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# Integrated Impact of Digital Elevation Model and Land Cover Resolutions on Simulated Runoff by SWAT Model

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**Abstract.** Complemental interactive effects of the Digital Elevation Model (DEM) and Land Cover (LC) resolutions on the estimated runoff by using Soil and Water Assessment Tool (SWAT), which is of critical importance for water resource management, was investigated in this paper. Also, to specify the optimal DEM and LC resolutions for maximizing accuracy of the estimated runoff for Dokan, Adhaim, and Duhok watersheds located in Iraq. Twenty daily time step based SWAT models of each watershed were implemented using five DEMs in conjunction with five LCs. Assessment of models results shows that the watershed delineation significantly affected by DEM resolution especially in flat regions. However, there is no clearly discernible trend of this effect on the determination of watershed boundary, stream network, number of sub-basins and total area. Furthermore, the number of Hydrologic Response Units (HRUs) and the maximum altitudes are directly related to the DEM whereas the minimum altitudes have an inverse relationship with the DEM. Also, the number of HRUs increases with the increase in LC resolution until it reaches a maximum value and then starts to gradually decrease. While there is no significant trend between the accuracy of the estimated runoff and the increase in the DEM and LC resolutions. The most accurate estimated runoffs of Dokan, Adhaim and Duhok Watersheds were obtained by using DEM 90 m and LC 1000 m, DEM 250 m and LC 1000 m, and DEM 30 m and LC 30 m with Nash and Sutcliffe Efficiency of 0.59, 0.68 and 0.69 respectively.

## 1 Introduction

Currently, hydrologic models employ satellites data such as Digital Elevation Model (DEM), Land Cover (LC), and soil data as inputs to these models with a certain spatial resolution. Recently, Soil and Water Assessment Tool (SWAT) is considered as one of the most useful tool for watershed modeling and management. It is important to understand the implications of using currently available satellites data of different resolutions on hydrologic models behavior. The spatial input data of hydrologic model raises several issues; A suitable spatial resolution of input data should be applied on the hydrologic model to get accurate runoff simulation and watershed delineation, Does the high (finer) resolution of input spatial data gives better runoff simulation than the low (coarser) resolution? and is the best resolution of input data used in specific watershed give the same results for anther different characteristics watershed in size and topography of watersheds?

Distributed hydrologic models divide the watershed into smaller units to represent heterogeneity within the watershed and model outputs are affected by geomorphologic resolution (Arabi et al, 2006). More detail in the input data is required to better describe spatial variability of the watershed. Proper model use requires an understanding of how model predictions vary according to level of data aggregation and whether or not those variations can be attributed to differences in watershed characteristics (FitzHugh and Mackay, 2001; Chang, 2009). Reducing the size and increasing the number of sub-units would be expected to affect the simulation results from the entire watershed (Tripathi et al., 2006). Jayakrishnan et al. (2005), concluded that application of SWAT is possible under lack of detailed digital data on land use, soil and elevation for model input. Also, fine resolution input data and parameters calibration efforts, should improve the results. Reddy et al, (2015) observed that reach lengths, reach slopes, sub-basins areas, and number of hydraulic Response Units (HRUs) varied substantially due to DEM resolutions, also they found that the maximum altitude decreases, and the minimum altitude increases, with decreasing DEM resolution. Tan et al, (2015), found that the total watershed area, number of sub-basins and number of HRUs changed unevenly with DEM resolution. Also, Meins, (2013) found that there is no trend in the accuracy of simulated flow when increasing the number of HRUs and defining the LC to matching default SWAT LC database leads to more additional uncertainty. Chaplot, (2005) examined DEMs of 20 to 500 m spatial resolution. The results indicated that the DEM resolution has a large influence on the simulated stream flow. Dixon et al, (2009) concluded that SWAT is indeed sensitive to the resolution of the DEMs, original 90 and 30 m DEM resampled to 90 m did not show the same trend. Therefore, the effects of resolution cannot be ignored and resampling may not be adequate in modeling stream flows using a distributed watershed model. Lin et al, (2013) investigated DEMs such as Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) 30 m and Shuttle Radar Topography Mission (SRTM) 90 m by SWAT model, the study showed that accuracy of runoff simulation using SRTM 90 m is better than that of ASTER 30 m. Zhang et al, (2014) assessed the sensitivity of SWAT model to the resolutions of DEMs. A range of 17 DEM spatial resolutions, from 30 to 1000 m, of Xiangxi River catchment area were considered. This assessment showed that the stream flow was essentially unaffected by the DEM resolution. Romanowicza et al, (2005) evaluated the sensitivity of simulated runoff to the LC data in Thyle catchment in Belgium by SWAT hydrologic model. The main conclusion of this evaluation was that the SWAT model is extremely sensitive to the quality of the LC data. Arnold et al, (2005) investigated the accuracy of stream flow simulation using two types of LC from different sources and resolutions, which are the LANDSAT-TM 30 m and AVHRR 1000 m resolution by SWAT model. The result showed that the source of LC information did not affect the SWAT simulation of stream flow. Mamillapalli et al. (1996) reported that there was a threshold beyond which higher resolution of data does not produce better results of predicted runoff. Jha et al. (2004) and Chang (2009) recommend that watershed assessment based on modeling should include a sensitivity analysis with varying sub-units size and number. There is not any established method for determining the optimal sub watershed/hydrologic response unit (HRU) configuration.

In previous studies there is no agreement about impact of DEM and LC resolution on simulated runoff by SWAT model, also a little attention had been given to the integrated impact of DEM and LC on simulated runoff and evaluating sensitivity of SWAT model to characteristics of watershed such as size and variances on topography and LC. Therefore, three watersheds of different characteristics were selected as the study area to assess the sensitivity of runoff modeling to DEM and LC resolutions using SWAT model.

## 2 Materials and Methods

### 2.1 Runoff Simulation Model

SWAT is a semi-distributed physically based hydrological model developed by the United States Department of Agriculture (USDA) (Arnold et al., 1998). The SWAT model can evaluate the impact of agricultural management on water, sediment and agriculture chemical yield in ungauged basins (Arnold et al., 1998).

SWAT discretize the watershed into sub-basins based on DEM, the hydrologic parameters such as slope, area, and length of sub-basins are extracted from the DEM, also, the DEM is used to extract channel properties such as channel length, width, depth and slope (Rao et al., 2010). In SWAT, the sub-basins subdivided into HRUs that consist of homogeneous land use, topographical, and soil characteristics (Arnold et al, 2011). The number and distribution of non-spatial HRUs created by SWAT are related to the resolution of input spatial data when made the matching between slope, LC and soil, SWAT process these HRUs to extract the hydrologic parameters and predict the evapotranspiration, surface runoff, groundwater flow and sediment yield, etc. that take place at the HRU level. Furthermore, the water balance is simulated at this level before runoff is routed to the reaches of the sub-basins and then to the basin channels (Neitsch et al. 2011). Accordingly, SWAT is considered as the efficient tool to investigate the complemental interactive effects of DEM and LC resolution on runoff simulation. Water balance equation, Eq. (1) is the fundamental base of SWAT:

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

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).

SWAT optionally provides the Soil Conservation Service Curve Number (SCS-CN) (USDA-SCS, 1972) method to estimate the surface runoff and the Muskingum or variable storage method for flow routing in daily time base. Evapotranspiration can be estimated using Hargreaves (Hargreaves et al., 1985), Priestley-Taylor (Priestley et al., 1972) or Penman-Monteith (Monteith, 1965). Storage routing method is used to simulate the percolation process through soil layers. While the storage model (Sloan et al., 1984) is used to estimate the lateral sub-surface flow.

## 2.2 Uncertainty and Sensitivity Analysis

Sensitivity analysis is performed using Latin Hypercube Sampling (LHS) and One At Time (OAT) methods (Hardyanto et al., 2007). To create multiple random samples, this method is started with LHS to divide the considered parameters range into intervals and then varying each of the LH points within these intervals. The number of changes must be equal to parameters number one at a time. Accordingly, the total effect is the average of the partial change in Si,j index of each parameter which is calculated using Eq. (2) (Van Griensven et al. 2006a), The highest sensitive parameter is given the first rank. While the rank of the lowest sensitive parameter can be equal to the total number of parameters.

$$\mathrm{Si,j} = \left[\frac{100\times\left(\frac{\mathrm{M(p1,.....,pi+(1+fi),.....,p)-(p1,....,pi,.....,p)}}{\mathrm{[M(p1,....,pi+(1+fi),....p)+M(p1,....,pi,....p)]/z}}\right)}{\mathrm{fi}}\right] \quad (2)$$

Where M is the model function, fi is the percentage change in parameter p for a LH point *j*.

The SWAT Calibration and Uncertainty Program (SWAT-CUP), is a software developed specially for calibration and uncertainty analysis of SWAT models. SWAT-CUP package software developed by Abbaspour (2011), includes five calibration programs (SUFI-2, PSO, GLUE, ParaSol and MCMC).

