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Application of Arc-GIS, HEC-GeoHMS and HEC-HMS in a holistic sense for estimation of rainfall-runoff process: case study over Ballikaya Basin

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ABSTRACT. In this paper, the relationship between rainfall and runoff is examined according to SCS-CN method based on DEM, soil and land use maps over Ballikaya Watershed. For the applicability of the method, firstly, the basin physical characteristics are compiled in Arc-GIS environment. Then, parameters related to the physical properties of the land are processed via HEC-GeoHMS, and continuous rainfall-runoff simulations are estimated by the HEC-HMS. The simulation parameters are conducted with five different objective function methods, and evaluations of the model performance are explained in addition to graphical methods with different metrics including NSCE, MRE and PCC. Results show that the HEC-HMS simulations capture time of the peak although predictions slightly underestimate value of the peak flows and runoff volume. Nevertheless, runoff fluctuation is simulated well respect to observed hydrographs over the watershed during both calibration and verification periods. In addition, the obtained simulation values with this study show that the hydrograph values of the rivers in the Ballikaya Watershed have the potential to be predicted via computer environment without any need from gauging measurements. Results can be used to investigate potential drought and flood risks over the region based only on the weather forecasts for the future studies.

Keywords: Ballikaya Basin; continuous rainfall-runoff simulations; HEC-GeoHMS; HEC-HMS; SCS-CN.

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Introduction

Flood is concerned as a major natural hazard that affects different regions of the world each year. In recent years, there has been significant amount loss of lives, damages of property and infrastructure due to floods around the world, and unfortunately these numbers continue to rise. According to the World Disasters Report (International Federation of Red Cross and Red Crescent Societies [IFRC], 2010), in just eight years, an average of 99 million people per year have been affected by various natural disasters, mainly floods, throughout the world. As reported by the Republic of Turkey Ministry of Agriculture and Forestry, General Directorate of Water Management, it is expected that there will be an increase in the number of floods and their damages due to human activities (i.e. settlement in the floodplains, intervention in the stream beds, and climate change; Su Yönetimi Genel Müdürlüğü [SYGM], 2017). In this context, flood management can be ranked as one of the biggest problems in a region. For this purpose, flood analysis is based on understanding the relationship between rainfall-runoff and capturing of the flow hydrograph generated by precipitation over a basin.

Rainfall-runoff relationship and flood estimations can be easily performed through remote sensing and hydrological package programs including the former mentioned methods with the developing technology. Many programs have been developed on designing and modeling the rainfall-runoff process, one of which is the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). The model has been tested in long-term water regime and flash flood modeling for many years while it is also widely used on a global scale. For instance, Chu and Steinman (2009) stated in their study in Western Michigan that they reached detailed hydrological findings of runoff amounts and its fluctuation in the Mona Lake Basin by the HEC-HMS model. As another example, Jin, Liang, Wang, and Tumula (2015) simulated rainfall- runoff process using the HEC-HMS model in typical semi-arid and semi-humid climates in Northern China. For this purpose, Jianghe Basin was selected and the suitability and accuracy of different components in the model (i.e. Initial Constant-Rate, Soil Conservation Service-Curve Number [SCS-CN], Kinematic Wave, SCS Unit Hydrograph, Muskingum methods) were investigated. The results showed that the SCS-CN model performed better in this climatic area compared to the observed flow while its accuracy depends on hydrological characteristics, topography, soil type and land use in the region. In addition, Sardoii, Rostami, Sigaroudi, and Taheri, (2012), moreover, run different loss modules (Initial & Constant, Green & Ampt, SCS-CN) with calibrated model to estimate rainfall-runoff process in Iran. For this purpose, Amirkabir Dam Basin has been selected and seven different storm events have been modeled. Sensitivity analysis of the variables used in each method for model calibration was also performed. The analysis resulted that the most sensitive parameters were initial loss (in Initial & Constant method), curve number (in SCS-CN method) and soil moisture (in Green & Ampt method). According to the statistical performance evaluations used in the study, the Green & Ampt module yielded the best results, while the SCS-CN approach was better than the Initial & Constant method. Majidi and Shahedi (2012) also used HEC-HMS in their study to estimate the rainfall-runoff process and simulate associated five different storms in the Abnama Basin, in Southern Iran. Green & Ampt, SCS Unit Hydrograph and Muskingum Routing methods were applied to predict infiltration, excess rainfall and flow routing, respectively. Model calibration and sensitivity analysis were performed with the optimization method since preliminary results showed strong bias between observed and predicted peak flow values. The analysis exhibits that lag time is a sensitive parameter, so the model validation using the optimized parameter showed a reasonable difference in peak flow, and emphasized the importance of proper calibration of the model.

According to Maidment and Ahrens (1999), when hydrometeorological modeling is well calibrated based on precipitation driven runoff scenarios, the results of the models provide a reliable tool for decision-making by national policy makers in a region and country. For example, Boyogueno, Mbessa, and Tatietse (2012) used the HEC-HMS model to capture the rainfall-runoff model of the Sanaga Basin, in Cameroon. Various aspects of modeling including surface runoff, direct runoff, base-flow, underground water, infiltration losses, and the interactions between them were discussed in the study. The model provided acceptable results in tropical and equatorial climate regions with a small number of data sets. The obtained results have contributed to the planning of Mbakaou Dam and consequently the increase of hydroelectric production, and hydrometeorological management such as flood prevention. Moreover, Emam, Mishra, Kumar, Masago, and Fukushi (2016) examined the effects of land use and climate changes on flooding (i.e. hydrograph fluctuation and peak flow values) in the Ciliwung River Basin in Jakarta, Indonesia. In the study, HEC-HMS model was applied to attain the peak river flow values for present and future conditions. The model was analyzed according to the flow values observed during the calibration and validation periods. It is estimated that peak flow will increase by 20% due to land use changes predicted in the region by 2030; with the future climate scenario, the peak flow that can be caused by rainfall with a return interval of 50 years will increase by 130%. Based on the results of this study, the implementation of a flood management plan in the area to reduce flooding in the near future is expressed as an emergency.

