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RESEARCH PAPER

Determination of the direct runoff using the soil conservation service curve number method and its applicability to Lüleburgaz Sub-Basin (Thrace Region)

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Abstract
Lüleburgaz Sub-basin, located within the Ergene Basin in the Thrace Region which is designated by the State Hydraulic Works. The Soil Conservation Service Curve Number (SCS-CN) Method was used to determine the runoff for the basin. In basins where flow values are not recorded for a long period, the SCS-CN is frequently used to obtain the flow indirectly. For this investigation, the land cover data was sourced from the Corine Cover Database, while the hydrological soil groups were acquired from the ORNL Distributed Active Archive Center for Biogeochemical Dynamics. Daily precipitation data were obtained from Lüleburgaz Meteorological Station for the years 2013-2017. All values were entered as data into the geographic information system-based software and analyzed with raster calculation. The SCS-CN method was employed to calculate the average runoff value for the basin, yielding a result of 157.6x10^6 m^3/year. Meanwhile, at the Lüleburgaz flow observation station, the average runoff was recorded as 135.8x10^6 m^3/year in between 2013 and 2017. It was determined that the runoff measured by the SCS-CN method was merely 1.16 times greater than the runoff recorded at the flow observation station. This shows that the SCS-CN method may be suitable for use in basins with similar characteristics where there is no flow observation station.

Introduction

Lüleburgaz Sub-basin is a part of the Ergene Basin, one of Turkey's most important basins. It is very close to one of the world's leading metropolises such as Istanbul and has a very important position due to its dense population (Edelman, 2021). In Turkey, where the water problem is increasing with global warming, it is of great importance to investigate the ground and surface waters, to determine the amount of water, and increase the water quality of this large basin. Determination of surface runoff, which is one of the hydrological variables, is also very important in water quantity calculation studies.

The SCS-CN method is a highly effective approach commonly employed to assess runoff resulting from rainfall. This model finds extensive application for rainfall-runoff modelling of small sub-basins worldwide (Beven, 2001; Das and Paul, 2006). The calculated runoff serves as a crucial factor in implementing effective land management and water planning strategies within the study area. This model, widely used in countries facing water scarcity and water quality problems (Muthu and Santhi, 2015; Rawat and Singh, 2017; Raju et al., 2018), has been the subject of extensive research. The applicability of SCS-CN management has been addressed in these studies. It is also highlighted that runoff resulting from precipitation plays a pivotal role in numerous water resources development and management endeavors, including flood control, irrigation planning, designing irrigation and drainage networks, and hydropower generation. In their study, Soulis et al. (2009) observed that, employing CN values generated through the standardized procedure, the SCS-CN method consistently overpredicted runoff for events with high rainfall depth and underpredicted runoff for events with low rainfall depth. On the other hand, Shadeed and Almasri (2010) demonstrate that when combined with GIS, SCS-CN method constitutes a potent tool for estimating runoff volumes in catchments across the West Bank, which encompass arid to semi-arid regions of Palestine. In the Liudaogou catchment in China, the SCS-CN model projected a gradual increase in runoff with rising rainfall when precipitation values were below 50 mm. However, the predicted runoff amount showed a rapid increase when rainfall exceeded 50 mm, as noted by Xiao et al. (2011). Fan et al. (2013) demonstrated the suitability and effectiveness of the enhanced SCS-CN method, which incorporates remote sensing variables for estimating surface runoff, in Guangzhou, China. Taher (2015) found an estimated total runoff volume of 75.80 mm^3 using the same method, which corresponds to 76% of the total annual rainfall. In their study, Satheeshkumar et al. (2017) established that the runoff in the Vaniyar sub-basin accounts for 6.6% of the total annual precipitation when employing the SCS-CN method. Lian et al. (2020) gathered an extensive dataset of rainfall-runoff monitoring data to recalibrate CN values across 55 study sites in China. Employing the revised CN method, they concluded that this approach offers a more accurate reference, particularly suitable for the prevailing natural conditions in China. In their study, Kumar et al. (2021) discovered that the overall average runoff volume amounts to 35.04x108 m³, equivalent to 17.21% of the total average annual rainfall in the Sind River Basin, India.