The Sequential Uncertainty Fitting version 2 (SUFI-2) is an algorithm of uncertainty parameters process the parameter ranges as the many tries steps to determine the most of the observed data within the 95 % band of estimation uncertainty. The overall uncertainty in output evaluated by the 95 % prediction uncertainty (95PPU). 95PPU calculated at the 2.5 % and 97.5 % locations of the cumulative distribution of the simulated stream flow as output element. It extracted from Latin hypercube sampling (Abbaspour et al. 2007). The goodness of fit for calibration evaluated using the P-factor and the R-factor indicators. The P-factor is the percentage of observed data matched by the 95 PPU. It ranges from 0 to 1, where 1 is ideal value and means all of the observed data are within the model calculations. The R-factor is the mean width of the band divided by the standard deviation of the observed variable. It ranges from 0 to ∞, where 0 indicates to perfect matching between simulated and observed. Based on the experience, an R-factor of around 1 is generally desirable (Abbaspour et al., 2007). SUFI-2 allows using different objective functions of optimization such as Nash–Sutcliff efficiency (NS), Eq. (3), (Nash and Sutcliffe, 1970) or coefficient of determination $R^2$, Eq. (5). NS and $R^2$ values greater than 0.5 are generally considered satisfactory and values greater than 0.75 are considered good (Gassman et al., 2007). Thus, the objective of the SUFI-2 is to maximize the P factor and to minimize the R factor, so that the optimal parameter range can be obtained. Global sensitivity analysis in SUFI-2 is calculated by plotting the Latin Hypercube generated parameters against the values of the objective function using multiple linear regression analysis. Then, a t-test is used to identify the relative significance for each parameter (Abbaspour et al. 2007). A more sensitive parameter has a greater t-test value and vice versa.

$$NS = 1 - \frac{\sum_i (Q_o - Q_s)_i^2}{\sum_i (Q_{o,i} - \bar{Q}_o)_i^2} \qquad (3)$$

$$R^2 = \frac{\left[\sum_i (Q_{o,i} - \bar{Q}_o)(Q_{s,i} - \bar{Q}_s)\right]^4}{\sum_i (Q_{o,i} - \bar{Q}_o)^2 \sum_i (Q_{s,i} - \bar{Q}_s)^2} \qquad (4)$$

Where, $Q_o$ is the observed flow, $Q_s$ is the simulated flow, $\bar{Q}_o$ is the Average observed flow, and $\bar{Q}_s$ is the average simulated flow.

## 2.2 Study Area

The study area was selected according to the data availability, watershed size and spatial variances of topographical and LC characteristics.  Therefore, Dokan, Adhaim and Duhok watersheds which are the most important watersheds in Iraq were selected to be the study areas, Fig. 1. These watersheds are different in topography, size, and LC. Dokan and Adhaim watersheds have large areas with topographies of steep and flat slopes respectively. While Duhok Watershed has a small area with a topography of steep to mild slopes.

### 2.3.1 Dokan Watershed

Dokan Dam Watershed has an area of 11700 $km^2$. It is located between 36° 51' 16" to 35° 28' 26" N and 44° 26' 25" to 46° 18' 16" E. Dokan basin covers an area within the  north east of Iraq-Kurdistan region and north west of Iran. It is bounded by the Great Zab basin from the north whereas from the south it is adjoined by the Adhaim and Diyala Rivers basins. Dokan Dam was constructed on Lesser Zab Stream that origins in the Zagros Mountains in Iran at an elevation of 3000 m a.s.l. Herbs and shrubs covering predominantly the top of mountains and vegetation of the open oak forest (Quercus of aegilops) dominant the hilly regions. The river valleys are characterized by wet forested plants cover. While the foothill zone, especially the plain of Arbil, is heavily cultivated, patches of natural vegetation with herbs in the genus Phlomis being very common (Frenken et al., 2009).

### 2.3.2 Adhaim Watershed

Adhaim Dam Watershed is about 11600 $km^2$ located in northeast Iraq between 35° 42' 24" to 34° 33' 8" N and 43° 41' 9" to 45° 27' 31" E. A network stream originates from mountain areas of elevation 1400-1800 m a.s.l. joining together at flat downstream area of an elevation of about 150 m a.s.l. creating Adhaim Stream. Barren land dominates the largest part of Adhaim Watershed, a few cultivated and orchards area of river irrigated in the western part of the watershed. The Cities of Kirkuk, Tuz Khormato, and other small towns located inside the watershed (Wahib et al., 2015).

### 2.3.3 Duhok Watershed

Duhok Dam Watershed is located on the far north of Iraq-Kurdistan region, between 37° 0' 25" to 36° 51' 53" N and 42° 50' 46" to 43° 5' 32" E. The total drainage area is 134.4 km$^2$. The watershed located in a mountainous area, mostly with very deep and barren slopes due to soil erosion. The watershed consists of two main streams (Garmava and Linava) with small river banks. The rocky slopes are total steep with more than 80 % decreasing in the direction along the stream, where they are between 20 and 30 % in the northern part. Rangeland dominates the largest part of the watershed, a few forests and wood land covering composed of dispersed oak trees and deciduous forest and shrubs on steep regions of the watershed, a small part of the watershed is cultivated lands mainly located along the rivers. Rainy irrigated cultivated lands such as vineyards can be found on the flat regions (Mohammed, 2010).

### 2.4 Input Datasets

The following datasets were collected, processed and used in this research:

### 2.4.1 Digital Elevation Model (DEM)

Nowadays, DEM become available as products of many satellites in different horizontal resolution and vertical accuracy. In this research, five free cost global DEMs were used. These DEMs are:

i. Advanced spaceborne Thermal Emission and Reflection Radiometer (ASTER) DEM of 30 m spatial resolution (ASTER GDEM Validation Team, 2009) with some improvements in absolute vertical accuracy of approximately 17 m and the absolute horizontal accuracy is about ±30 m (Jarihani et al., 2015).
ii. Resampled DEM of 50 m spatial resolution. The majority resampling techniques (Tan et al, 2015) was used in resampling ASTER DEM 30 to 50 m spatial resolution.
iii. Shuttle radar topography mission (SRTM) DEM of 90 m spatial resolution (SRTM, 2015).
iv. Resampled DEM of 250 m spatial resolution was produced from SRTM DEM of 90 m by using the majority resampling techniques (Mou et al., 2015).
v. GTOPO30 DEM of 1000 m spatial resolution (GTOPO30, 2015).

The names, resolutions, and sources of these DEMs are listed in Table 1. The DEMs of Dokan, Adhaim and Duhok Watersheds are shown in Figs. 2, 3 and 4 respectively. Since Duhok watershed is very small, only the DEM of 30, 50, 90 and 250 m spatial resolution was used in SWAT models of this watershed.

### 2.4.2 Land Cover (LC)

There are several institutions and research centers producing and publishing LC digital images with different spatial resolutions. Some of these images are suitable for hydrological studies and available with free charge. In this research, five types of LC images of spatial resolutions ranges between 15 to 1000 m were used. These images are:

i. Landsat LC of 15 m spatial resolution classifed by Mohammed (2010).

ii. Landsat LC of 30 m spatial resolution. This image was classifed by the National Geomatics Center of China (Chen, 2014).

iii. European Space Agency (ESA) LC of 300 m spatial resolution. This data was classified by ESA based on the United Nations Land Cover Classification System (UN-LCCS) (Wei Li, 2016).

iv. Moderate Resolution Imaging Spectroradiometer (MODIS) LC of 500 m (Muchoney et al., 1999).

v. MODIS LC of 1000 m spatial resolution (Muchoney et al., 1999).

The names, resolutions, and sources of the used LC images are listed in Table 2. The LC images of Dokan, Adhaim and Duhok Watersheds are shown in Figs. 5, 6 and 7 respectively. The LC image of 15 m spatial resolution was utilized only in Duhok SWAT model because this watershed has a small area compared to other considered watersheds, whereas all other LC images were utilized in SWAT models of Dokan, Adhaim and Duhok Watersheds.

#### 2.4.3 Soil Data

Food and Agriculture Organization of the United Nations (FAO, 1995) supplies soil database of 5000 soil types. This data comprising two layers (0 to 30 cm and 30 to100 cm depth) at a spatial scale of 1:5000000. The data were downloaded from (http://www.fao.org/nr/land/soils/digital-soil-map-of-the-world/en). The utilized soil maps in SWAT models for the Dokan, Adhaim and Duhok watersheds are shown in Figs. 8, 9 and 10 respectively.

#### 2.4.4 Weather Data

The Climate Forecast System Reanalysis (CFSR) dataset were used in this study (CFSR, 2015). CFSR provides the required weather data such as precipitation, maximum and minimum temperatures, relative humidity, solar radiation, and wind speed that used in SWAT for runoff simulation (Fuka et al, 2013 and Tomy et al, 2016). SWAT provides two options to input the weather data, the simulated and gauged weather. In this research, the gauged mode was used. The data were downloaded from (http://globalweather.tamu.edu/).

#### 2.4.5 Observed Runoff Data

The recorded runoff of the periods from 2010 to 2013 for Dokan and Adhaim watersheds and from 2009 to 2013 for Duhok watershed were used to calibrate and verify the SWAT models of these watersheds. The observed runoff data of Dokan and Adhaim watersheds were provided by Iraqi Ministry of Water Resources (MoWR) which are unpublished documents, The National Center for Water Resources Management/ Baghdad and Duhok Dam Directorate/Duhok Governorate provided the observed runoff data for Duhok Watershed (unpublished documents).