One of the applications made in the past through the SCS-CN module regarding flood analysis is Oleyiblo and Li (2010). This study was applied as a holistic sense with SCS-CN method and HEC-GeoHMS, in the estimation of the flow volume maxima and flood estimation of the Misai and Wan'an basins, in China. According to the model results, it is reported that there is a good correlation between the simulated and observed hydrographs and the relative errors in peak flow rates remain at acceptable limits. In addition to this study, continuous rainfall-runoff simulation over the Kosynthos River (Northeast of Greece) was studied by Kaffas and Hrissanthou (2014) using the HEC-HMS model. The conversion of rainfall losses and excess rainfall to direct flow hydrograph was estimated by the SCS-CN and SCS-Unit Hydrograph modules, respectively. Furthermore, the base-flow was calculated by applying the Exponential Recession method. The routing of the total flow hydrograph from the highest elevation to outlet of the basin was carried out by the Muskingum-Cunge model. As a result, it has been stated that simulated and observed flow values is highly correlated and the bias is insignificant, and concluded that the applied model for the long-term water regime of the region has potential to predict the flow measurements. However, the HEC-HMS hydrological model in Turkey is still widely and accurately unavailable due to difficulties in accessing the necessary data sets. In this study, with hydrograph simulation values obtained via HEC-HMS, the flow values of the streams in the Ballikaya River Basin will have the potential to be captured through computer environment without the need from measurements. Additionally, results from this research can be used to investigate potential drought and flood risks over the region based only on the weather forecasts for the future studies. For this purpose, model calibration was performed in order to adjust the parameter values in the HMS model to overlap the daily flow measurements of the rainfall-resulting estimations in the continuous simulation, and then the parameters were verified using daily data for another time period.

Material and methods

The drainage area delineated with the obtained Digital Elevation Model (DEM) data and based on gauging station coordinates in Geographic Information System (GIS) environment for basin modeling. Land cover, vegetation types, and soil maps were used in this study to divide catchment into sub-basins and to indicate the CNs. Then, the watershed characteristics were employed in rainfall-runoff process in the HEC-HMS environment. The simulated hydrographs attained using with five different objective functions and error propagation explained with various statistics and graphs (Figure 1).

Study region and data processing

The study area is Ballikaya Basin over Ceyhan Watershed located in the southeast Turkey with a domain ranging from 37º 04' N to 37º 12' N and 36º 50' E to 37º 02' E. The Ballikaya River is discharging at 37° 08' 04" N and 36° 52' 40" E. The region is critical because of the dam construction planned by the General Directorate of State Hydraulic Works. For the study area in Gaziantep, the boundaries of the basin were extracted by using Arc-GIS (Aeronautical Reconnaissance Coverage) using the DEM data with the spatial resolution of 30x30 m provided from the US Geological Survey (USGS) (Anonymous, 2018). In the application, Arc-Hydro module under Arc-GIS environment was implemented using the grid-structured digital elevation model to determine the parameters of the basin. Using the DEM data over the basin as input, terrain preprocessing is a series of steps achieved to derive drainage networks in Arc-Hydro. Raster analysis is performed to produce data on watershed characteristics such as flow direction, flow accumulation, stream definition, stream segmentation, and these data are then used to improve the vector representation of catchment and drainage lines. The DEM has a significant value in any hydrological study since they provide a clear view of the elevation variation in the basin and the main river path. Therefore, it is considered extremely important to obtain a robust DEM data to achieve accurate results for hydrological modeling. For this purpose, hydrologically adjusted DEM data was used in the study to produce flow direction and accumulation files for the region. The study area (~78 km^2) is divided into five sub-basins based on watershed characteristics (i.e. land use/cover, soil maps, and their associated CN) with drainage area varying from 6,47 to 23,12 km^2 (Figure 2). In Figure 2, blue and red lines represent the stream network and basin borders, respectively. The highest point (1428 m M.S.L., Mean Sea Level) is in the southern part and the lowest point (615 m M.S.L.) in the western corner with general elevation gradient dropping from east to west.

The main soil types over the basin consist of Red Mediterranean (72,72%), Brown Limeless Forest (27,23%), and Colluvial soil (0,04%; Figure 3a). The Red Mediterranean, which forms the largest percentage of basin soil, is spread throughout the North and Southeast of the watershed, while the Brown Forest soil type is located in the Southwest of the catchment. The Colluvial soil, on the other hand, representing the lowest percentage is located in a small area at the outlet of the basin. The land cover data set was obtained with a spatial resolution of 100x100 m from Corine Land Cover (CLC; Copernicus, 2012). CLC is one of the data sets produced within the framework of the Corine Land Cover Program according to the land use/cover status in 2012. The CLC, which is coordinated by the European Environment Agency provides consistent information on land cover and its associated changes across Europe based on the interpretation of satellite images by participating countries. These products are available in both raster (100 m resolution) and vector (ESRI and SQLite geodatabase). CLC data has some generalizations: the minimum mapping unit for status layers is 25 ha; the minimum width for linear phenomena is 100 m, which means that areas less than 25 ha and any road or river with a width of less than 100 m will not appear in the data set (Copernicus, 2012). Ballikaya Basin has ten classes of land use/cover including cultivated lands, coniferous forest, natural vegetation, mixed forest, natural pastures, non-irrigated arable land, irrigated land, sparse vegetation, shrub and vineyard (Figure 3b). However, since the data set has coarse spatial resolution and there are only small/sparse settlements in the study area, no residential area can be seen clearly.