Ultimately, the studies mentioned above have proven the accuracy of the SCS-CN method for determining surface runoff due to precipitation. Therefore, this study aims to ascertain the runoff amount of the Lüleburgaz Sub-basin using the SCS-CN method. The runoff amount calculated by this method was compared with the data measured at the streamflow observation station, and the method's applicability was tested in similar basins without streamflow observation data.

Study Area

The study area covers a large part of Lüleburgaz and Pınarhisar districts of Kırklareli province in the Marmara Region and is located within the coordinates N5011100-N5104560 and E3033610-E3106660 (Figure 1). The lands of Lüleburgaz 80 district is flat and generally has a hilly terrain. The most important plain and valley of the region is Ergene. The Ergene Plain, with a minimum height of 35 m and an average height of about 100 m, is very fertile and its northern border is defined by the Yıldız Mountains, which are about 1000 m high. The most important river of the study area is the

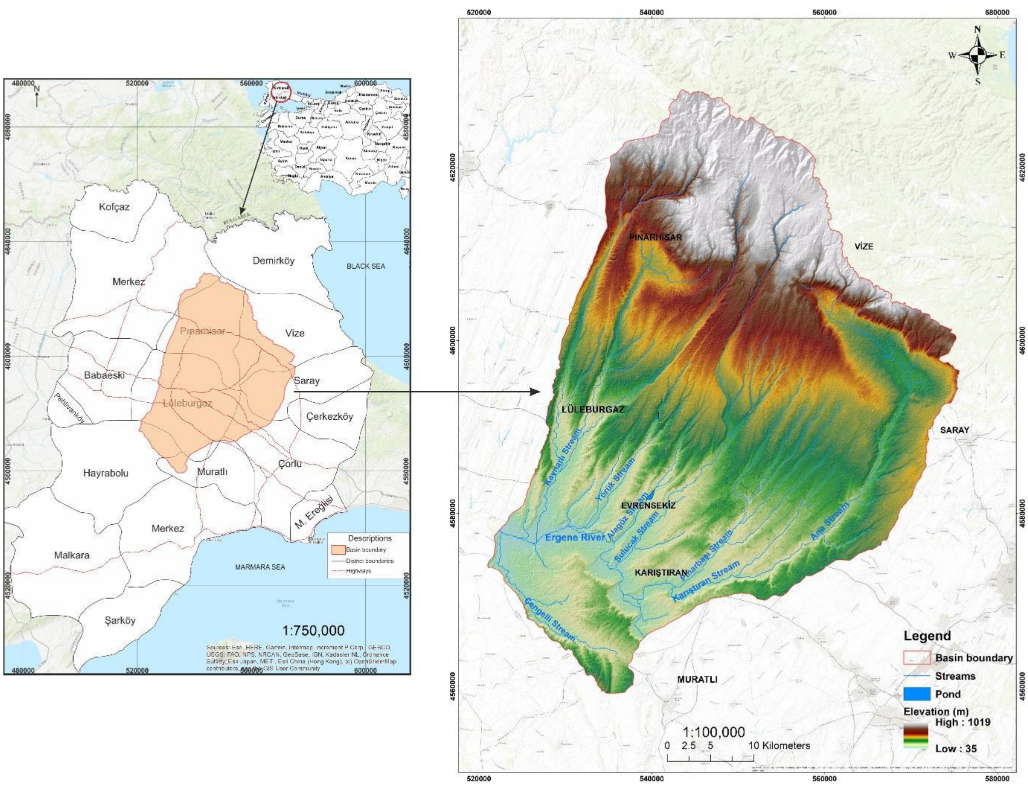

Figure 1. Location and elevation map of the study area

Ergene River passing through Lüleburgaz district (Ministry of Environment and Urbanization, 2014).

