Araştırma Makalesi
Adıyaman Üniversitesi
Mühendislik Bilimleri Dergisi
16 (2022) 1-9

ACQUISITION OF AFRIN BRIDGE BASIN CHARACTERISTICS AND CURVE NUMBER METHODOLOGY VIA GIS

Kübra ÖZDEMİR[1], Muhammet Ömer DİŞ[2*]

[1,2] Kahramanmaraş Sütçü İmam Üniversitesi, İnşaat Mühendisliği Bölümü, Kahramanmaraş, Türkiye
Geliş Tarihi/Received Date: 27.05.2021 Kabul Tarihi/Accepted Date: 25.02.2022 DOI: 10.54365/adyumbd.943684

ABSTRACT

By using remote sensing data, Geographic Information Systems (GIS) provide convenience in determining basin morphology and watershed planning studies. For this aim, the applicability of the Arc-GIS software in the Afrin Bridge Basin by processing the Digital Elevation Model (DEM) data using the hydrological analysis tools and watershed parameters (i.e. basin boundary, variation of elevation, drainage area, stream network, and slope) were investigated. Additionally, soil and Land Use/Land Cover (LULC) maps were attained using ORNL-DAAC and CORINE data sources with 250-m and 100-m spatial resolution, respectively. By combining these maps and basin characteristics, the Curve Number (CN) values, required parameters for the SCS-CN method used in the rainfall-driven runoff estimations, are mapped over the region. While acquisition of soil, LULC, CN maps and the stream morphology enables the basin to be evaluated together with climatological data, flood risks and hydrographs of the region can be determined.

Keywords: *Curve Number, Digital Elevation Model, GIS*

AFRİN KÖPRÜSÜ HAVZASI ÖZELLİKLERİNİN VE EĞRİ SAYISI METODOLOJİSİNİN CBS İLE BELİRLENMESİ

ÖZET

Uzaktan algılama verileri kullanılarak Coğrafi Bilgi Sistemleri (CBS), havza morfolojisinin belirlenmesinde ve havza planlama çalışmalarında kolaylık sağlamaktadır. Bu amaçla, Sayısal Yükseklik Modeli (SYM) verilerinin Arc-GIS yazılımının hidrolojik analiz araçları kullanılarak işlenmesiyle Afrin Köprüsü Havzasında uygulanabilirliği ve havzaya ait parametreler (havza sınırı, rakım değişimi, drenaj alanı, akım ağı ve eğim gibi) araştırılmıştır. Ek olarak, toprak ve Arazi Kullanımı/Arazi Örtüsü (AKAÖ) haritaları ise sırasıyla 250-m ve 100-m mekânsal çözünürlüklü ORNL-DAAC ve CORINE veri kaynaklarından yararlanarak elde edilmiştir. Bu haritaların ve havza özelliklerinin birleştirilmesiyle, yağış bazlı akışların tahminlerinde kullanılan SCS-CN yöntemi için gerekli olan, bölgeye ait Eğri Numarası (CN) değerleri haritalaştırılmıştır. Toprak, AKAÖ ve CN haritalarının ve akarsu morfolojisinin belirlenmesi havzanın klimatolojik veriler ile birlikte değerlendirilmesine olanak sağlarken, bölgeye ait taşkın riskleri ve hidrografları belirlenebilir.

Anahtar Kelimeler: *Eğri Numarası, Sayısal Yükseklik Modeli, CBS*

1. Introduction

While water scarcity problems arise with the increase of water pollution and the decrease in the amount of usable water, natural disasters such as floods with the effects of other excess rainfall and irregular urbanization threaten the living creatures and the future of vital water. This situation affects scientific research and political decisions regarding to conservation and sustainability of water. This impact has created awareness of recognizing and understanding water as a natural resource [1]. The European Union Water Framework Directive (EU-WFD) declared the necessity for member and

e-posta[1] : kubraozdemir46@hotmail.com ORCID ID: https://orcid.org/0000-0002-4373-7526
* e-posta[2] : momerdis@ksu.edu.tr ORCID ID: https://orcid.org/0000-0002-3347-5112 (Sorumlu Yazar)

wishing to become a member country to manage their water resources at basin scale [2]. The basin is a hydrological unit that explains the natural boundary of water resources and the movement of flow. It also determines the boundaries of existing areas in a hydrologically independent way [3-4]. Basins are emerging as suitable planning units for natural resource issues such as water quality, water reserve, aquatic life and many wildlife environments [5-6]. For this reason, the knowledge of the both hydrological and topographic characteristics of a basin is important in study of stream morphology, basin planning and management. Basin modeling programs are used as digital footer and supply very popular opportunities. The use of Geographic Information Systems (GIS), one of these computer programs, is increasing day by day and enables determining many features of the basin in a shorter and safer manner thanks to the integrated software [4,7].