## 2.5 Model Setup

In this research, ArcSWAT 2012 hydrologic model connected to ESRI ArcView 10.2.2 GIS software (ESRI 2014) was used for runoff simulation, all of the spatial data were projected to the WGS1984-UTM Zone 38N projection. The threshold sub-basin area of both Dokan, Adhaim and Duhok watersheds were setting on 200, 200 and 10 $km^2$ respectively. For all models (Dokan, Adhaim and Duhok), slope is classified into five classes (0-10, 10-20, 20-30, 30-40 and >40) with multi slope directions. The LC was reclassified by HRU definition window to matching SWAT default database of LC, this process was completed depend on legends of classes that supplied by the LC producers, the data linked to the SWAT database by create lookup tables in required format and connected with similar LC in default SWAT database. The soil map and database of FAO were used for all models by adding the FAO soil database to SWAT user soil. The completed processing depends on legends of soil classes that are attached with FAO soil maps, this data was linked to the SWAT user soil database by creating lookup tables in required format and connected with added soil user database. Multiple HRUs created within each sub-basin, and the threshold area setup on zero percent for slope, land cover, and soil data. In this step, all LC, soil, and slope classes in a sub-basin were considered in creating the HRUs to represent all slopes, LC, soil classes without approximation.

The optional keys that were selected for the simulations of all models included: Runoff Curve Number (CN) method for estimating surface runoff from precipitation, Penman-Monteith method for estimating potential evapotranspiration (ET), and Variable Storage method to simulate stream water routing. All other SWAT default parameters were used as its original values. The observed runoff data for the period from 1 Jan. 2010 to 31 Dec. 2013 were used to calibrate and validate Dokan and Adhaim Watersheds models. Whereas that of the period from 1 Jan. 2009 to 31 Dec. 2013 were used to calibrate and validate Duhok Watershed model.

## 2.6 Calibration and Validation

SWAT-CUP was used to perform the calibration and validation processes for all the considered models, by using the Sequential Uncertainty Fitting version 2 (SUFI-2). In SUFI-2 the Nash–Sutcliff efficiency (NS) set as objective function and coefficient of determination ($R^2$) as minor indicter for evaluating the model performance. The data of the period from 1 Jan. 2010 to 31 Dec. 2011 were used for calibration and that of the period from 1 Jan. 2012 to 31 Dec. 2013 were used for validation for both Dokan and Adhaim models. Whereas the data of the period from 1 Jan. 2009 to 31 Dec. 2011 were used for calibration and that of the period from 1 Jan. 2012 to 31 Dec. 2013 were used for validation of Duhok models. The suggested calibration parameters of Abbaspour et al, (2015a) and other parameters were used as trial to get most sensitive parameters for each model. SWAT-CUP set up on 200 simulations in first iteration with (2 to 5) iterations for each model (Abbaspour, 2015b). The second step, the models were run for validation period by using the best parameter ranges extracted from calibration processing with the same number of simulations of last calibration iteration.

## 3 Results and Discussions

### 3.1 Watersheds Boundaries and Stream Networks

The DEM of a certain horizontal resolution has a particular vertical accuracy. Also, the DEM based method used in SWAT is depended on altitudes of DEM to capture the desired point in determining the boundary or stream position of the watershed. In flat topography regions, the variances on vertical altitudes are small this was reflected on the ability of DEM based method to capture the desired altitudes and thus on watershed delineation.

The obtained delineations of Dokan, Adhaim and Duhok watersheds through applying the DEM based method in ArcSWAT were as shown in Figs. 11 to 13. For Dokan watershed, the delineated boundary and stream network utilizing the 1000 m DEM, Fig. 11, is significantly different from these delineated using other DEMs. While delineation of Adhaim watershed, Fig. 12, shows that there is a large variation in the boundary and stream network that delineated using the considered five DEMs. This large variation is very clear within the western side of this watershed because this side of the watershed has an almost flat topography. In Duhok models, approximately all DEMs show same watershed boundary and stream network, Fig. 13. This is because the watershed surrounded by a steep mountain from all directions.

### 3.2 Total Watersheds Area, Number of Sub-basins and Altitudes

Different total areas of each watershed were computed as the DEM resolution of each watershed was changed, Table 3. The total area of Duhok watershed, which is the smallest modeled watershed in this study, is gradually increased with the decrease in DEM resolution. While no clear relationship was found between the total watershed area and DEM resolution for the two large watersheds (Dokan and Adhaim). Also, it can be noticed that the number of sub-basins changed unevenly with DEM resolution. The maximum number of sub-basins and the corresponding DEM resolution for Dokan, Adhaim and Duhok watersheds were 35 (with 250 m DEM), 37 (with 50 m DEM) and 7 sub-basins (with 30, 50 and 90 m DEM) respectively.

The estimated minimum and maximum ground elevation versus the DEM resolution for the considered watersheds is shown in Fig. 14. This figure shows that there is an overestimate for the minimum elevations and underestimate for the maximum elevations with the decrease (coarser) in DEM resolution. This is due to the loss of detailed topographic information at coarser resolution.

### 3.3 HRU Analysis

Variation of HRUs number with LC for each DEM resolution was evaluated, Figure 15. This evaluation shows that with the decrease (coarser) in DEM resolution the number of HRUs decreases for each LC resolutions. While the number of HRUs increases with the decrease in LC resolution until a specific resolution and then recede. This because there are two parameters controlling the number of HRUs for particular LC, which are the LC resolution and number of feature classes. While for particular DEM one parameter controlled the number of HRUs, which is the slope.

## 3.4 Runoff Evaluation

The initial models of Dokan and Adhaim show up, high flow peaks, low base flow, and anteceded peaks (simulated shift to left) in comparison with the observed flow. Unlike that for Duhok models, which show up high base flow, late peaks (simulated shift to right) while the flow peaks were still high. Results of the best validated models are shown in Fig. 16. For Dokan Watershed, the model of DEM 90 m resolution (SRTM) and LC of 1000 m resolution (MODIS) has the maximum NS value than the other models with 0.59 and 0.61 of NS and $R^2$ respectively for the validation period. For Adhaim Watershed, the model of DEM 250 m resolution (SRTM) and LC of 1000 m resolution (MODIS) achieved the best result than the other models with 0.74 and 0.68 of NS and $R^2$ respectively for the validation period. While for Duhok Watershed the model of DEM30 m resolution (ASTER) and LC of 30 m resolution (Landsat) achieved the best results with 0.69 and 0.69 of NS and $R^2$ respectively. These values are acceptable according to Abbaspour et al. (2007).

## 4 Conclusions

The sensitivity of SWAT hydrologic model to the resolution of input DEM and LC data for three watersheds of different characteristics was examined. From the results, it can be concluded that variation of DEM resolution causes big variances in watershed delineation, stream network position and total area. The watershed delineation, stream network position and total area are highly effected by the DEM resolution and the characteristics of the watershed terrain especially in flat watersheds. However, losses of detailed topographic information at coarser resolution produced an overestimate for the minimum elevations and underestimate for the maximum elevations with the decrease (coarser) in DEM resolution. Also, the number of sub-basins changed unevenly with the change in DEM resolution.

The results indicated that with the decrease in DEM resolution the number of HRUs decreases for each LC resolutions. While the number of HRUs changed unevenly with LC resolution. In spite of, Adhaim Watershed is larger than Dokan Watershed for all resulting models, the number of HRUs of Dokan is higher than that of Adhaim, because the variances of slopes and LC in Dokan Watershed are higher than that of Adhaim Watershed. In other word, HRU is the matching between the three elements of slope, LC, and soil creates the HRU, so the large variances in these three elements create large number of HRU and vice versa.

Accordingly, the models of finer DEM and LC resolutions did not provide accurate runoff simulation by SWAT model, also the large number of HRUs of higher data storage and longer time of run, calibration, and validation did not improve the runoff simulation. This is because that the increase in the number of HRUs increases the hydrologic parameters and then this leads to generate over parameterization. While the number of observed variables used in calibration is only the observed flow and the uncertainty in LC data plays an important role when defining HRUs. The LC classes adjusted to matching the default SWAT LC classes, this introduces much uncertainty on simulated runoff especially with the high number of HRUs.

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**Table 1.** Utilized DEMs in SWAT models of Dokan, Adhaim and  Duhok Watersheds Watershed.