In the Ergene Basin, summers are hot and dry while winters are cold and snowy. Although the temperature difference varies from year to year, some years may have warmer winters than Central Anatolia. The reason for this is the mixture of the continental climate of Central Europe with the Mediterranean, Black Sea and Marmara climates. The precipitation catcment area of the study area is approximately 2150 km^2. The region experiences an average annual precipitation of 581 mm, with the highest average temperature typically occurring in August at 41°C, and the lowest in February at -20°C (General Directorate of Meteorology, 2017).

Materials and Methods

Materials

The SCS-CN (Curve Number, SCS 1986) is an empirical rainfall-runoff model utilized for calculating the excess water lost through infiltration following precipitation. Primarily employed for estimating water quantities in small catchments, this model focuses on the computation of infiltrated water (McCuen, 1982; Mishra & Singh, 1999). For this model;

-Daily precipitation data (2013-2017)

-Land use/land cover

-Hydrological soil groups (HSG)

-Parameters such as Antecedent Moisture Content (AMC) are used.

In order to calculate the average precipitation, monthly average precipitation data of 5 meteorological stations in the basin were evaluated (Table 1). Land use/cover data for the SCS Runoff Curve Number Method was obtained from the Corine Cover Data base, and hydrological soil groups were obtained from ORNL DAAC (Distributed Active Archive Center For Biogeochemical Dynamics) at 250 m resolution. Various soil types and minimum infiltration rates for Türkiye were suggested by Özer (1990) (Table 2). Land Use/Cover was downloaded and prepared from the 2018 Corine Cover Data base.

Table 1. Meteorological stations within the study area

Station Number	Station Name	X	Y	Z (m)	Average precipitation (mm)
19320	Vize	564145	4601931	150	535.6
17631	Lüleburgaz Tigem	526138	4577713	45	589.6
18398	Pınarhisar	543598	4608907	266	602.8
1045	Dambaslar	520947	4564503	76	586.6
18796	Ahmetbey	548543	4587310	118	576.6

Land cover encompasses the vegetation that blankets the land surface, including forests, soil, agricultural areas, and various land uses such as settlements, mining sites, dumping areas, etc. As defined by Halley et al. (2000), it also involves human activities associated with the land. (Table 3).

Table 3. Map codes of land use cover

Land use	Map code
Urban fabric (continuous)	111
Urban fabric (discontinuous)	112
Industrial and Commercial areas	121
Roads and railway networks	122
Mining and dump sites	131, 132
Agricultural fields	211, 212, 213, 222
Pastures, meadows and grazing lands	231, 242, 243
Forests	311, 312, 313
Transitional wood and shrub	321, 324, 333
Wetlands	511, 512

Table 2. Hydraulic Soil Groups (Özer, 1990)

Soil Group	Description	Minimum Infiltration Rate
A	Medium degree of infiltration, well drained. Mainly sandy and gravelly soils with low runoff potential and high waterpermeability.	7,6-11 mm/h
B	Medium infiltration degree, medium drainage. Soils with medium fine to medium coarse grain size with normal flowpotential and medium degree of water permeability (silty soils).	3,8-7,6 mm/h
C	Low drainage with slow infiltration. Soils with high runoff potential and slow water permeability (sandy clay)	1,2-3,8 mm/h
D	Low drainage with very slow infiltration. High clay soils with very high runoff potential and very slow water permeability(silty, sandy clay, clay)	0-1,2 mm/h

Methods

The Soil Conservation Service Curve Number Method is commonly employed in basins where extended flow data is unavailable. This method serves to indirectly acquire the necessary flow information essential for designing structures like flood control and water storage. The current data required to determine the surface flow can be obtained quickly and reliably with Remote Sensing and Geographical Information Systems.

