://gdex.cr. usgs.gov/gdex/
3	SRTM v4.1	90m	http://srtm.csi.cgiar.org/
4	SRTM	250m	http://srtm.csi.cgiar.org/
5	GTOPO	1000m	http://earthexplorer .usgs.gov/



a-Adhaim land cover 30m. **b- Adhaim land cover 300m.**

c-Adhaim land cover 500m. **d- Adhaim land cover 1000m.**

Figure 3: The LC/LU utilized in SWAT models for Adhaim Watershed; a-Adhaim land cover 30m, b- Adhaim land cover 300m, c-Adhaim land cover 500m and d- Adhaim land cover 1000m.

Table 2: Utilized LC/LU data in SWAT models of Adhaim Watershed

No	Name	Spatial resolution	Source
1	Landsat	30m	http://www.globallandcover.com/
2	ESA	300m	http://maps.elie.ucl.ac.be/CCI/viewer/download.php
3	MODIS	500m	http://gdex.cr. usgs.gov/gdex/

4	MODIS 1000m	http://gdex.cr.usgs.gov/gdex/

3.Soil Data

Soil data was obtained from the global soil datasets of the Food and Agriculture Organization, United Nations, which supply data for 5000 kinds of soil, two layers (0 to 30 and 30 to 100 cm in depth) at a spatial scale of 1:5 000 000. The soil chemical and physical properties such as available water content, soil texture, hydraulic conductivity, organics carbon content and bulk density on different layers of each soil are available in FAO soil database. The database was added to SWAT database and lookup tables was used for soil classification in SWAT hydrologic model.

4.Weather Data

CFSR is stand of Climate Forecast System Reanalysis that provided the weather data requirements such as precipitation, maximum and minimum temperatures, solar radiation, relative humidity, and wind speed that used in SWAT for runoff simulation [24]. SWAT provides two options to input the weather data that are simulated and gauged weather, in this study the gauged mode used in simulations. The data downloaded on November 24, 2015 from (http://globalweather.tamu.edu/).

5. Observed Flow

The observed income flow collected from The National Center for Water Resources Management/ Baghdad for Adhaim on daily time step [25].

6. Calibration and Validation

In this study, SWAT-CUP 2012 used to calibrate and validate all the models. The sequential uncertainty fitting version 2 (SUFI-2) was selected. The Nash and Sutcliffe Efficiency (NS) was set as an objective function and coefficient of determination (R^2) as minor indicter for evaluating the model performance. NS and R^2 values greater than 0.5 are generally considered satisfactory and values greater than 0.75 are considered good [1]. SWAT-CUP set on 200 simulations for the first iteration and the simulated and observed added to SUFI2 on daily time step from 1/1/2010 to 12/31/2011 for calibration and from 1/1/2012 to 12/31/2013 for validation. The sensitive parameters of global sensitivity used in calibration and the best ranges exported to validation period with the same number of simulations of last calibration iteration. The P-factor and R-factor used for evaluate the acceptance of the calibration iterations, the calibration iterations stopped when P-factor is 0.6 or more and R-factor is around 1 [26].

3.Results

According to the SWAT methodology of modeling a watershed, delineation of the watershed is the first stage of the modeling processes. Therefore, results of Adhaim watershed delineation for the considered DEMs were compared to observe the effects of DEM resolution on the values and characteristic of the delineation parameters, Figure 4.