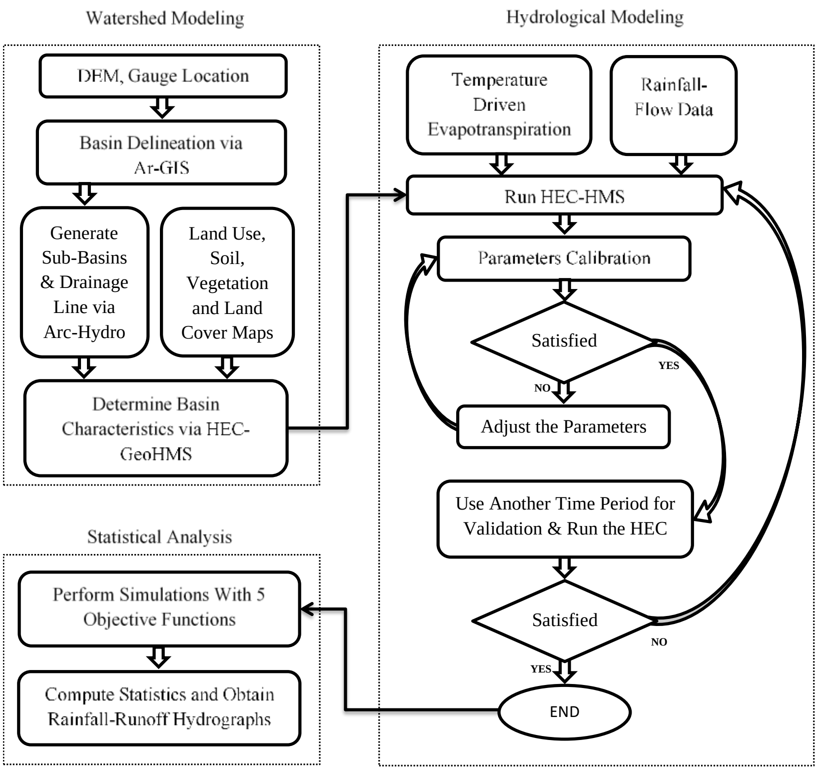

Figure 1. Flow diagram used in methodology.

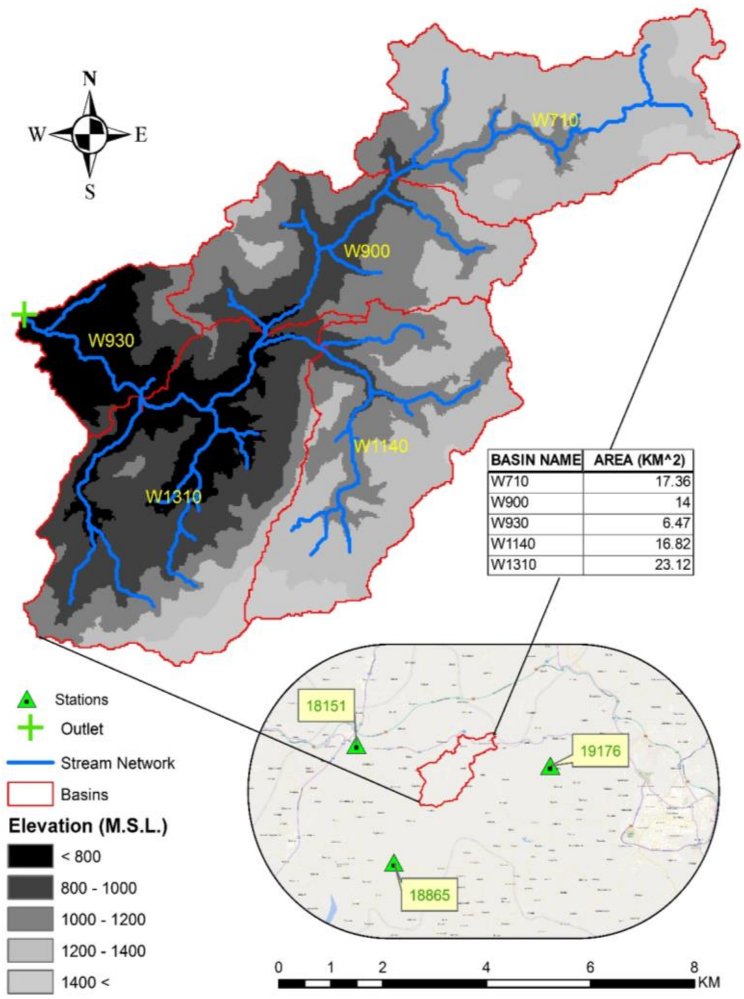

Figure 2. Map of Ballikaya Watershed and its sub-basins with their coverage areas.

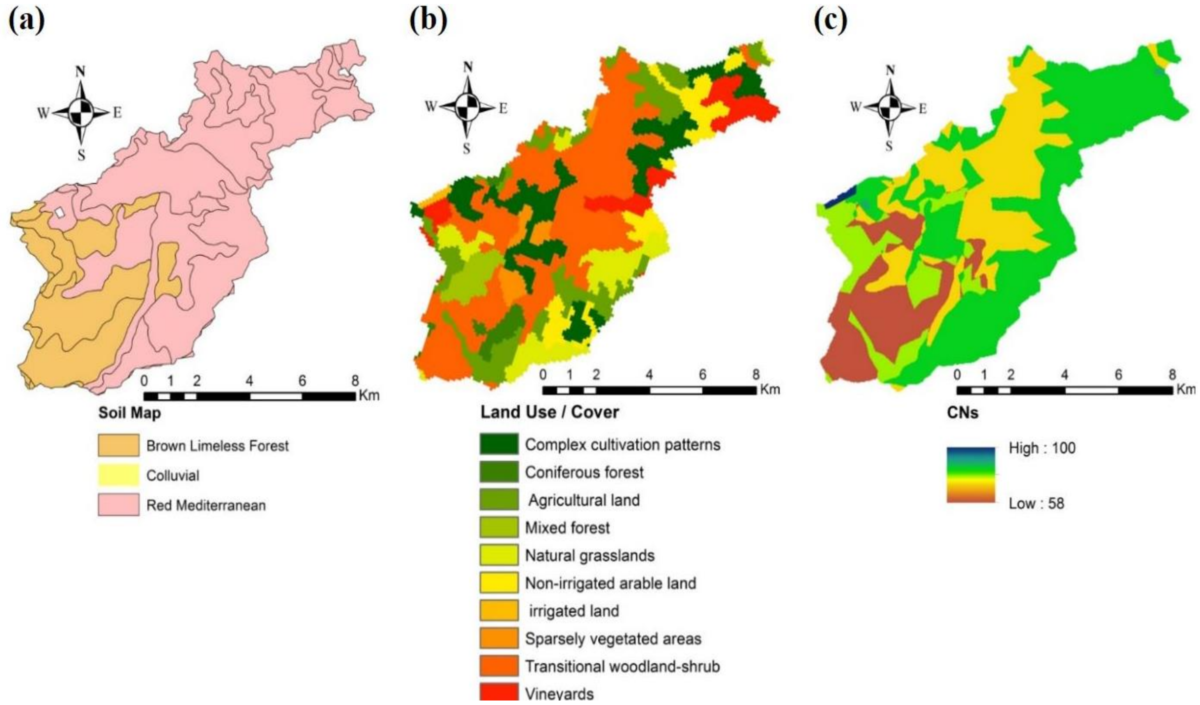

Figure 3. Ballikaya Basin characteristics.