The curve number, denoted as CN, is a numerical value determined based on the catchment's topography, soil type and land cover. This number ranges from 0 to 100. A value of 100 represents completely impermeable surfaces or the surface portion of water bodies, while CN values for other surfaces are less than 100 and generally range between 55-95 (Hawkins et al., 2002). According to this method, the relationship between precipitation (P) and runoff (Q) is expressed as;

$$Q = \frac{(P - Ia)^2}{((P - Ia) + S)}$$

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

Where P is precipitation (mm), Q is flow (mm), S is water retained by the soil (mm), Ia: λS, "Ia" represents the water quantity prior to runoff, including factors like initial abstraction, infiltration, or rain interception by vegetation, while "CN" stands for the surface runoff curve number. CN, as already mentioned, is determined by factors such as land cover, hydrological soil groups, and Antecedent Moisture Condition (AMC) values within the catchment, as specified by Johnson (1998). For AMC, SCS (1972) considered three different conditions (Dry (I), Normal (II) and Moist (III)) according to the moisture condition of the soil before the onset of rainfall and proposed three different CN (CN I, CN II and CN III) values according to these conditions (Table 4). AMC II, also known as CN II, can be synonymous with average soil moisture. Additionally, there are dry conditions, labeled AMC I or CN I, and moist conditions, denoted as AMC III or CN III.

Table 4. CN values according to the AMC

CN	Total precipitation values for the previous 5 days (mm)	
	Dry season	Wet season
I	< 12.7	< 35.5
II	12.7-28	35.5-53
III	>28	>53

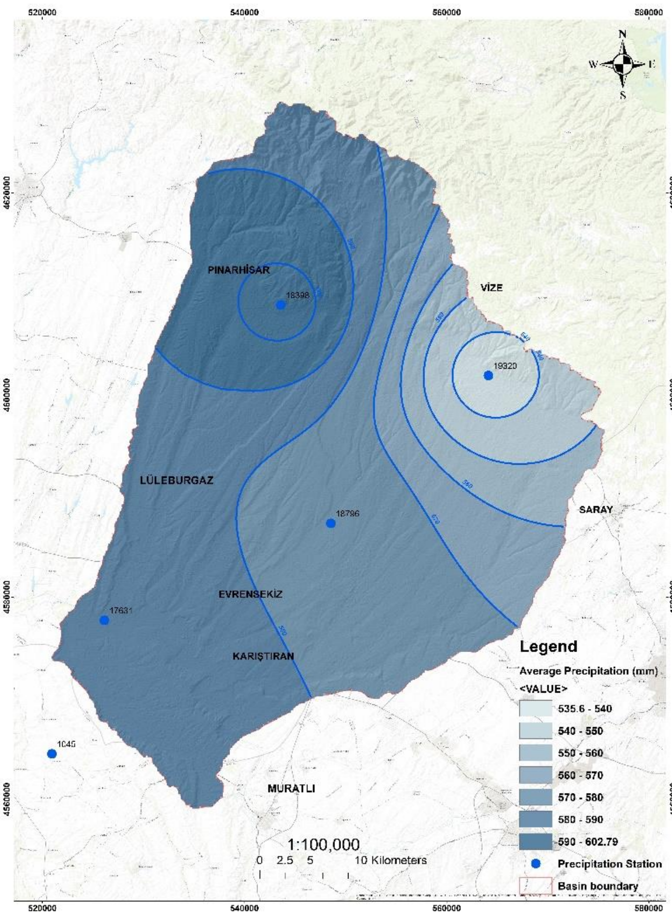

Figure 2. Average precipitation of the study area

To calculate the CN value for AMC II, it is multiplied by an adjustment factor determined by the current AMC, thereby establishing the adjusted number of curves;

$$CNII = \frac{\sum_{i=1}^{n}(CN_i * A_i)}{\sum_{i=1}^{n} A_i}$$

Where CN II is CN II value for the catchment, for each land use/cover and hydrological soil group, CNi represents the corresponding CN value, while A_i represents the area associated with each land use/cover and hydrological soil group.