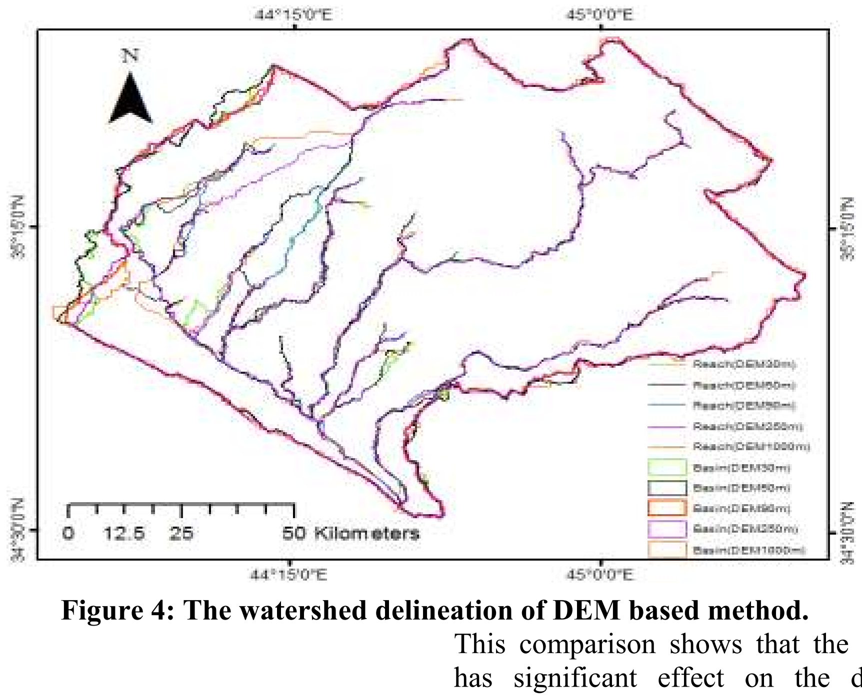


Figure 4: The watershed delineation of DEM based method.

This comparison shows that the DEM resolution has significant effect on the determination of watershed boundary and stream network. In addition, total area of the watershed is sensitive to DEM resolution without considerable trend, Table 3. Moreover, the minimum altitudes increase and the maximum altitudes decrease as the DEM resolution decrease (coarser). These results are consistent with the finding of Reddy et al., (2015) [27] and Mou et al., (2015) [19].

Results of applying the LC/LU of 30, 300, 500, and 1000 *m* in SWAT hydrologic model for Adhaim watershed, Table 4, show that there is no considerable relationship between the resolution of the LC/LU layer and the number of classes. The LC/LU produced by Europe Space Agency (ESA) of 300 *m* resolution has the largest number of LC/LU classes (12 LC/LU classes).

The analysis of HRU was based on setting the threshold of subbasin area on 200 km². While, the threshold of HRU delineation was set on zero for slope, LC/LU and soil for all models. In other words, only DEM and LC/LU data of different resolutions were tested. Table 5 shows that the number of subbasins changes unevenly with the change in DEM resolution, with a maximum of 37 subbasins for the 50 *m* resampled DEM. While the number of HRUs is highly depends on the DEM resolution. The number of HRUs decreases with the decrease in the DEM resolution. Accordingly, it can clearly observe that the DEM resolution significantly affected the estimated runoff of Adhaim watershed.

Table 3: Model performance of computed elevations, slopes and total areas.

No.	Model of:	Elevation (m a.s.l)			Slope			Total area (km^2)
	DEM	Min.	Max.	Av.	Min.	Max.	Av.	
1 to 4	30	94	1855	424	0	198	10.6	12013
5 to 8	50	102	1853	422	0	229	7.64	12116
9 to 12	90	99	1847	428	0	164	5.05	11910
13 to 16	250	99	1844	428	0	93.7	3.67	11901
17 to 20	1000	103	1654	429	0	35	3.25	11979

Table 4: The LC/LU types and percentage of Adhaim Watershed.