Basin Land Use/Land Cover (LULC), soil, vegetation, drainage characteristics can be obtained from satellite images and other sources (i.e. terrain analysis, remote sensing, drone monitoring, and simulations), and processed after geometric corrections with GIS. The LULC map used in this study was obtained from the Copernicus Land Monitoring Service (CORINE) data source. CORINE is a program launched in 1985 aimed at collecting information for the European Union on priority issues related to the environment (i.e. air, water, soil, land cover, coastal erosion, biotopes). It is the management of the same basic data and the creation of a standard database for the purposes of determining environmental changes in land, rational management of natural resources and environmental-related policies in all European Environment Agency (EEA) member states in accordance with the criteria and classification system established by the EEA. According to the criteria and classification units of the EEA (44 classes), changes in LULC for monitoring land using satellite images are detected with the help of remote sensing and GIS [8]. Additionally, soil map data was obtained from the Oak Ridge National Laboratory Distributed Active Archive Center (ORNL-DAAC). The ORNL-DAAC for Biogeochemical Dynamics is a NASA Earth Observing System Data and Information System (EOSDIS) data center managed by the Earth Science Data and Information System (ESDIS) Project. The ORNL-DAAC is operated by Oak Ridge National Laboratory in Tennessee, and is a member of the Remote Sensing and Environmental Informatics Group of the Environmental Sciences Division (ESD) [9]. Later, these processed geomorphological data can be made available for use by modifying new data entry and analysis in the desired region [10]. Then, it is possible to determine water potentials and predict flood estimations using rainfall-runoff simulations by obtaining accurate basin characteristics with developing computer technology.

In this aim, numerous methods (i.e. Rational, Time-Area, Unit Hydrograph, Curve Number and etc.) have been developed in order to establish a relationship between rainfall and runoff. For example, the Rational Method that assumes rainfall intensity does not change temporally over the drainage area is widely used in urban areas [11]. The peak rate of the flow is reflected by the rainfall intensity, and peak flow rate values are determined based on the drainage area, rainfall intensity and flow coefficient [12]. On the other hand, the Time-Area Method, as its name suggests, has been developed based on the time step that takes into account the lag time of flow from a basin area divided into sub-basins to the outlet. The method converts an effective storm hyetograph into hydrograph [13]. Another method, the Unit Hydrograph (also called the Unit Graph Method), was developed in the 1930s by Sherman [14-15]. The procedure assumes that the discharge at any given time is proportional to the runoff volume, and that the time factors affecting the hydrograph shape are constant. Likewise, the Unit Hydrograph is a discharge hydrograph resulting from one-inch direct runoff due to precipitation uniformly and spatio-temporally distributed over the basin for a given period of time [16]. One of the most widely used rainfall-runoff model for routine design purposes is the Curve Number (CN) Method. This method is a popular rainfall-runoff model that links rainfall to runoff events assembling an empirical number depending on the land use, vegetation cover, hydrological soil group, and hydrological conditions of the region [11, 17].

Rainfall-driven runoff forecast, prediction of the flood risk situation, and existing water potential over a region is extremely vital importance for living things and decision-making mechanisms. For this purpose, basin geomorphological maps via GIS were determined in order to use the CN methodology, which has both national and international applicability and requires less data parameters. The Afrin Bridge Basin, located Gaziantep and Kilis, was chosen for the convenience of access to data and the projects such as utilizing the existing water potential in the region with the dam. For this purpose, data (i.e. updated elevation, slope, LULC, soil, and CN maps) and their spatial distribution over the area can be processed quickly by using tools such as GIS in parallel with the developing technology; thus, possible flooding and time loss can be prevented. In the study, obtained Digital Elevation Model (DEM) from satellite data is applied in Arc-Hydro module by using Arc-GIS program. By processing DEM data into the module, the basin boundaries were determined by assessing the process steps of projection transfer, filling gaps in the DEM, acquiring the flow direction and accumulation maps, basin delineation, polygon conversion. By deriving slope, soil, LULC information, infiltration capacity, CN values were determined and mapped over the region. GIS provided a fast, economical and practical solution compared to classical methods in obtaining basin parameters.