Results and Discussion

The SCS-CN method is used with high accuracy, especially in semi-arid regions such as Asia (Kumar and Jhariya, 2017; Raju et al., 2018; Al-Ghobari et al., 2020; Rao, 2020; Shi and Wang, 2020). According to Kumar and Jhariya (2017), using the SCS-CN method, the accuracy assessment of the areas suitable for recharge structure potential maps of the Bindra basin was found to be 82.60%. Raju et al. (2018) found that over the past 20 years, the ungauged watershed has shown annual averages of 688.82 mm of rainfall, 478.06 mm of runoff, a runoff volume of 699.75 m³, and a runoff coefficient of 0.69. Al-Ghobari et al. (2020) reported that using the SCS-CN method for rainfall-runoff linear regression analysis demonstrated a strong correlation of 0.98 in Saudi Arabia. Shi and Wang (2020) used a modified SCS-CN method and the results demonstrated that the model efficiencies of the proposed method increased to 80.58% during the calibration period and 80.44% during the validation period.

The SCS-CN method has recently been used in other continents besides Asia and has yielded highly accurate results (Caletka et al., 2020; Walega et al., 2020; Soulis, 2021). Walega et al. (2020) compared the SCS-CN method with other modified methods and found that direct runoff calculated using the modified Sahu-Mishra-Eldho method and the original SCS-CN method was close to each other for the Coweeta watershed. According to Caletka et al. (2020), the acquired findings for the five basins in Czechia indicate the necessity for a systematic yet site-specific revision of the traditional CN

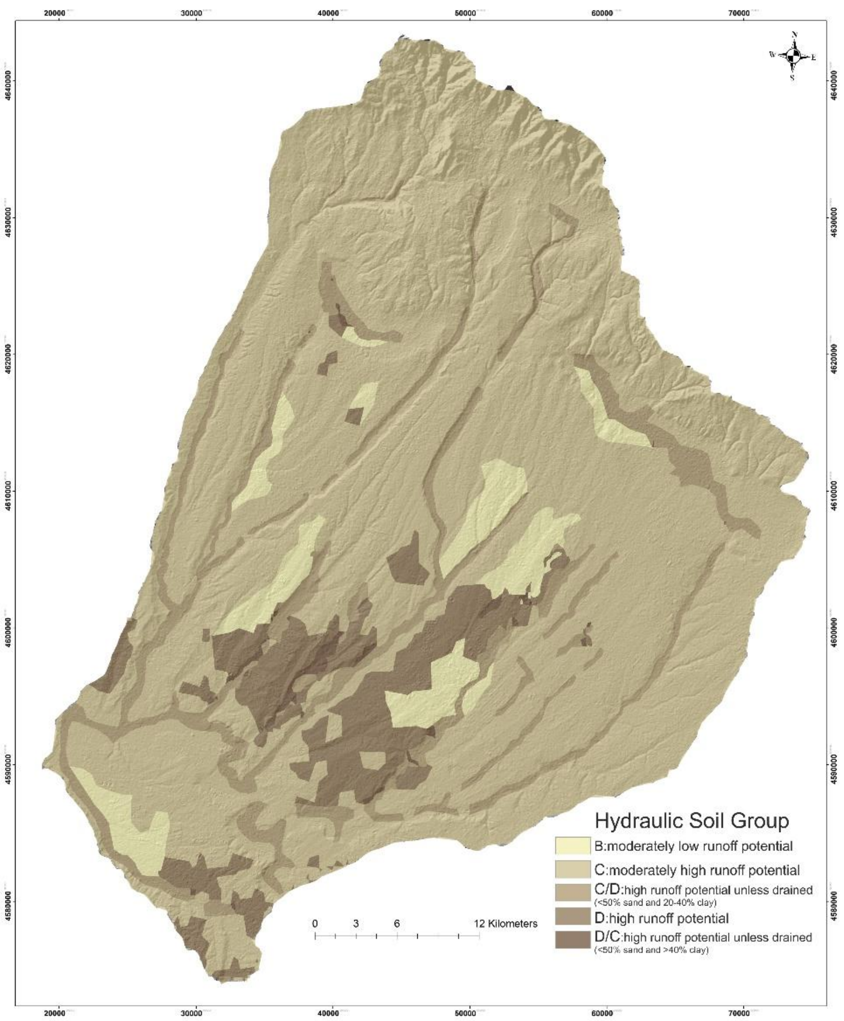

Figure 3. Hydraulic soil groups of Luleburgaz Sub-basin

method, which could help enhance the accuracy of CN-based rainfall-runoff modeling. As with many studies mentioned above, the original SCS-CN method was used in this study, and data with 86% accuracy was obtained using actual flow data.