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

**Table 2.** Utilized LC data in SWAT models of Dokan, Adhaim and Duhok Watersheds.

| No | Name | Spatial | Source |
|---|---|---|---|
| 1 | Landsat | 15 m | Mohammed, 2010 |
| 2 | Landsat | 30 m | http://www.globallandcover.com/ |
| 3 | ESA | 300 m | http://maps.elie.ucl.ac.be/CCI/viewer/download.php |
| 4 | MODIS | 500 m | http://gdex.cr. usgs.gov/gdex/ |
| 5 | MODIS | 1000m | http://gdex.cr.usgs.gov/gdex/ |

**Table 3.** Total area of Dokan, Adhaim and Duhok Watershed.

| DEM resolution | Dokan | | Adhaim | | Duhok | |
|---|---|---|---|---|---|---|
| | Total area ($km^2$) | No. of sub-basins | Total area ($km^2$) | No. of sub-basins | Total area ($km^2$) | No. of sub-basins |
| 30 | 11499 | 33 | 12013 | 33 | 133.8 | 7 |
| 50 | 11357 | 33 | 12116 | 37 | 134.5 | 7 |
| 90 | 11336 | 33 | 11910 | 35 | 135 | 7 |
| 250 | 11558 | 35 | 11901 | 31 | 137.5 | 5 |
| 1000 | 11552 | 31 | 11979 | 33 | * | * |

*indicated no model in this resolution.

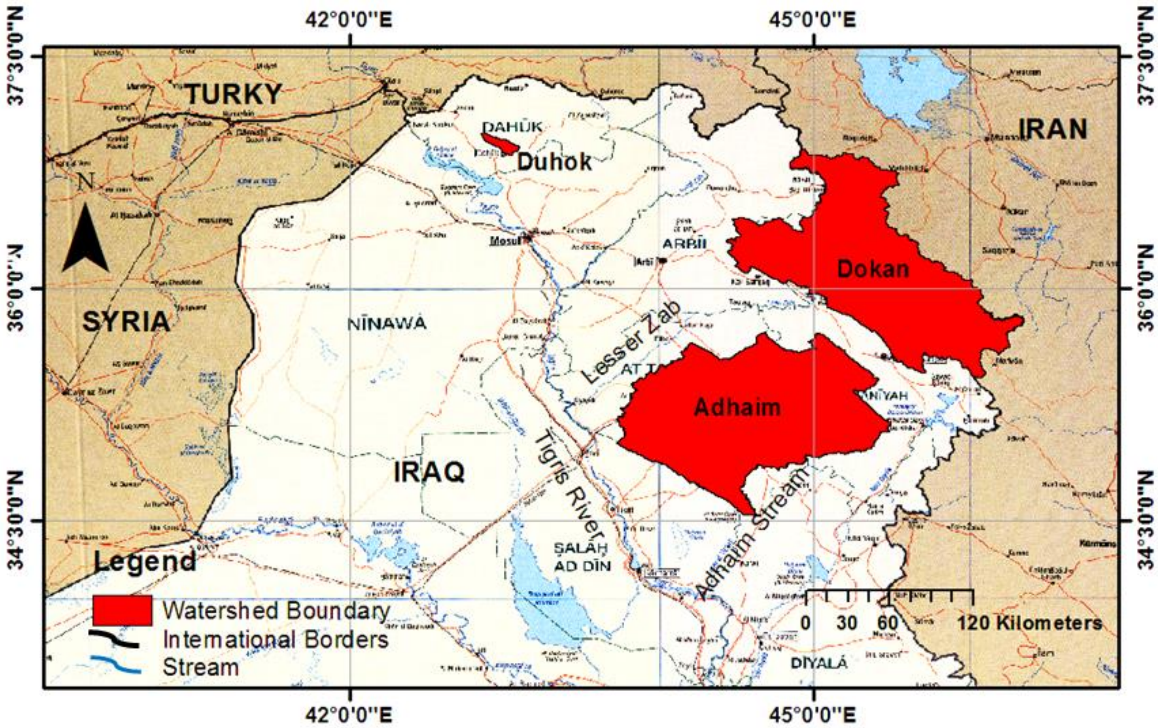


Figure 1. Location of study area.

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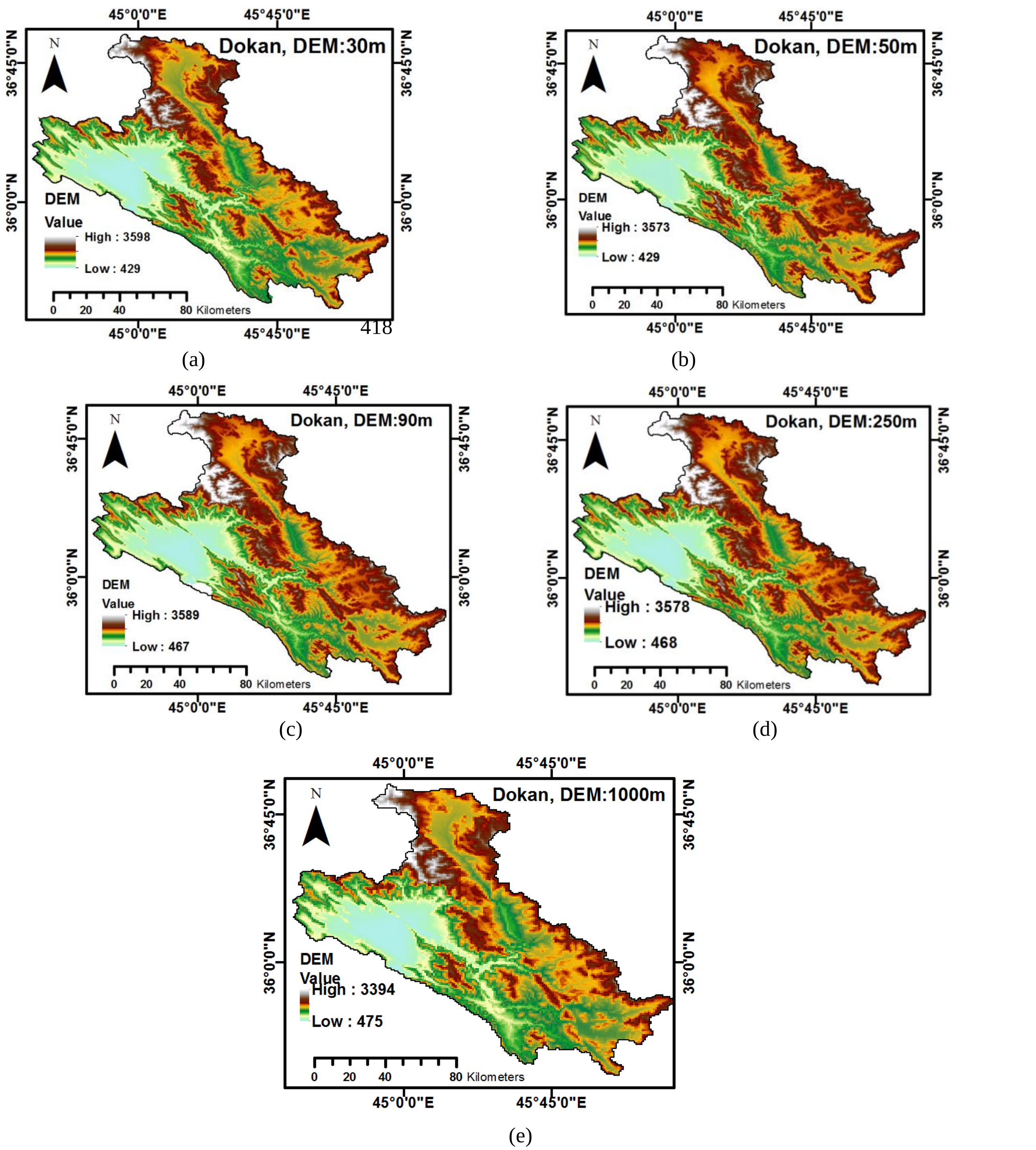


**Figure 2.** The DEMs utilized in SWAT models for Dokan Watershed; (a) Dokan DEM 30 m, (b) Dokan DEM 50 m, (c) Dokan DEM 90 m, (d) Dokan DEM 250 m, (e) Dokan DEM 1000 m.