2. Materials and Methods

Arc-GIS software was used to determine the basin boundaries and characteristics of the study area. Firstly, in this purpose, DEM data was obtained from the US Geological Survey (USGS) with 30x30 m spatial resolution [18]. After adding acquired DEM data into Arc-GIS software, slope, elevation analyzes, and basin delineation can be attained from it. It is impossible to transfer the physical earth, in the form of a sphere, to the map environment without any deterioration. The process of reducing the three-dimensional earth to two dimensions and representing it with the help of mathematical or geometric relations is called projection [19]. In the study, Universal Transversal Mercator (UTM) projection, frequently used in Turkey, applied. In this projection system, the world is divided into 60 slices at 6^o intervals. Therefore, DEM data were adjusted to European Datum 1950 Zone 37N in accordance with the location of the region. In the DEM maps uploaded to the Arc-GIS software, the steps of projection transformation, filling the gap, determining the flow direction, and converting the flow accumulation to polygon format were done, respectively. Basin boundaries were determined as a result of these process steps.

Errors in DEM data are corrected by the Filling Gaps tool after the projection conversion is completed. As a result of this process, the water will discharge from the higher cell value to the lower one with ensuring the flow of water. Additionally, accurate determination of flow direction is the basis for determining the drainage structure of a basin. The D8 method, the earliest and simplest method for specifying flow direction, has been adopted in Arc-Hydro module. The cells are encoded according to the clockwise-running D8 algorithm developed by Jenson & Domingue [20]. This method is to assign flow from each pixel to one of its eight neighbors by determining the direction with the steepest downward slope. For this aim, the flow direction of each cell is determined. In this algorithm, each of the numbers 1 (East), 2 (Southeast), 4 (South), 8 (Southwest), 16 (West), 32 (Northwest), 64 (North), and 128 (Northeast) refers to one flow direction. Flow accumulation, on the other hand, refers to the amount of water accumulation in each cell of the basin and can be calculated by flow direction according to the natural laws of water movement. The flow accumulation counts the number of cells flowing into a given cell. Accordingly, areas with very high values are probably main streams or rivers whereas areas with lower values can be intermittent streams. Upstream drainage area in a given cell can be calculated by multiplying the flow accumulation value by the cell area. The cells of the resulting flow accumulation grid were used in the study to determine whether they were a part of a flow based on the size of the drainage area or the number of cells accumulated.

Once flow accumulation is complete, the basin can be delineated based on the State Hydraulic Works (DSI) flow gauging station point. The stream discharges at 36°48'27" N and 36°58'55" E outlet location and runoff observation are recorded at D19A006 Station operated by the DSI (Figure 1). As it can be seen from the figure, the study area is located within the borders of Gaziantep and Kilis provinces. The basin area and its characteristics can be determined with converting cellular data into polygon format. The basin area is calculated from the attribute table and the total drainage area calculated as approximately 619 km^2.