Precipitation, undoubtfully, is the most important component of a hydrometeorological model and is necessary in almost all of the applications. Besides, it is the trigger of runoff process in basins (Hydrologic Engineering Center [HEC] & Hydrologic Modeling System [HMS], 2018; Xavier Júnior, Stosic, Stosic, Jale, & Xavier, 2018). On the other hand, precipitation values contain probably one of the biggest uncertainties and furthermore differ spatio-temporally (Ibrahim-Bathis & Ahmed, 2016). Rain-gauges data was applied in the Ballikaya region since they are generally the best source for historical data. As it can be seen from the Figure 2, three meteorological stations are available around the basin, measured by the Turkish State Meteorological Service (MGM), namely 19176 Sehitkamil (2017-2020), 18865 Islahiye Alaca Koy (2016-2020) and 18151 Nurdagi (2012-2020). However, due to the lack of long-term data on the first two monitoring stations, precipitation data was obtained from Nurdagi station with daily temporal resolution to be used in the simulation (MGM, 2020). Daily runoff values of Ballikaya (D20A040) station at the basin outlet were obtained from the General Directorate of State Hydraulic Works (DSI).

Hydrological modelling

The HEC-HMS hydrological modeling system is a software developed by the US Army Corps of Engineers (USACE). The Model is capable of simulating the precipitation-runoff processes of dendritic basin systems (HEC & HMS, 2018). The HEC-1, the previous version of HEC-HMS, which introduced in 1968, is one of the earliest researches and engineering applications widely used by institutions, governments and companies. In 1998, HEC-HMS was developed by USACE as a version suitable for operating in Windows environment including a Graphical User Interface (GUI). The GUI in the model allows users to comfortably manipulate hydrological elements and contentedly interpretate the data. The program is a generalized modeling system that can represent many different basins. The model is constructed by defining boundaries around a river basin of interest and separating the hydrological cycle into manageable pieces. Any flow mass or energy in the cycle can then be represented with a mathematical model. In most cases, several model options are available to perform each flux. The model provides simulation of land surface processes of the hydrologic cycle, and contains components for precipitation, potential evapotranspiration, snowmelt, canopy interception, surface storage, infiltration, surface runoff, base flow, channel routing, and channel losses and gains. Each element helps users to select the most suitable model for presenting watershed features. Components and their limitations are explained extensively in the HEC-HMS user manual (HEC & HMS, 2018). HEC-GeoHMS, on the other hand, has been developed as a geospatial hydrology tool kit for engineers and hydrologists. It allows users to visualize spatial information, document basin conditions, conduct spatial analyses, delineate sub-basins and streams, generate inputs to hydrological models. Working with the software through its easy GUI, menus, and tools, in a Windows environment allows the user to create hydrological inputs that can be applied directly with HEC-HMS (Hydrologic Engineering Center [HEC], & Geospatial Hydrologic Modeling System [GeoHMS], 2013). First of all, sub-basins were separated using Arc-GIS with location of Ballikaya gauging station and DEM data, and a study area was defined in HEC-GeoHMS for use in the HEC-HMS environment.

Soil conservation service curve number method

One of the most popular methods that used to determine runoff from a given precipitation input for an event-based or continuous simulation is the SCS-CN module in the HEC-HMS modeling. It is a physically-based and spatially distributed hydrological model (Viji, Prasanna, & Ilangovan, 2015). This method has an empirical structure developed by the American Environmental Protection Agency, in 1972. The module uses the CN, which expresses the amount of rainfall-runoff and the process depending on the physical characteristics of the basin. This method is widely used today by using the physical characteristics of the watershed such as land use/cover, soil type, and hydrological soil groups (United States Department of Agriculture [USDA], Natural Resources Conservation Service [NRCS], & Conservation Engineering Division [CED], 1986; Olivera, 2001; Hydrologic Engineering Center [HEC], & Hydrologic Modeling System [HMS], 2016). This method has been recommended for both rural and urban watersheds and has simple applicability with HEC-HMS and various computer models worldwide (Lin & Perkins, 1989). According to this method, the relationship between rainfall and the runoff depth can be expressed as follows:

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad for P > I_a \tag{1}$$

$$Q = 0 \qquad for P < I_a \tag{2}$$

$$I_a = \lambda S \tag{3}$$

$$S = \frac{25400}{CN} - 254 \tag{4}$$

where:
Q represents runoff depth (mm);
P denotes rainfall depth (mm);
I_a symbolizes initial abstraction (mm);
λ stands for initial abstraction ratio, and;
S is basin's potential maximum retention (mm).

In this method, a procedure is used that connects the maximum potential amount of water that the catchment can hold from the runoff begins, the S parameter, which is a function of the CN, to the available water capacity of the soil. CN is a hydrological parameter used in hydrology to determine the amount of precipitation infiltrates into the soil or aquifers and provides corresponding surface flow from the excess rainfall. In places such as urban areas (woodlands and dry soil) the increment (decrement) in CN values and consequently yields high amount of flow (infiltration) capacity. The three main factors affecting the CN values are Antecedent Moisture Condition (AMC), soil type, and land use. Runoff in a storm is directly related to effective rainfall. The effective rainfall, on the other hand, is inversely proportional to hydrological losses, including surface retention, evapotranspiration, and infiltration. In wet seasons, however, infiltration is the most important loss. In addition, actual infiltration rates and quantities depend heavily on the AMC. The SCS-CN method is divided into three moisture levels: dry (AMC I), average (AMC II) and moist (AMC III; USDA, NRCS, & CED, 1986; Mishra & Singh, 2003). Chow, Maidment, and Mays (1988) proposed relationships to calculate the CN variable for each humidity situation. However, most CN value tables have been developed for average condition as follows:

$$CN = \frac{25400}{S + 254} \qquad \text{Case-II (Average)} \tag{5}$$

Soil types have a fundamental role in the calculation of infiltration and rainfall-runoff estimations in the catchment scale. Each Hydrological Soil Group (HSG) has a certain infiltration rate. HSGs are divided into four groups as A, B, C, D from low flow potential to high according to their infiltration capacity. At the same time, HSGs under various land use/cover and soil types are important in the determination of CN values (USDA, NRCS, & CED, 1986). In the Ballikaya Basin, colluvial soil is classified as type-A and limeless brown forest soil as type-B. Red Mediterranean soil, on the other hand, can be considered to have C class features with low drainage and high flow capacity in the region, while residential areas, which are covering diminutive area, can be accepted as a type-D with very high overland-flow potential. Land use pattern in a basin is another important factor that directly influents CNs and surface runoff volume. However, land use classes with similar characteristics can be classified as a same group in order to facilitate curve number calculation. For example, urban, residential, public facilities and schools can be considered as one group with the name of middle residential. Similarly, rivers, lakes and marshes can be classified into another group with the name of water. In addition, it is possible to group forest and agriculture classes within themselves (Merwade, 2012). While, in this study, Ballikaya River Basin initially consisted of ten different categories (Figure 3b), the region was reclassified into four groups based on Merwade's suggestion. After reclassification process, residential class did not occur due to the fact that the data sets have sparse spatial resolution and settlement is generally rural and scattered. On the other hand, the vegetation cover of the basin is mainly composed of agricultural areas with a high rate of 55,5% and forests with 44%. The water class has a very small percentage (about 0,43%) of the basin land cover. Since it is very difficult and time-consuming to estimate CN in the traditional way, a GIS-based CN method has been produced for Ballikaya Basin. The CN values for Ballikaya Basin range from 58 to 100 with an average of 75, and this distribution is shown in Figure 3c.

Model parameters, calibration and validation

Calibration and validation of models are prerequisite before they can be used in research or field applications. A successful calibration of a model with appropriate data is an important step in establishing a reliable catchment representation and requires an accurate and reliable history record of both rainfall and runoff data. Hydrological model calibration is the process of matching simulated hydrographs with observed ones by adjusting model parameters. On the other hand, basin models have a large number of parameters that cannot be measured in-situ and these need to be estimated through model calibration (Duan, Sorooshian, & Gupta, 1994). HEC-HMS has both automatic and manual calibration options. Manual calibration is the process of manually changing model parameters to synchronize the simulated and observed hydrographs. This method is usually tedious and requires a lot of experience, however, it is practical only when there are a small number of input parameters that need to be adjusted (Boyle, Gupta, & Sorooshian, 2000). In automatic calibration, the model results can be clearly visualized and are generally faster than manual calibration (Madsen, 2000). In addition, if the number of parameters used in calibration is large, automatic calibration is a better option to reduce labor intensity. Moreover, the automated approach for model calibration reduces time with the speed and power advantage of high-performance computers (Dis, Anagnostou, Zac, Vergara, & Hong, 2015). The automatic calibration procedure in HEC-HMS requires the selection of an objective function that measure of how well the model is calibrated relative to the selected objective. In order to represent and investigate the hydrological response of the Ballikaya Basin, rainfall-runoff simulations (including calibration and validation) were compared with the in-situ measurements. In this study, the objective functions of Percent Error in Discharge Volume (PEDV), Variance of Squared Residuals (VSR), Peak-Weighted Root Mean Square Error (PWRMSE), First Lag Auto Correlation (FLAC), and Percent Error in Peak Discharge (PEPD) were used in calibration process due to their performance. While the model automatically calibrated for around a year (06/November/2014- 28/October/2015), the validation carried out for another time period between 29/December/2016 and 30/September/2017 to evaluate the accuracy of calibration parameters.

In the model to determine rainfall-driven runoff applying the CN methodology for incremental losses, impervious areas, CN and I_a ratio values should be given as input parameters. It has also been noted that CNs are the most sensitive inputs in estimation of direct runoff via the SCS-CN methodology (Soomro et al., 2019). This situation reveals that there is an increasing need to know basin characteristics such as land use, vegetation cover and ground features and to conduct field-required verification studies before the CN assignment. Hydrological parameters such as CN and impervious area can be derived from soil and land use data as catchment average or grid-based quantities. According to the CN map, Figure 3c, the value in each sub-basin was obtained as the catchment averages with the help of HEC-GeoHMS. In addition, I_a is generally estimated as 20% of S value for runoff estimation (United States Department of Agriculture [USDA], & Soil

Conservation Service [SCS], 1971). The SCS Unit Hydrograph method converts excess rainfall into a runoff hydrograph, and the lag time parameter, defined as the time interval between the peak of the hydrograph and the center of the hyetograph, must be specified in the method (HEC & HMS, 2018). These parameters were created with HEC-GeoHMS using GIS data sources, and the calculated values were considered as initial parameters. They, then, were adjusted using calibration and validation of the HEC-HMS model. For each basin, the lag time, T_L, was computed in (hours) using Equation 6. This equation is based on the curve number method described in the National Engineering Handbook (Natural Resources Conservation Service [NRCS], & United States Department of Agriculture [USDA], 2004).

$$T_L = \frac{L^{0,8} * (S+1)^{0,7}}{1900 * W^{0,5}} \qquad (6)$$

where:

L is the hydraulic length of the river basin (ft), it can also be defined as the longest flow from the highest elevation to the outlet. W represents average land slope (%) and the unit of storage coefficient, S, is inch in this equation. Table 1 shows these subbasin characteristics values for the study area. Majority of the watershed is described as agricultural and forested, so the impervious area ranges from 2,56 to 3,08% while CNs vary between 67,93 to 79,84.

In this study, the Muskingum method was used to route the hydrological runoff from the sub-basin outlets to the main outlet. The input parameters required for the HEC-HMS model in Muskingum approach flood routing are K and X. K is essentially the travel time through the reach. It can be assessed from knowledge of the cross-section properties and flow properties. However, since there is no information about the cross-section and flow characteristics, it can be set as 1 hour initially, then the actual value can be defined by calibration. X, on the other hand, refers to the weighting between the input and output stream; it varies from 0 to 0,5. In practical applications, the value of zero results in maximum change (attenuation), and 0,5 does not result in any change. In most stream channels, a medium (0,25) value is used, which is found through calibration (HEC & HMS, 2018).