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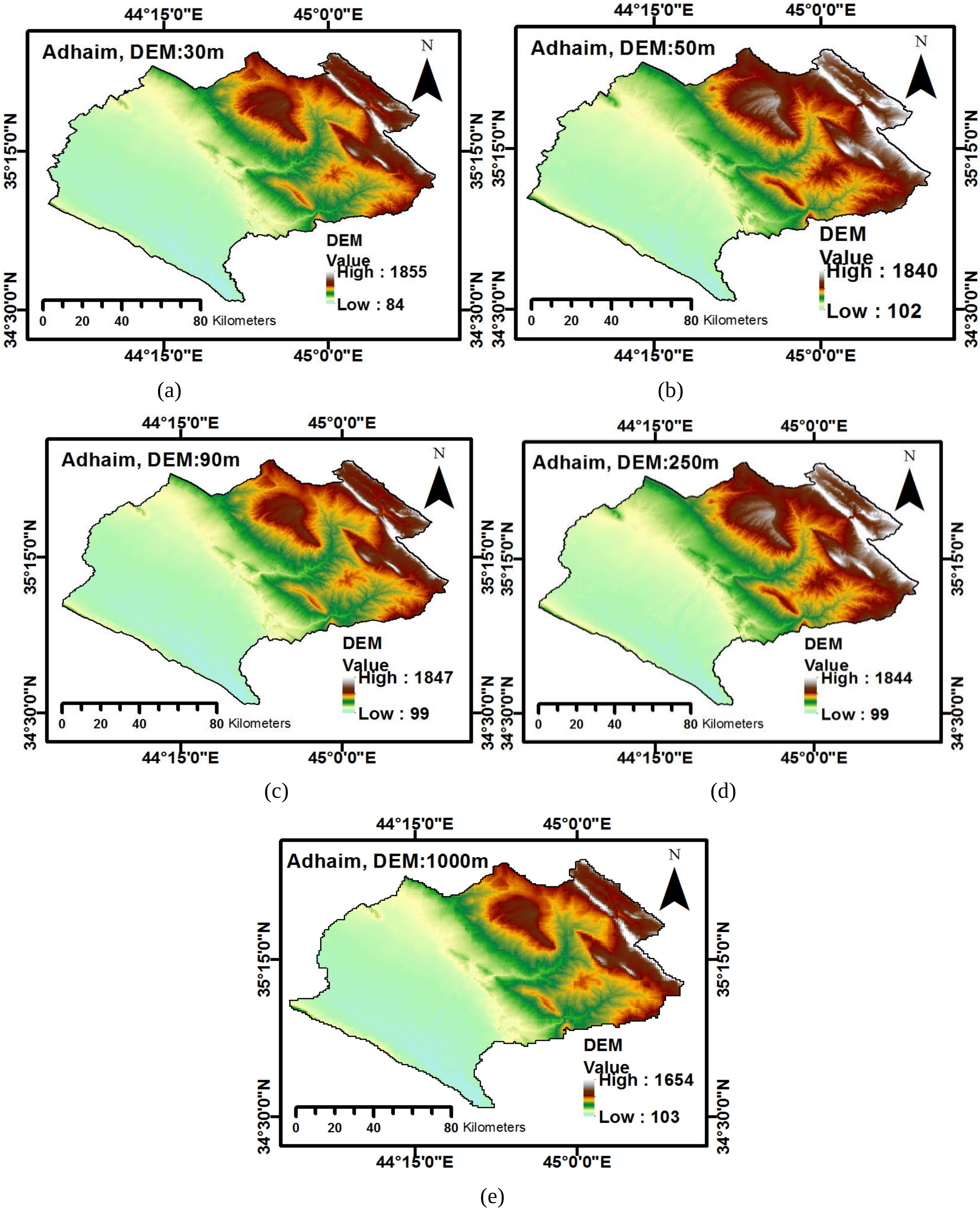


**Figure 3.** The DEMs utilized in SWAT models for Adhaim Watershed; (a) Adhaim DEM 30 m, (b) Adhaim DEM 50 m, (c) Adhaim DEM 90 m, (d) Adhaim DEM 250 m, (e) Adhaim DEM 1000 m.

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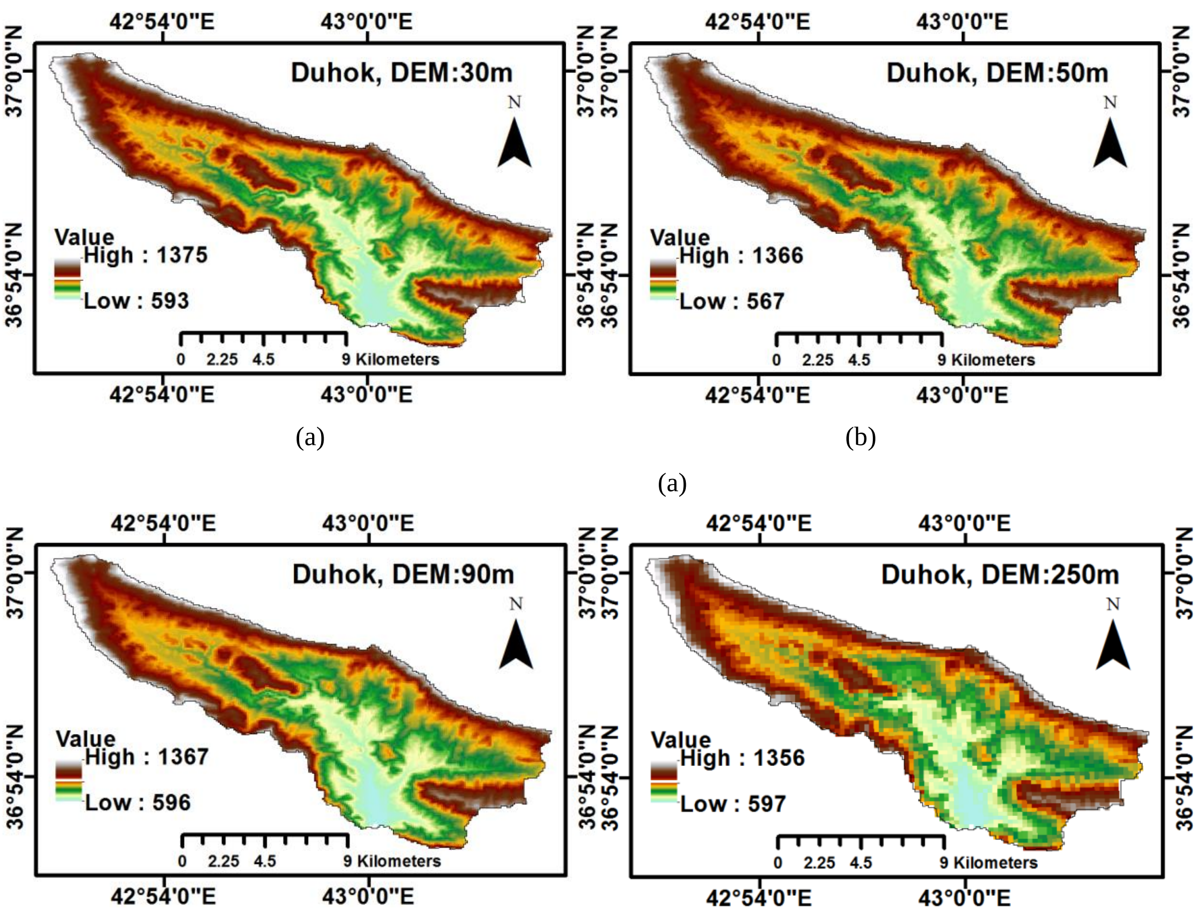


(a) (b)

(a)

(c) (d)

**Figure 4.** The DEMs utilized in SWAT models for Duhok Watershed; (a) Duhok DEM 30 m, (b) Duhok DEM 50 m, (c) Duhok DEM 90 m, (d) Duhok DEM 250 m.

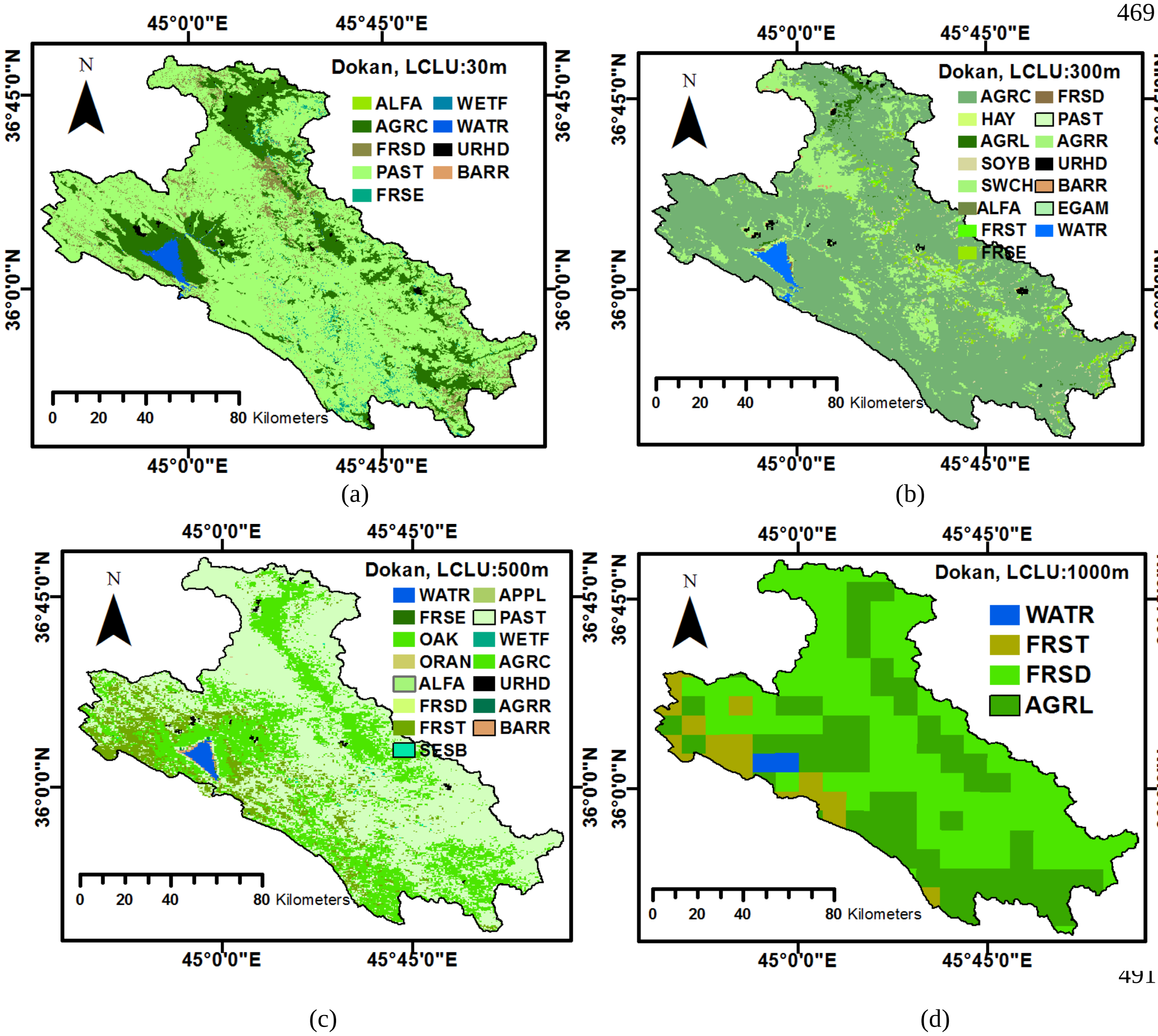


**Figure 5.** The LC utilized in SWAT models for Dokan Watershed; (a) Dokan LC 30 m, (b) Dokan LC 300 m, (c) Dokan LC 500 m, (d) Dokan LC 1000 m.