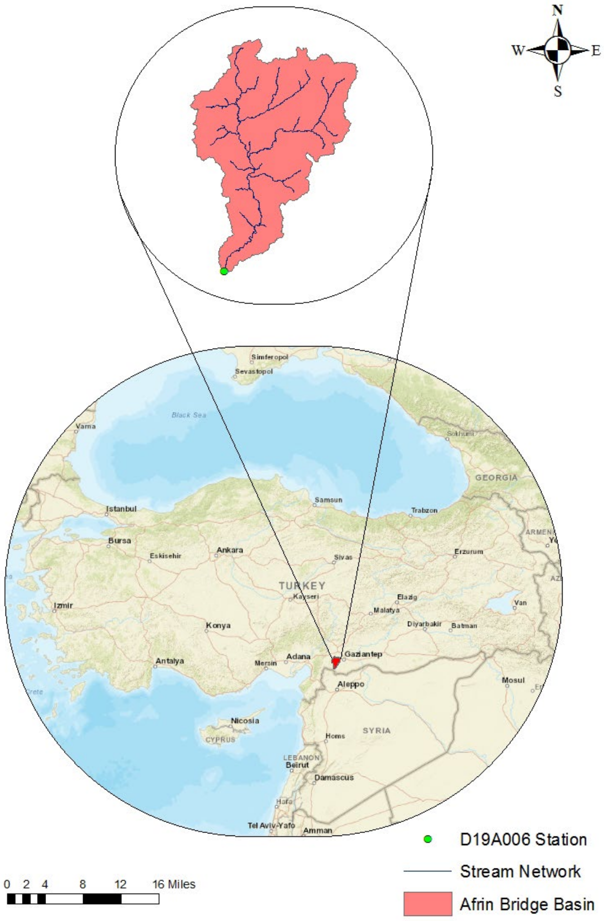

Figure 1. Location of the Study Area

The CN methodology, developed by the U.S. Natural Resources Conservation Service (NRCS), is applied to rainfall driven runoff simulations [16]. CNs values are a dimensionless parameter used in the estimation of the basin infiltration capacity, and rainfall-surface runoff potential. The values vary 0-100 (30-100 in practical) and determined based on basin geomorphological characteristics (i.e. soil map and LULC). The method uses LULC map and Hydrological Soil Group (HSG) information to derive CN values (Table 1). Therefore, the LULC map, produced from satellite images of the CORINE, obtained with 100 m spatial resolution [8]. Additionally, the soil information map downloaded from the ORNL-DAAC database with 250 m spatial resolution [9]. Then, it is added to Arc-GIS software to determine the soil map of the study area. HSG and LULC maps contain important information regarding to the basin runoff potential and basin infiltration capacity. Combining these maps play an important role in the preparation of the CN maps. The basin CN values are determined by combining the information regarding to basin characteristics additional to soil and vegetation maps of the basin. As it can be seen from the Table 1, CNs values can be determined based on these combined maps. HSGs can be divided into four different groups depending on region infiltration capacity and runoff potential. Among these four HSG characteristics, the soils in group-A have a high permeability value due to their sand or gravel content, even if they are moist. On the other hand, group-D is the soils with very high runoff potential and the smallest infiltration capacity. In other words, while the infiltration rate of the group-A is the highest, the infiltration rate towards the group-D decreases. Additionally, although the HSGs are the same, CNs values differ depending on LULC map for wetlands, forest areas, agricultural areas, and residential areas (Table 1). The obtained flow curve numbers will allow the use of the most preferred Soil Conservation Service-Curve Number (SCS-CN) method in a hydrological model for rainfall-runoff modeling and determination of water potential. The flow diagram developed for the GIS-based determination of the basin morphological characteristics and the CN methodology obtained accordingly are given in Figure 2. As it can be seen from the figure, DEM, LULC, and HSG data sets are used to acquire CNs values and several steps done during this process.

Table 1. Curve Number According to Hydrological Soil Groups [21]

Land Use /Land Cover	Curve Number According to HSG			
	A	B	C	D
Medium Residential	57	72	81	86
Agricultural	67	77	83	87
Forest	30	58	70	77
Wetlands	100	100	100	100