No.	LC/LU:30		LC/LU:300		LC/LU:500		LC/LU:1000	
	Class	%	Class	%	Class	%	Class	%
1	AGRL	30.15	AGRC	13.16	WATR	0.02	WATR	1.24
2	FRSD	0.76	SWCH	0.05	FRSD	63.08	FRST	7.77
3	PAST	62.27	AGRL	0.01	APPL	0.001	PAST	54.33
4	WETF	0.03	FRSE	0.01	PAST	4.91	AGRC	36.66
5	WATR	0.22	FRSD	0.002	AGRL	10.59	*	*
6	URHD	1.2	AGRR	70.08	URHD	0.6	*	*
7	BARR	5.39	PAST	0.04	AGRR	0.03	*	*
8	*	*	URHD	0.97	BARR	20.76	*	*
9	*	*	BARR	15.52	*	*	*	*
10	*	*	HAY	0.02	*	*	*	*
11	*	*	RNGB	0.001	*	*	*	*
12	*	*	WATR	0.14	*	*	*	*

* indicates no LC/LU class.
AGRC: Agricultural close grown, FRSD: Forested deciduous, PAST: Pasture, WETF: Wet land forested, WATR: Water, URHD: Urban high density, BARR: Bare land, HAY: Hay, AGRL: Agricultural land generic, SOYB: Soybean, FRST: Forested mixed, AGRR: Agricultural row crops, EGAM: Eastern gam grass, ALMD: Almomds, OAK: Oak, SESB: Sesbania, WETN: wetland non forested, SWCH: Alamo switch grass, RNGB: Range grasses, APPL: Apple.

Table 5: Model performance of computed number of subbasins and HRUs.

No.	Model of: DEM	Model of: LC/LU	No. of Subbasins	No. of HRU
1	30	30	33	1449
2	30	300		1490
3	30	500		1116
4	30	1000		604
5	50	30	37	1280
6	50	300		1413
7	50	500		1033
8	50	1000		564
9	90	30	35	1221
10	90	300		1329
11	90	500		1028
12	90	1000		560
13	250	30	31	1106
14	250	300		1120
15	250	500		960
16	250	1000		560
17	1000	30	33	594
18	1000	300		632
19	1000	500		542
20	1000	1000		364

The response of model to various LC/LU and DEM data was assessed by fitting the observed runoff with the simulated runoff. Model output was calibrated and validated using the NS as objective function in SWAT-CUP and R^2 was used as a minor indicator. The obtained hydrographs of the calibrated and validated twenty models were analyzed to select the model of the highest NS in validation period. The model of DEM 250 *m* resolution (SRTM) and LC/LU of 1000 *m* resolution (MODIS) has the highest NS and R^2 of 0.74 and 0.68 respectively, Figure 5. This because the finer DEM and LC/LU resolutions increase the number of hydrologic parameters to be used in optimization against one variable which is observed flow.