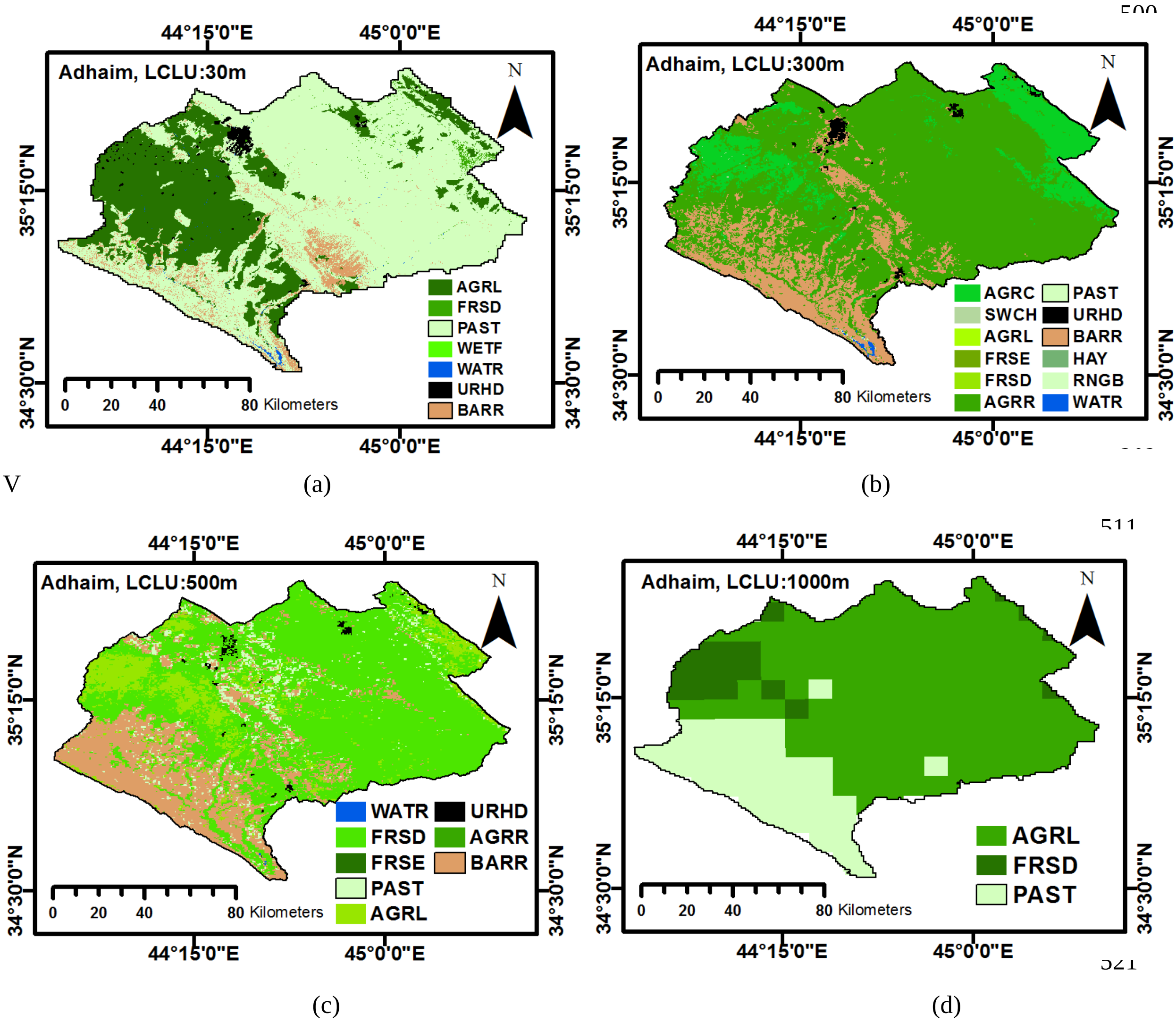


**Figure 6.** The LC utilized in SWAT models for Adhaim Watershed: (a) Dokan LC 30 m, (b) Dokan LC 300 m, (c) Dokan LC 500 m, (d) Dokan LC 1000 m.

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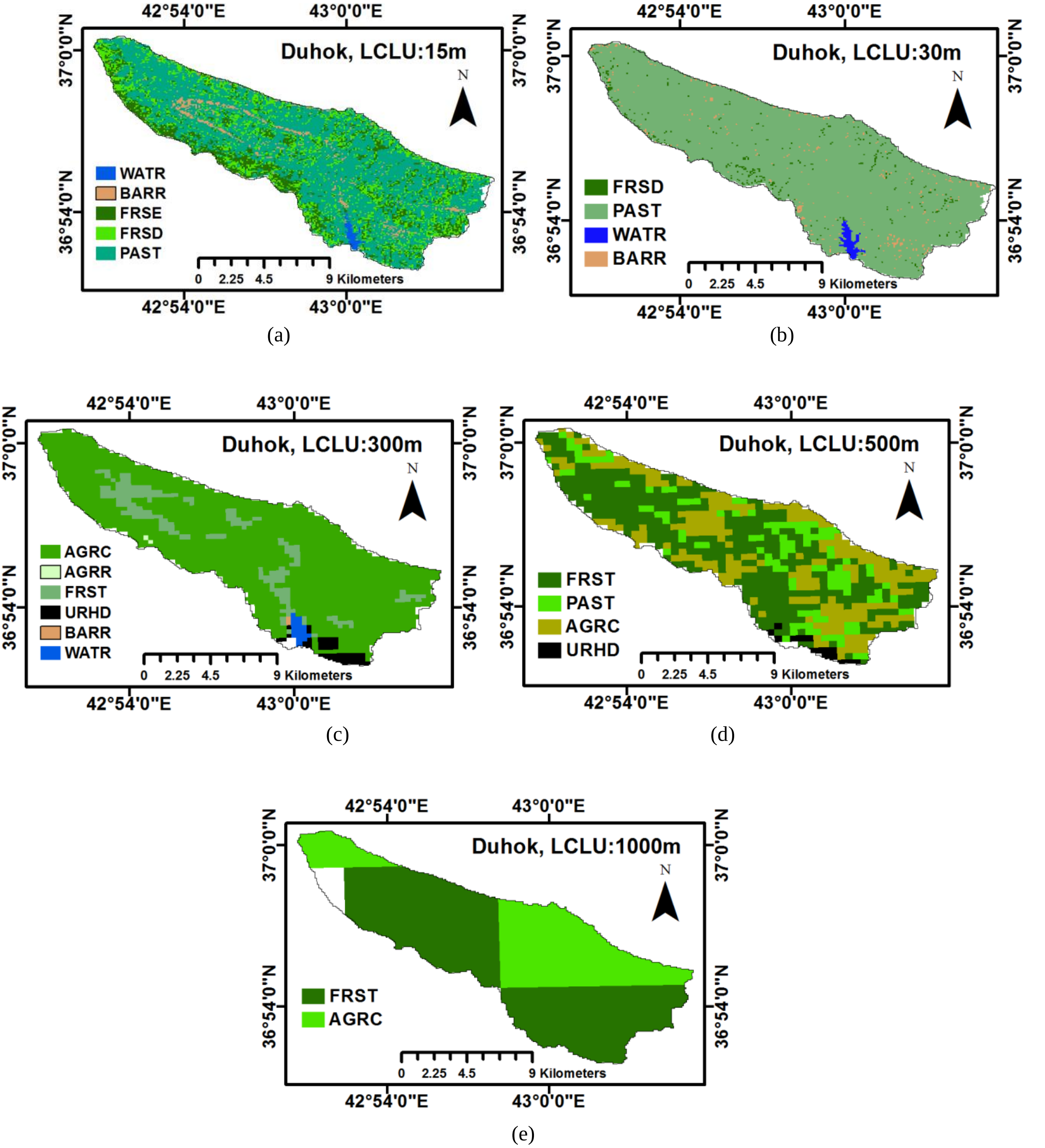



**Figure 7.** The LC utilized in SWAT models for Duhok Watershed; (a) Duhok LC 15 m, (b) Duhok LC 30 m, (c) Duhok LC 300 m, (d) Duhok LC 500 m, (e) Duhok LC 1000 m.