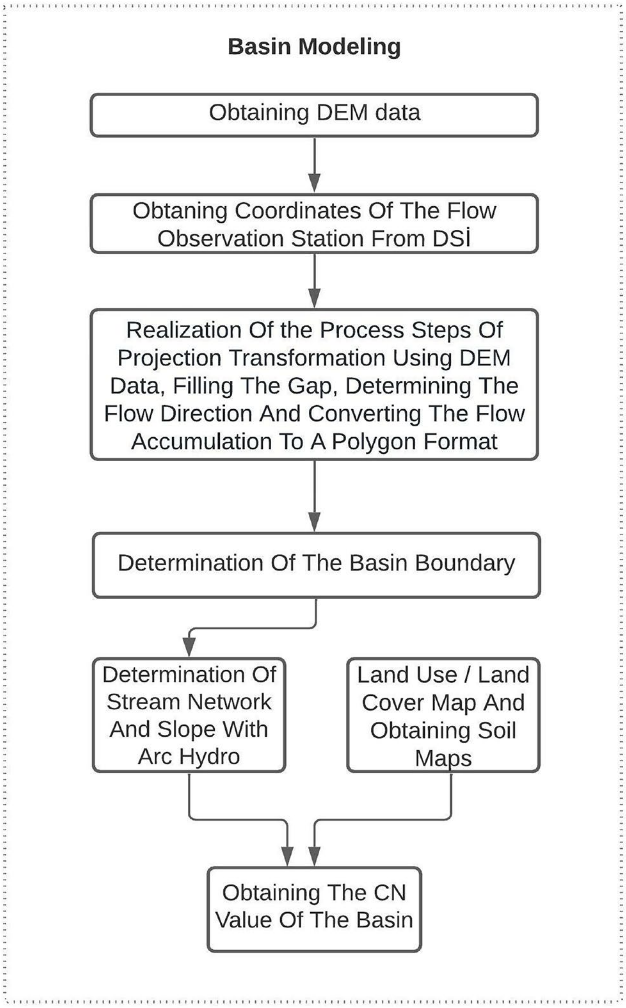

Figure 2. Flow Diagram for the Methodology

In order to find the rainfall-driven runoff in any region and period, the runoff depth, Q, [inches] can be drived by Equation 1 by using the water balance equation and the proportional equation hypothesis of the SCS-CN method [16]. In this equation, P represents rainfall depth [inches], and S [inches] known as basin's potential maximum retention after runoff begins. Where S is related to the HSG and LULC maps through the CNs and it is calculated by the following Equation 2. Acquiring these maps and basin features can be used in a hydrological model combining with additional meteorological data (rainfall, temperature, evapotranspiration, wind and etc.), and surface flow and related flood risk/water resources potential can be estimated.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad (1)$$

$$S = \frac{100}{CN} - 10 \quad (2)$$

3. Results and Discussions

The elevation of the basin ranges from 402 m to 1486 m with general elevation gradient accelerating from South to North and the outlet point of the basin is in the southwestern of the basin (Figure 3a). The basin slope, that determines the flow of water, is one of the important elements, and can be acquired based on the DEM data. Figure 3b shows the distribution of basin slope values. As can be seen from the Figure 3b, most of the slope values varies from 0 to 60% range over the region while the interval of 40-60% (0-20%) is dominant in the northwestern and southern (middle) part of the basin. It is expected that the surface runoff will be high in areas with high slope values while the amount of infiltration is anticipated to be high in areas with low slope values. The drainage network covers all tributaries of the streams, whether artificial or natural, permanent or temporary, participating in the flow. The amount of water flowing into the stream is directly proportional to the basin area and the precipitation. The drainage network system is a vectorial system and is created by taking into account flow direction maps [22-23]. Figure 3c shows the stream network of the Afrin Bridge Basin, represented with blue-colored lines. The total stream length in the region is 185.44 km.