Statistical indices

Statistical criteria are widely used by hydrologists to assess the proximity of simulation behaviors to measurements (Krause, Boyle, & Bäse, 2005). The following criteria were used in this study for the evaluation between rainfall-driven simulation and observed runoff values: Nash Sutcliffe Efficiency Coefficient (NSCE), Mean Relative Error (MRE), and Pearson Correlation Coefficient (PCC). NSCE value varies from '-∞' to '1'. In fact, convergence to one increases the satisfaction of model results, while the fact that the value is less than zero emphasizes that the mean observation value is better predictor than estimation. On the other hand, 'NSCE=1' corresponds to a perfect match of the model with the observed one. The Nash Sutcliffe efficiency is calculated as shown in the following equation:

$$NSCE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{o,i} - Q_{s,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{o,i} - \acute{Q}_o\right)^2} \qquad [-\infty, 1] \qquad (7)$$

where:

Q_o stands for observed runoff data;

Q_s represents the output value of the HMS model;

$\acute{Q}_o$ is the mean of all observed runoff values, and;

n is the total number of time steps.

MRE is an indication of how close predictions are to observations (Equation 8). The range of MRE values is from '-∞' to '∞'. While positive (negative) MRE values indicate over(under)-estimations, the approach of the metric value to zero increases the performance success of the simulation. The 'MRE=0' implies that the simulation results capture the measurements accordingly. PCC is defined as the measurement of the strength of the relationship between observations and predictions and their association with each other. It can be calculated using Equation 9, and $\acute{Q}_s$ represents the mean of all simulated flow values. This value varies between '-1' and '1'. 'PCC = 0' demonstrates that there is no association between the two variables. Closeness to '1' ('-1') reveals a strong correlation and linear (inverse) proportion between estimations and observations.

Table 1. Sub-basin characteristics.

Sub-basin	Area (km^2)	Impervious (%)	CN	W (%)	L (m)	S (m)	T_L (hour)
W710	17,37	2,56	79,84	0,06	9506,7	0,07	2,06
W900	13,94	2,98	75,42	0,22	8076,4	0,08	1,08
W930	6,47	2,82	75,62	0,31	5458,9	0,08	0,66
W1140	16,82	2,75	78,98	0,47	7624,1	0,07	0,63
W1310	23,12	3,08	67,93	0,52	7701,8	0,12	0,82

$$MRE = \frac{\sum_{i=1}^{n}\left(Q_{s,i} - Q_{o,i}\right)}{\sum_{i=1}^{n} Q_{o,i}} \qquad [-\infty, \infty] \qquad (8)$$

$$PCC = \frac{\sum_{i=1}^{n}\left(Q_{o,i} - \acute{Q}_o\right)\left(Q_{s,i} - \acute{Q}_s\right)}{\sqrt{\sum_{i=1}^{n}\left(Q_{o,i} - \acute{Q}_o\right)^2 \sum_{i=1}^{n}\left(Q_{s,i} - \acute{Q}_s\right)^2}} \qquad [-1,1] \qquad (9)$$

Results and discussion

The effect of precipitation on runoff in the region was investigated using scatter diagram during calibration and validation periods. For this purpose, normalized flow depth values were obtained in mm/day by dividing the flow values into the corresponding area, and these values were plotted with the effective rainfall in the region. As it can be seen from the Figure 4, high amount of rainfall corresponds peak discharge flow rates and they are remarkably correlated. Considering the calibration and validation periods of about a year, the flow values generated by rainfall are explained by the correlation between rainfall and runoff. These values are 0,64 and 0,68 for calibration and validation periods, respectively. This situation indicates that many storm events are only caused by rainfall. At the same time, the fact that the maximum normalized flow values correspond to the peak rainfall events reveal that the flooding cannot be explained by the snow melting and/or the destruction of the hydraulic structure such as any dam or regulator in the region. It is also noticed that, from the same figure, at some flow rates occurring during both periods, there is a greater surface flow than the corresponding precipitation and this can be the result of the base flow or lag time.

The simulated runoff from each of the objective function methods were compared with the observed discharges and analyzed statistically. In Figure 5, the simulated and observed daily discharges at the outlet station with the rainfall measurements are drawn to evaluate how they are distributed during the data period. As can be seen from the hyetographs, peak discharge rates in the hydrographs are directly caused by rainfall, which supports the findings in the Figure 4. By generally looking at the hydrographs in Figure 5, the model performs well over Ballikaya region and the variability is captured with precipitation-driven runoff simulations via HEC-HMS during data periods. Furthermore, the simulated hydrographs have a very similar slope to the increment and reduction curve of the observed hydrographs. In general, peak formation times can be acquired by all five objective functions. As shown in the graph, the hydrograph obtained by the PEPD objective function, as the name indicates, provides the best estimation in terms of the peak values during both calibration and validation periods. During the calibration period, (left column of the figure), the observed hydrograph shows three runoff peaks, and the discharge timing of these peaks was accurately captured by the model. However, simulated values are slightly lower than the observed ones with the exception of PEPD objective function. The difference between simulated and observed flow can be reduced by adding base flow data. Another interesting observation that should be noted is the relationship between the amount of rainfall and the initial abstraction especially in the first two months (November, December), the precipitation did almost not generate runoff in the wet season like winter. On the other hand, it is seen that the second peak of the observed flow is quite high, although the corresponding precipitation (47 mm) is lower than the previous one. It is most likely a result of the soil becoming saturated after the rainfall (60 mm) event that caused the former runoff peak. This result highlights the importance of warm-up period and initial abstraction during calibration period. The parameters from the calibration procedures were then kept constant, and the observed rainfall-runoff records in a new period were validated in order to verify how effective the calibrated parameters were. There is only one big peak flow event observed during the validation period. The model predicts the time of the peak well in all objective functions in terms of the hydrograph's rise and dropped curves. Model estimations tend to be lower than the observed flow for peak value the exception of the fifth objective function (right column of the figure).