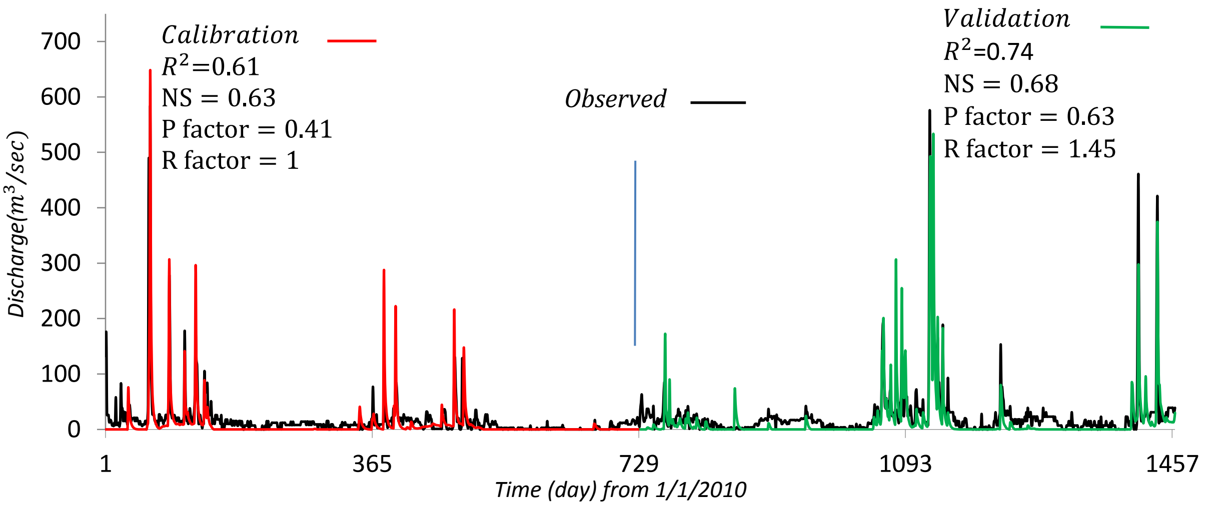


Figure 5: The best-validated model of 20 different models (Adhaim DEM250m and LC/LU 1000m)

Accordingly, the SWAT model of Adhaim Watershed not necessary provides the best-estimated runoff with the high resolution of DEM and LC/LU data. The DEM of finer resolution produce a high number of

HRUs. While the effect of LC/LU resolution on the number of HRUs related to the types and number of classes in the LC/LU digital map of the modeled watershed. There is no observed trend when increasing the number of HRUs on simulated runoff by SWAT. The effect of over parameterization occurs more prominently when increasing the number of HRUs, because the number of parameters also increases with the number of HRUs while the number of variables used for calibration unchanged. In addition, uncertainty in LC/LU plays an important role when defining HRUs. Using default SWAT parameters to represent the different LC/LU types introduces much uncertainty in the resulting runoff especially when the number of HRUs is increased. Therefore, the expected increase in the accuracy of runoff estimation with increase in the number of HRUs is highly complicated and more studies that are extensive are required to comprehend this issue.

4.Conclusions

Estimation of runoff in a watershed usually deals with some uncertainties due to variation of the related input variables. DEM and LC/LU data is considered one of the main important runoff modeling parameters that affects the uncertainties of simulation results. In this study, the uncertainties arising due to utilize different DEM and LC/LU data to estimate the runoff of Adhaim Watershed by using SWAT model were assessed. Based on the results of the applied SWAT models, the major findings of this study can be summarized as follows:

1. Specifying the watershed boundary and stream network is significantly affected by the DEM resolution. In addition, the total area of the watershed is highly sensitive to the DEM resolution without considerable trend. Whereas, the minimum altitudes increase (decrease) and the maximum altitudes decrease (increase) as the DEM resolution decrease (increase).
2. LC/LU resolution has a significant effect on the number of classes that can be recognized through the supervised classification without considerable relationship.
3. The number of subbasins and HRUs is highly depends on the LC/LU and DEM resolution. There was no specific trend that can be recognized for each of these numbers with LC/LU resolution. Whereas, the number of HRUs decreases (increases) with the decrease (increase) in the DEM resolution while the number of subbasins unevenly changed with the change in DEM resolution.
4. The most accurate surface runoff of Adhaim Watershed estimated by using SWAT models was not obtained with the high resolution of DEM and LC/LU data. Accordingly, the accuracy of runoff estimation of Adhaim watershed by using SWAT model is highly depends on the DEM and LC/LU resolutions.
5. The model of DEM 250 *m* resolution (SRTM) and LC/LU of 1000 *m* resolution (MODIS), which has the highest NS and R^2 of 0.74 and 0.68 respectively, produce the most accurate surface runoff.
6. The DEM of 250 *m* resolution (SRTM) and LC/LU of 1000 *m* resolution (MODIS) are the best DEM and LC/LU data for simulating the runoff of Adhaim Watershed by using SWAT model. Accordingly, it is recommended to use these DEM and LC/LU for estimating the surface runoff of Adhaim Watershed by using SWAT model.
7. The expected increase in the accuracy of runoff estimation with the increase in the number of HRUs is very complex therefore; more extensive studies are required to comprehend this issue.

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