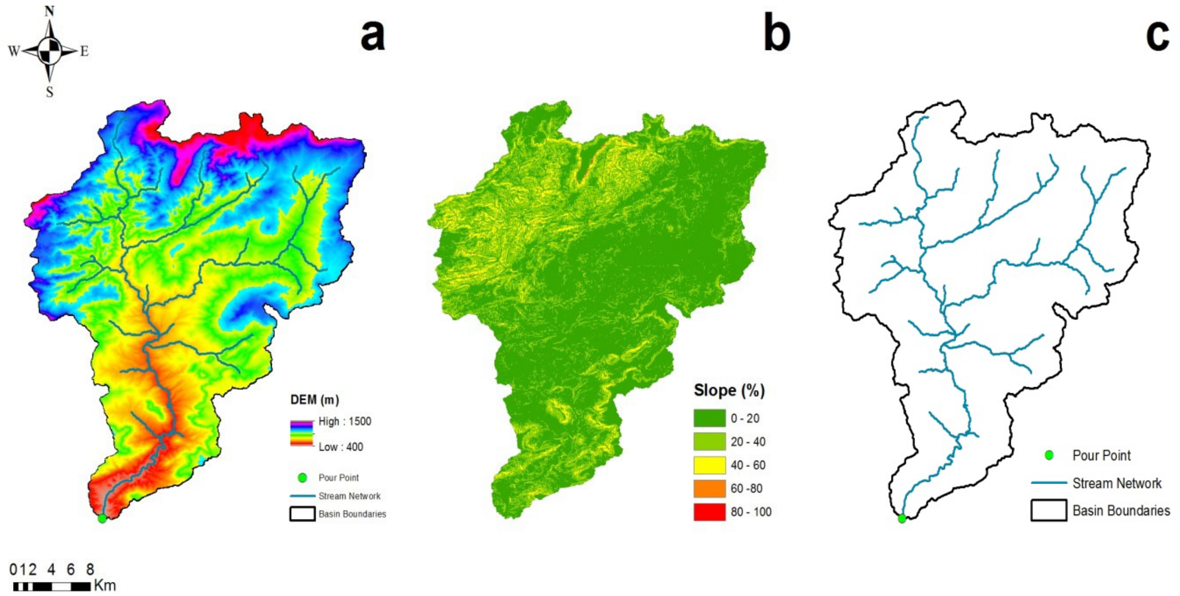

Figure 3. Basin Border, Slope Maps, and Stream Network, Respectively

As it can be seen from the Figure 4a, most of the basin consists of agricultural land. In order to facilitate the interpretation of the LULC map, the study area has been reclassified according to Başyiğit's CORINE land use map table [24]. According to the new map, the region is divided into four groups as agricultural land areas (64.90%), forest (34.90%), water body (0.20%), and residential areas

(0.09%) (Figure 4b). Soil map, additionally, is classified into four groups according to infiltration rates: A (the highest degree of infiltration capacity), B, C, and D (the lowest degree of infiltration capacity). These infiltration groups are shown in Figure 4c, as can be seen from the figure, most of the study area belongs to Group D. The distribution of CNs values over the region is presented in Figure 4d. As it can be recognized from the CN map, the numbers are between 30 and 100. The lowest values of the basin are indicated in gray and are located in the northwestern of the basin.