Model outputs obtained from hydrological simulations are summarized in Table 2 for calibration and validation periods, respectively. During the calibration period, it can be seen that the simulated and observed peak discharges for all objective functions used in this study occurred on the same day (11/February/2015). Even though the timing of the peak is accurately obtained for calibration period, HMS simulations slightly underestimate the highest peak flows for the first four objective functions. The result acquired with PEPD function, on the other hand, show that the simulated peak value captures the observed one, perfectly. As can be seen in Figure 5, while heavy rainfalls are expected to produce more runoff amounts in the January months when extreme rainfall occurs, this inconsistency in terms of peak discharges can be explained by the uncertainties in the both precipitation and flow observation data and/or the initial soil moisture. In addition, during the calibration period, it is observed that all objective functions except PEPD underestimate total flow volumes (Table 2). While the predictions via the PEDV, VSR, and FLAC objective functions tend to be slight underestimation, this bias was considerably increased with the PWRMSE-driven simulation. For PWRMSE and PEPD, the percentage of variation between observed and simulated total flow volume was calculated as -27,5 and +25%, respectively. Here, the plus sign indicates that the observed value is higher than calculated value in terms of total volume and the minus sign indicates that it corresponds to another situation. The modeled peak flow during the verification period, on the other hand, occurred a day after the observed peak flow regardless of the objective functions. Regarding the runoff volume, the first four objective functions-driven hydrographs produce closest estimates relative to the reference one. However, when it comes to the fifth function (PEPD), simulated runoff volume visualizes overestimation with 39,5% variation. Although rainfall-runoff estimations capture overall the flow volume well, it is observed that simulations tend to underestimate the peak flow value regardless the objective functions. These underestimations vary with the range from -36 to -59%.

The model performance also evaluated using NSCE, MRE, and PCC for calibration and validation period. In addition, known statistical parameters such as mean and standard deviation were used in the evaluation process. Table 3 provides the statistics of the daily observed and simulated runoff at the Ballikaya outlet station for objective functions used in both periods. As can be seen from the Table 3, NSCE values vary 0,46-0,57 (0,28-0,34) for the first four functions-driven simulations during the calibration (validation) period. Although the peak values are best acquired when using hydrographs derived from the PEPD objective function (Figure 5 and Table 2), obtained NSCE parameter using the PEPD exhibits the value of zero and this reveals that observation averages should be used instead of the simulation for this function. MRE results range from -0,27 (underestimation) to 0,25 (overestimation) during calibration, and from -0,09 to 0,39 during validation period. From the perspective of the MRE, the values being at the zero-level obtained using PEDV, VSR, and FLAC functions means that the daily total water volume was captured well while PWRMSE objective function-driven simulation dominates to underestimation during the calibration period. It is also clear from the MRE statistics that hydrographs obtained by the PEPD objective function during both periods tend to overestimation in general. Moreover, during verification period, the other four objective functions-driven flow simulations exhibit unbiased to slight under/overestimations with the range from -0,09 to 0,02. In terms of PCC aspect, the smallest value obtained through the calibration is 0,78, which means that there is a strong positive linear relationship between measurements and predictions. In the validation period, the PCC values are in the 0,6 level, indicating that the linear relationship still continues with a slight reduction.

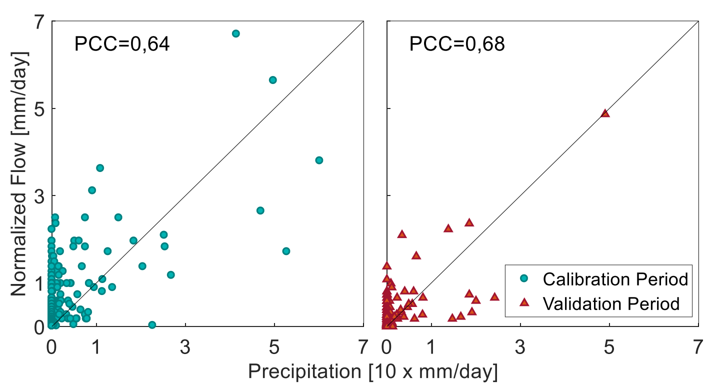

Figure 4. Effect of precipitation on normalized flow depth in terms of scatter diagram.

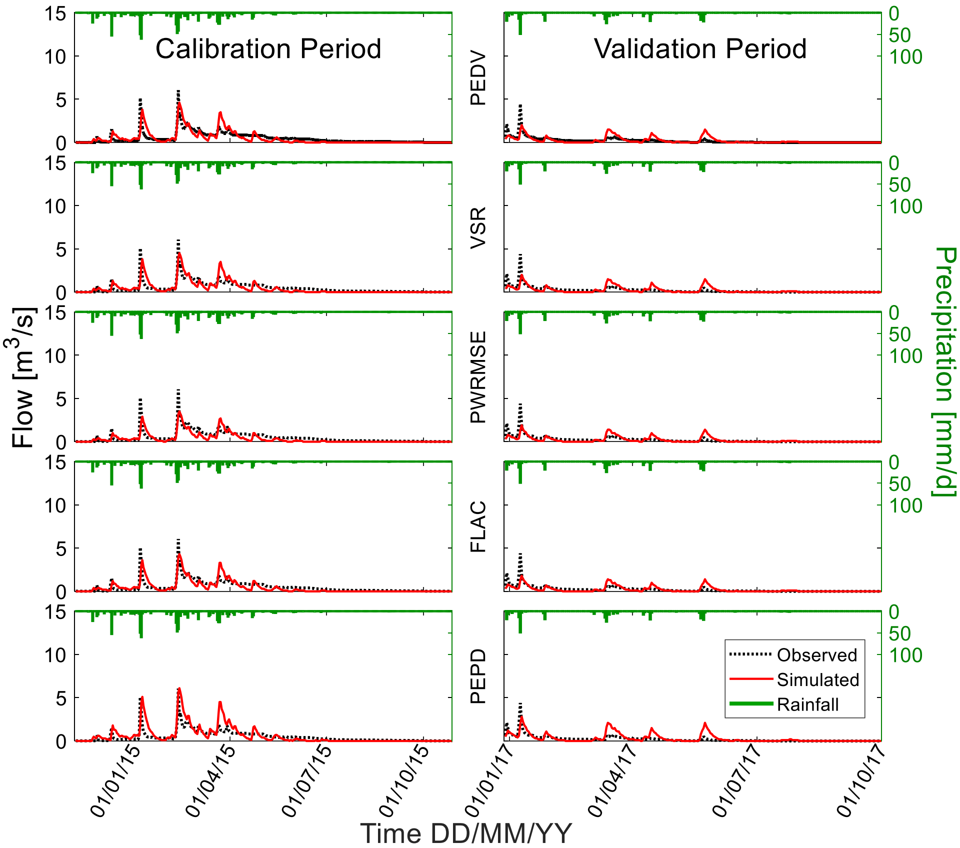

Figure 5. Comparisons between the skills of rainfall-driven streamflow simulations relative to observations in terms of time series plot at multiple objective functions.