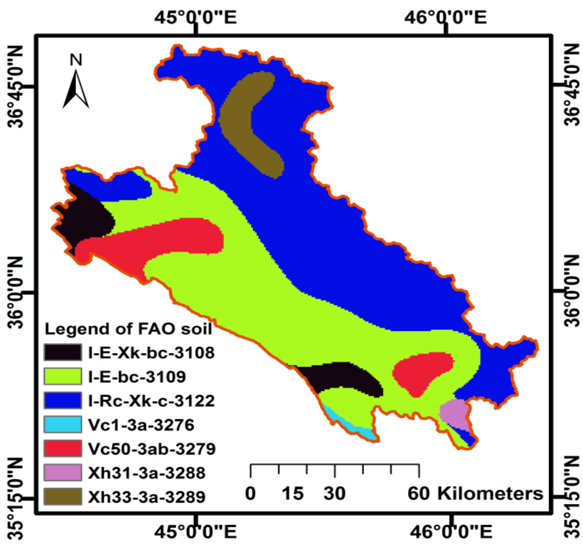



**Figure 8**. Utilized soil map in SWAT model of Dokan watershed.

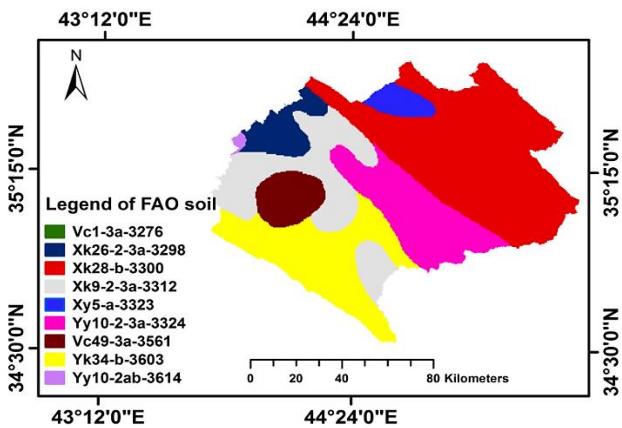



**Figure 9**. Utilized soil map in SWAT model of Adhaim watershed.

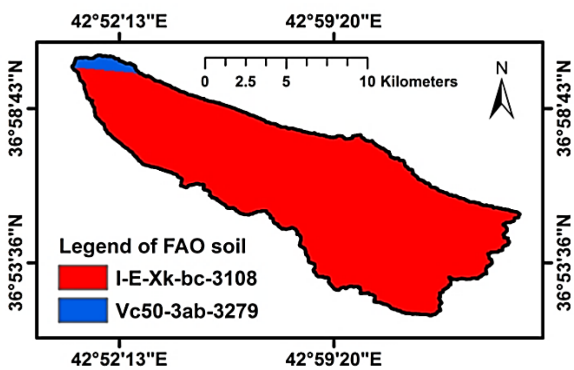



**Figure 10**. Utilized soil map in SWAT model of Duhok watershed.

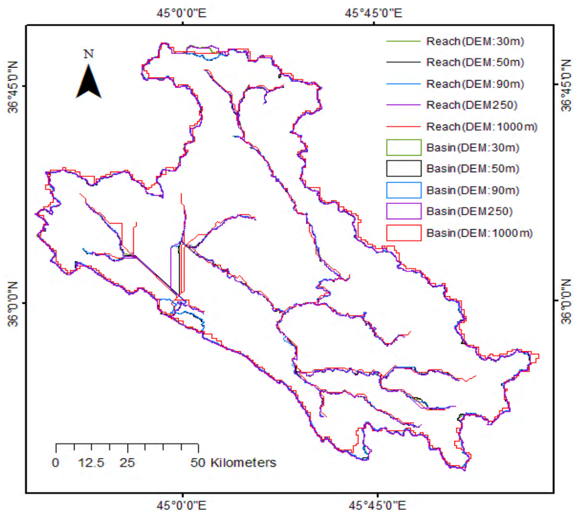



**Figure 11.** Delineation of Dokan watershed.

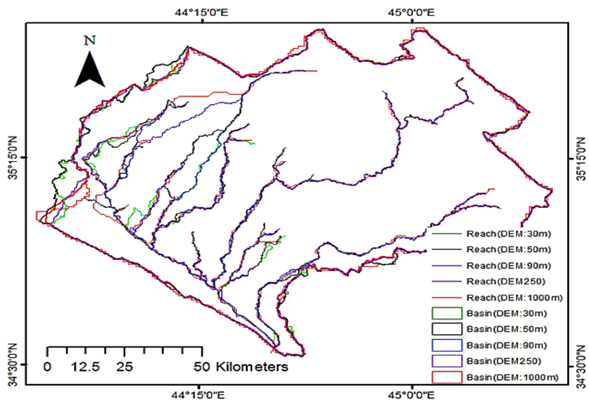



**Figure 12.** Delineation of Adhaim watershed.

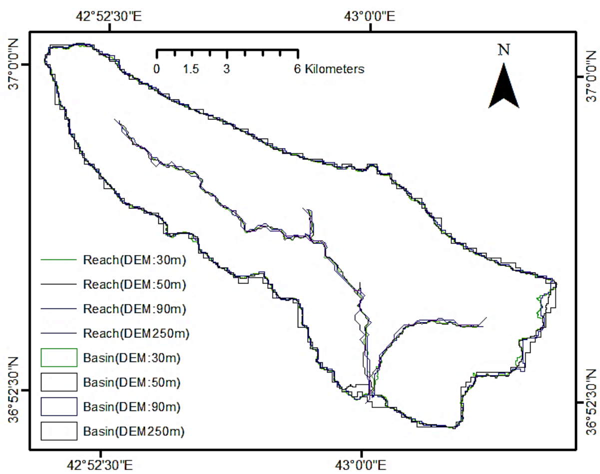
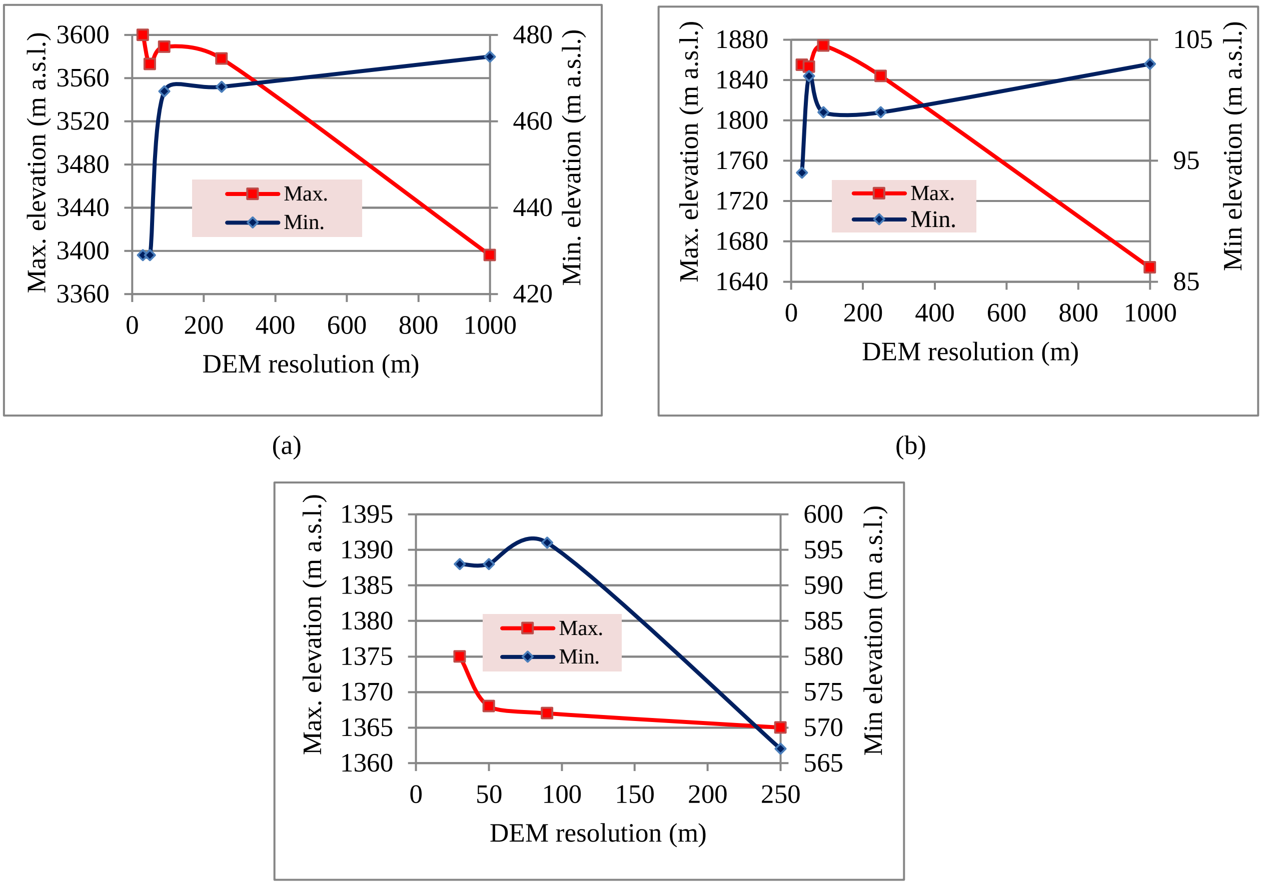
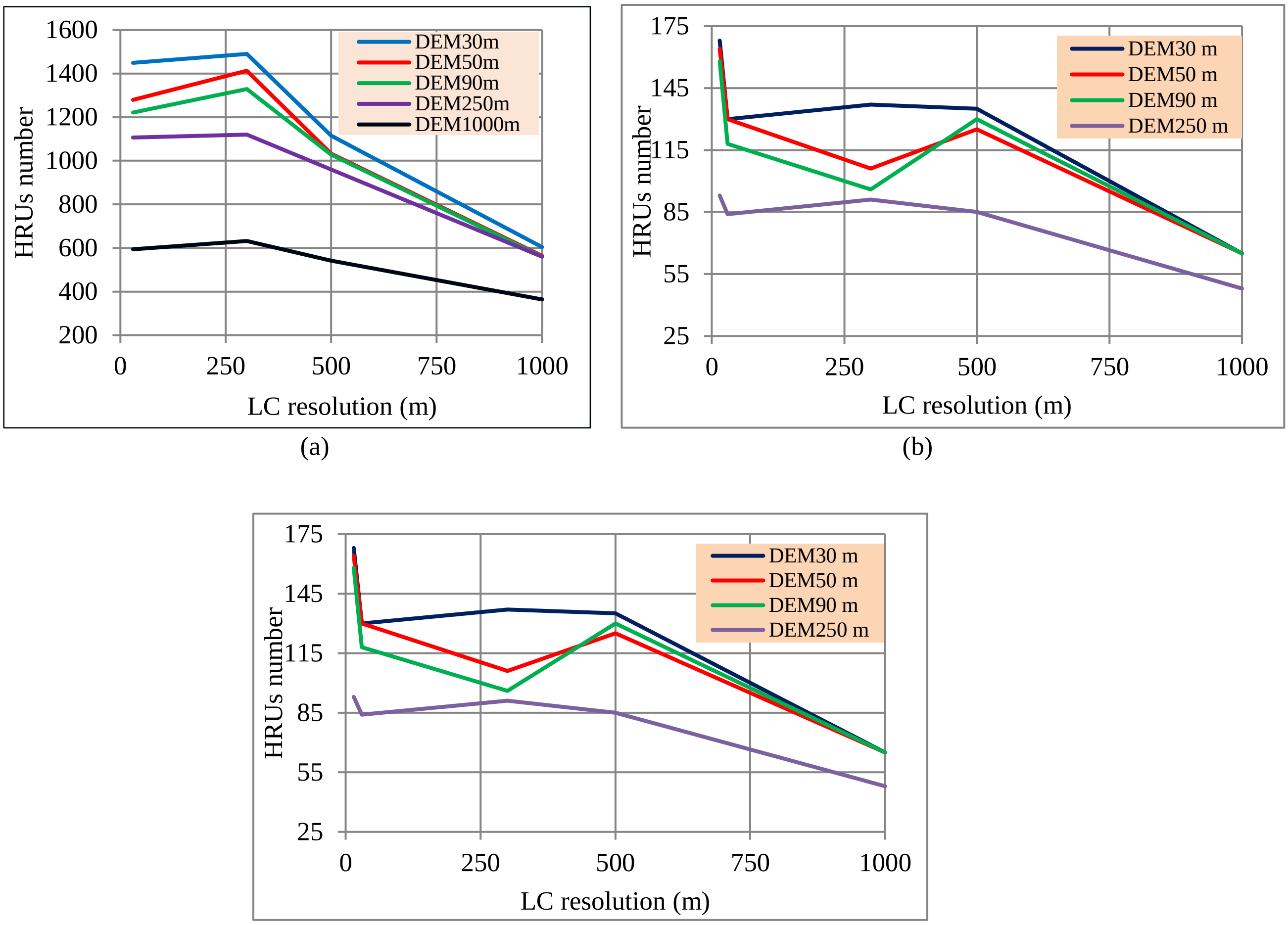