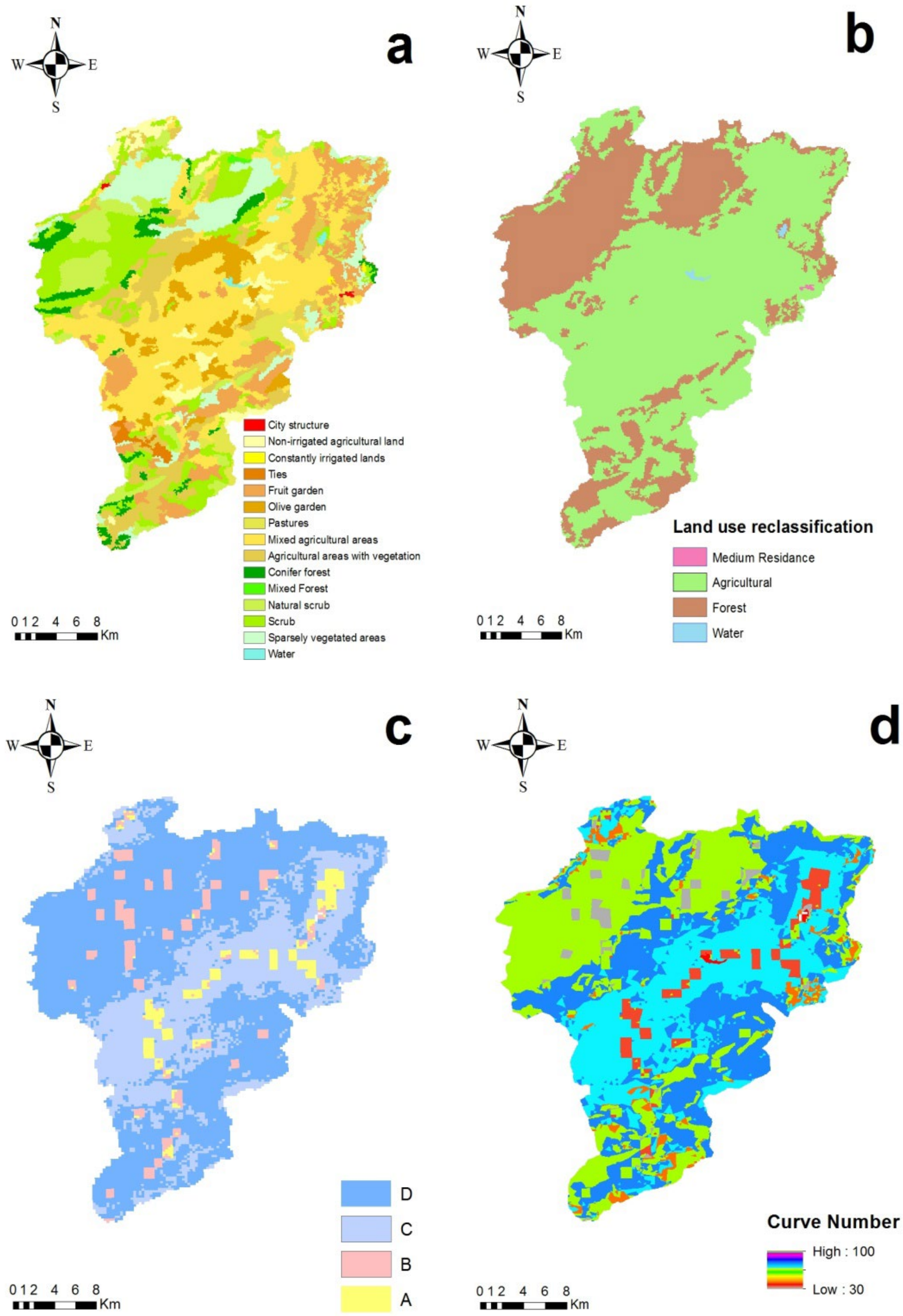

Figure 4. LULC, Reclassified LULC, Basin Soil, and CNs Maps, Respectively

4. Conclusions

In this study, the acquisition of basin parameters and geographical information systems of the Afrin Bridge Basin (619 km^2) has been examined. As a first step, in basin planning studies, basin boundaries and associated parameters are quickly and practically obtained using hydrological analysis tools of the Arc-GIS software developed on the basis of GIS. DEM maps used in the study can be applied not only for the study region, but also for the entire region of Turkey. Determination of basin maps such as soil, land use, vegetation cover, and slope allow understanding basin characteristics and adding these obtained data recommends acquiring the parameters of basin runoff coefficients. The basin CN is a rainfall-runoff method established by the US Soil Conservation Service. For this method, it is necessary to know the soil map, LULC data over the basin. As can be seen from the HSG map, the majority of the basin consists of the groups-C and D, that refers the soil has very low permeability capacity. In addition, it is observed from LULC map, that the settlement area is low in the region while agricultural and forest areas are dominant. Combining these two maps result high CN values in the region. The combination uses of basin parameters (i.e. basin boundary, elevation, drainage area, flow network, slope, soil map, land use, vegetation cover, curve number and etc.) and meteorological data (i.e. precipitation, temperature and evapotranspiration) are promising the chance to simulate rainfall-runoff processes over the study area with a hydrological model with application of SCS-CN methodology. Water potentials and possible flood predictions can be analyzed with required calibration and validation of a hydrological model in the region.