Table 2. Comparison of direct flow, peak timing and peak discharge for objective functions.

Objective Functions	Calibration			Validation		
	Normalized Volume (mm)	Peak Flow (m^3 s^{-1})	Peak Date	Normalized Volume (mm)	Peak Flow (m^3 s^{-1})	Peak Date
PEDV	181	4,6	11/02/15	66	2	10/01/17
VSR	179	4,5	11/02/15	64	2	10/01/17
PWRMSE	139	3,5	11/02/15	60	1,9	10/01/17
FLAC	172	4,3	11/02/15	59	1,8	10/01/17
PEPD	239	6,1	11/02/15	90	2,8	10/01/17
Measurement	192	6,1	11/02/15	65	4,4	09/01/17

Table 3. Performance statistics of multiple objective functions at daily time scale.

Statistical Indices	Calibration					Validation				
	PEDV	VSR	PWRMSE	FLAC	PEPD	PEDV	VSR	PWRMSE	FLAC	PEPD
Mean	0,46	0,45	0,35	0,43	0,60	0,22	0,21	0,20	0,19	0,29
Std. Dev.	0,79	0,78	0,61	0,75	1,05	0,37	0,36	0,34	0,33	0,50
NSCE	0,46	0,46	0,57	0,52	0,00	0,28	0,28	0,33	0,34	0,00
MRE	-0,06	-0,07	-0,27	-0,10	0,25	0,02	-0,01	-0,07	-0,09	0,39
PCC	0,79	0,78	0,79	0,79	0,79	0,62	0,61	0,62	0,63	0,63
Observed Mean:				0,48		Observed Mean:			0,21	
Observed Std. Deviation:				0,67		Observed Std. Deviation:			0,39	

The majority of the NSCE, MRE, PCC metrics values range at acceptable levels during both calibration and validation data period. NSCE and PCC values for calibration are better than those ones for validation. However, except for the PEPD function, the MRE values are slightly better than the calibration periods. Furthermore, watershed conditions are likely to differ from calibration to validation time. In this particular case, there is a thirteen-month gap between the calibration and validation periods. During this time, basin conditions can also change widely.

Conclusion

In this study, HEC-HMS hydrological modeling software was applied to Ballikaya River Basin and model parameters were calibrated. The calibrated model can be used as a decision support tool in floodplain management and flood damage forecasting, as well as for determining the current water potential. The data used in this study were obtained from the DSI for flow records, and meteorological data were attained from the MGM. The DEM for the study area was processed in the Arc-GIS environment using terrain preprocessing tools to define the catchment, sub-basin and flow network. Then, its results were used in HEC-GeoHMS to extract hydrological parameters of the river basin (Land use/cover, soil type, and HSG). These hydrological parameters, subsequently, were employed in rainfall-runoff estimations in the HEC-HMS model. The surface runoff simulation was achieved using the SCS Unit Hydrograph method while the infiltration analysis was performed by the SCS-CN method. The flood wave routing in the HEC-HMS model was carried out implementing the Muskingum method.

The main objective of this study is to determine the basin characteristics of the region and to predict potential flood, drought and/or water potentials depending on these features. For this purpose, hydrological model parameters were calibrated and validated based on streamflow observations according to different objective functions. HEC-HMS parameters (CN, Ia, TL, X, K and etc.) were calibrated for a record of nearly a year and validated for the other data period. The objective function, which provides the best estimates of model parameters in terms of the peak and volume difference between simulated and observed hydrographs, needs to be selected for each model calibration step. In this study, different objective functions (i.e. PEDV, VSR, PWRMSE, FLAC, PEPD) are utilized to estimate the goodness of fit between calculated and observed discharge during the calibration period. Hydrographs have been obtained according to these five different objective functions. Then, simulations were evaluated with graphical methods and statistical parameters. The calibrated model perfectly predicted the timing of the peak flow respect to the model estimations in the region. However, the peak flow and flow volume assessments show slight underestimation via the first four objective functions while the peak flow is precisely captured with the fifth function (PEPD). It is also detected that the flow volume in this function is overestimated according to the observed flow values. The difference of peak time between the observed and validated hydrograph is only a day during the validation period. On the other hand, it has been noticed that the magnitude of peak flow driven by all objective functions tends to underestimate observations. In terms of flow volume, it was recognized that only the PEPD function in HEC-HMS overestimated it, while the flow volumes of all other functions were very close to the observations. The differences between simulated and observed flow data are generally evaluated using several different statistical indices to show whether the model gives satisfactory predictions. Results indicate that during the calibration period, the highest NSCE value was acquired in the PWRMSE function (0,57), while the lowest value (0) was obtained in PEPD, which means that the mean observation value is better predictive than the calculated data in terms of this metric aspect. NSCE values for validation were lower than calibration periods and ranged from 0 to 0,34. The MRE results show that the values range from -0,27 to 0,25 for calibration and -0,09 to 0,39 for validation. The correlation, on the other hand, about 0,78 during calibration period while it decreases to 0,62 for validation process, indicating that there is a positive linear relationship over these two periods.

The method obtained will also possible be used in neighboring watersheds by the model parameters that have already been calibrated and validated, as well as it is possible to control these parameters with the post-2021 water year data. In future studies, since the existing data set has coarse spatial resolution and there are only small residential areas in the study area, this has an adverse effect on CN estimations. Therefore, it is predicted that higher resolution land cover maps may also increase model performance. For possible studies, moreover, base-flow analysis can be added to the model to see how this component affects the calibrated hydrograph. In addition, the applicability of the model can be tested and flood frequency analysis or potential droughts can be predicted by using the remote sensing and radar rainfall data without the need for gauging observation data and consequently by extending the data set periods.

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