**Figure 13.** Delineation of Duhok watershed.



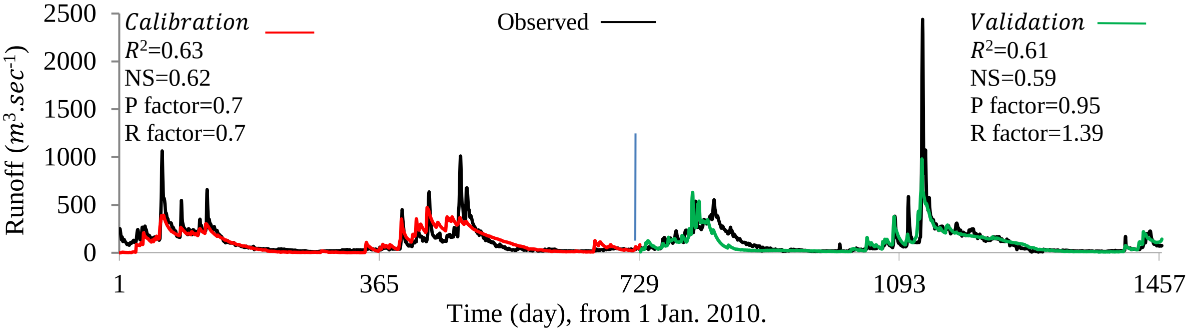

(c)

**Figure 14.** Minimum and Maximum ground elevation for different DEM resolution; (a) Dokan watershed, (b) Adhaim watershed, (c) Duhok watershed.

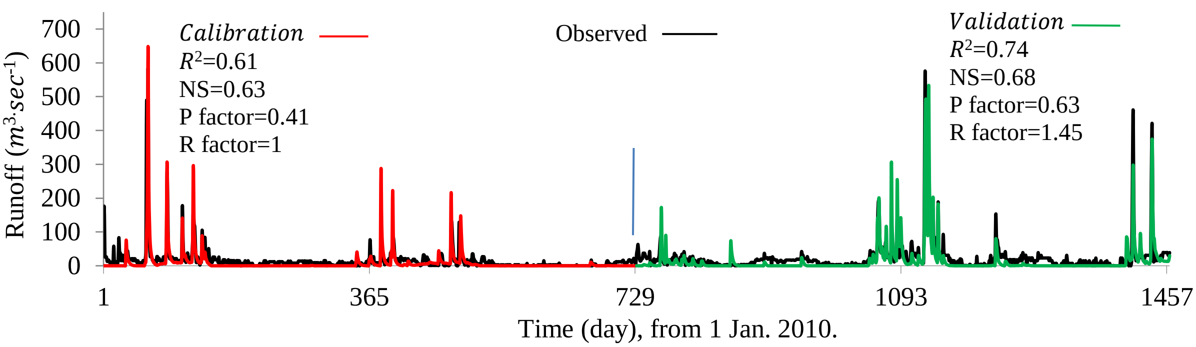



(c)

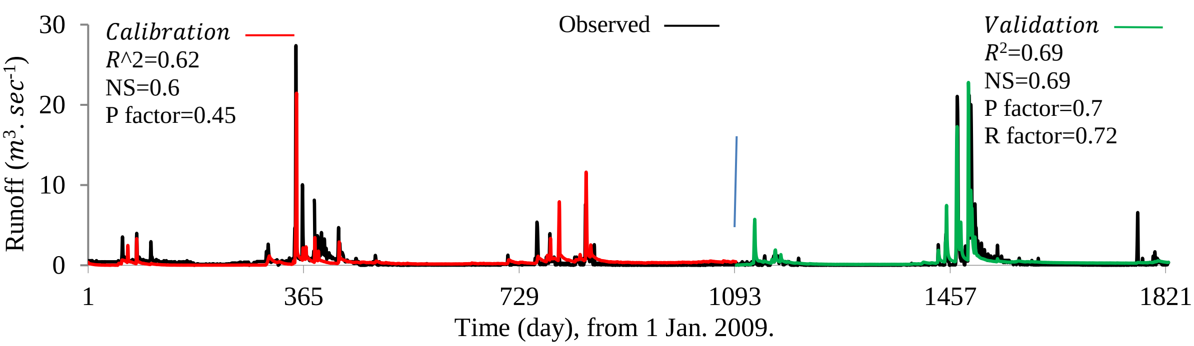
**Figure 15.** HRUs number of the watersheds versus DEM and LC resolution; (a) Dokan watershed, (b Adhaim watershed, (c) Duhok watershed.




(a)




(b)




**(c)**

**Figure 16**. Results of the best validated models; (a) Dokan model (DEM250m, LC1000m), (b) Adhaim model (DEM250m, LC1000m), (c) Duhok model (DEM30m, LC30m).