References

[1] Karadağ AA. Kovada Gölü Alt Havza Sınırlarının Belirlenmesi. Düzce Üniversitesi Ormancılık Dergisi 2012; 8(1): 58-76.
[2] Directive of The European Parliament and of The Council of 23 October 2000 Establishing a Framework for Community Action in The Field of Water Policy. http://www.managenergy.net (Accessed 18.03.2021)
[3] Mostaghimi S, Park SW, Cooke RA, Wang SY. Assesment of Management Alternatives on a Small Agricultural Watershed. Journal of Water Resources 1997; 31(8): 1867-1997.
[4] Reis A, Dindaroğlu T. Havzalarda Bazı Hidrolojik Karakteristiklerin Archdyro Yazılımı Kullanılarak Belirlenmesi. Turkish Journal of Forest Science 2020; 4(1): 146-159.
[5] Williams JE, Wood CA, Dombeck MP. Watershed Restoration: Principles And Practices Bethesda (MD). American Fisheries Society 1997.
[6] Köseoğlu G, Özdemir B. CBS Teknolojilerinin Havza Sınırlarının Belirlenmesinde Karar Destek Mekanizması Olarak Kullanılması. Coğrafyacılar Derneği Yıllık Kongresi Bildiriler Kitabı. 19-21 Haziran, 2013; İstanbul, 238-245.
[7] Yazıcı N, Babalık AA, Dursun İ. Havza Yönetiminde CBS ve Uzaktan Algılamanın Önemi. International Marmara Sciences Congress, Tam Metin Kitabı (Natural and Applied Sciences) (ISBN: 978-605-69509-6-4), 01-03 Kasım, 2019; Kocaeli, 256-261.
[8] CORINE, Coordination of Information on the Environment, CORINE Land Cover Data Website. https://land.copernicus.eu/. (Accessed 10.10.2020).
[9] ORNL-DAAC, Oak Ridge National Laboratory Distributed Active Archive Center, Soil Map Data Website. https://daac.ornl.gov/. (Accessed 11.12.2020).
[10] Özdemir H. SCS-CN Yağış-Akış Modelinin CBS ve Uzaktan Algılama Yöntemleriyle Uygulanması: Havran Çayı Havzası Örneği (Balıkesir). Coğrafi Bilimler Dergisi 2007; 5(2): 1-12.
[11] Dingman SL. Physical Hydrology. Upper Saddle River (2nd ed.). New Jersey: Prentice Hall; 2002.

[12] Beven KJ. Rainfall-runoff modelling. The primer (2nd ed.). New Jersey: Wiley-Blackwell; 2012.
[13] Ponce VM. Engineering Hydrology. Principles and Practices. New Jersey: Prentice Hall; 1989.
[14] Sherman LK. Streamflow from Rainfall by the Unit-Graph Method. Engineering News Record 1932; 108: 501–505.
[15] Sherman LK. The Hydraulics of Surface Runoff. Civil Eng1940; 10:165–166.
[16] Natural Resources Conservation Service & US Department of Agriculture –USDA. Hydrographs. Part 630: Hydrology. National Engineering Handbook; 2007.
[17] Hawkins RH, Van Mullem JA, Ward TJ, Woodward DE. ASCE/EWRI Task Committee Report on the State of the Practice in Curve Number Hydrology. Draft report to the American Society of Civil Engineers; 2006.
[18] Geographic Information Systems, Digital Elevation Model Data Website. https://earthexplorer.usgs.gov/. (Accessed 25.05.2020).
[19] Çabuk A, Çabuk KM, Aksoy T, Şimşek B, Güney Y, Avdan U, Uyguçgil H, Çömert R. Coğrafi Bilgi Sistemlerine Giriş. Anadolu Üniversitesi Yayını No: 3752, Açıköğretim Fakültesi Yayını No: 2567, Eskişehir,190s; 2018.
[20] Jenson SK, Domingue JO. Extracting Topographic Structure from Digital Elevation Data for Geographical Information System Analysis. Photogrametric Eng Remote Sensing 1988; 54: 1593-1600.
[21] Halley MC, White SO, Watkins EW. ArcView GIS extension for estimating curve numbers, *ESRI User Conference*, 2000; San Diego, California.
[22] Eraydın E, Çoşkun HG, Ağiralioğlu N. Uzaktan Algılama ve CBS Yöntemleri Kullanılarak Akış Eğri Numaralarından Eşen Çayı Havzası için Taşkınların Belirlenmesi. TUFUAB VIII. Teknik Sempozyumu, 21-23 Mayıs, 2015; Konya, 429-436.
[23] Güler E. Hidroelektrik Potansiyel Belirlemeye Yönelik Uzaktan Algılama ve CBS Tabanlı Hidrolik Modelleme, Yüksek Lisans Tezi, İ.T.Ü, Fen Bilimleri, İstanbul; 2008.
[24] Başyiğit L. CORINE Arazi Kullanım Sınıflandırma Sistemine Göre Arazi Kullanım Haritasının Hazırlanması: Isparta Örneği. Tarım Bilimleri Dergisi 2004;10(4): 366-374.