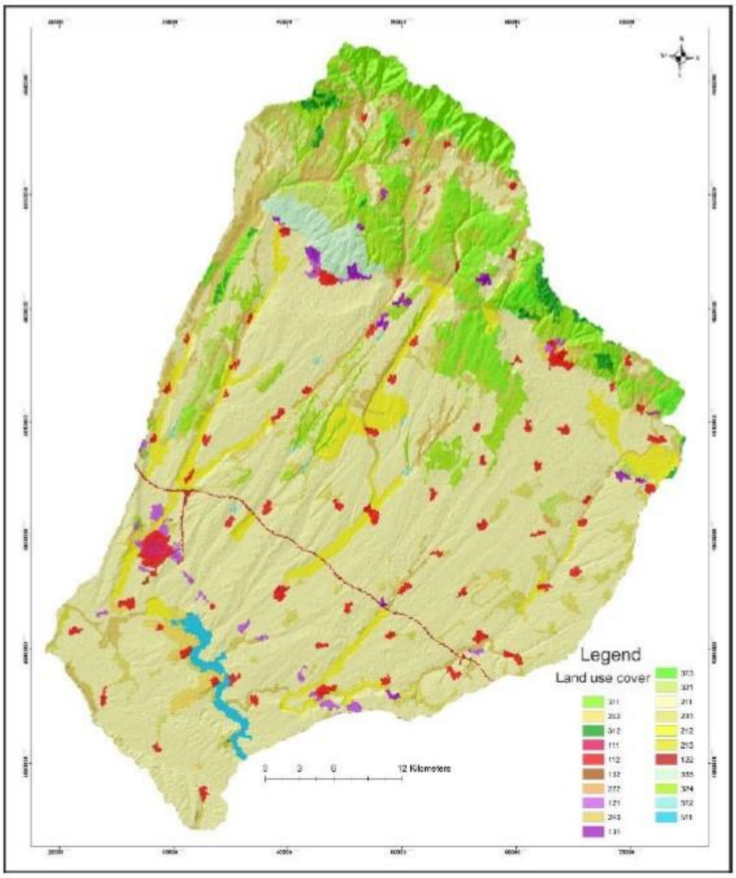

Figure 4. Land-use cover map of Luleburgaz Sub-basin

Upon evaluating the precipitation data from five meteorological stations in the study area, the basin's average precipitation was determined to be 581.4 mm, as illustrated in (Figure 2). HSG map for the study area was created based on the data acquired from the ORNL DAAC regarding hydraulic soil groups. The HSG data in vector format was converted to raster format with

Table 5. The CN values were calculated according to the land cover and hydrological soil groups

Land Use Cover	CN Values according to Hydrological Soil Groups			
	A	B	C	D
Industrial areas	81	88	91	93
Commercial areas	89	92	94	95
High-density settlement	77	85	90	92
Medium-density settlement	57	72	81	86
Low-density settlement	51	68	79	84
Well-covered forest	25	55	70	77
Poorly covered forest	45	66	77	83
Pasture, grazing land	49	69	79	84
Agricultural fields	72	81	88	91
Mining sites	76	85	89	91
Open areas (park, garden)	39	61	74	80
Roads, streets	98	98	98	98
Wetlands	100	100	100	100

25x25 m pixels. Hydraulic soil groups in the study area were determined as B, C, C/D, D and D/C (Figure 3).

The land use cover codes for the study area were generated using a GIS-based program with Corine Land Cover (2018). A detailed description of the land use cover codes in the study area is given in Table 3. Notably, agricultural areas and forested regions form a significant portion of the study area, as depicted in Figure 4.

In the GIS database, CN values and areal data are available in the map produced with the cross function. CN values of sub-basins according to different AMC classes were calculated by some formulae. Among these, CN II values according to AMC II class are given in Table 5 and shown in Figure 5 on the map.

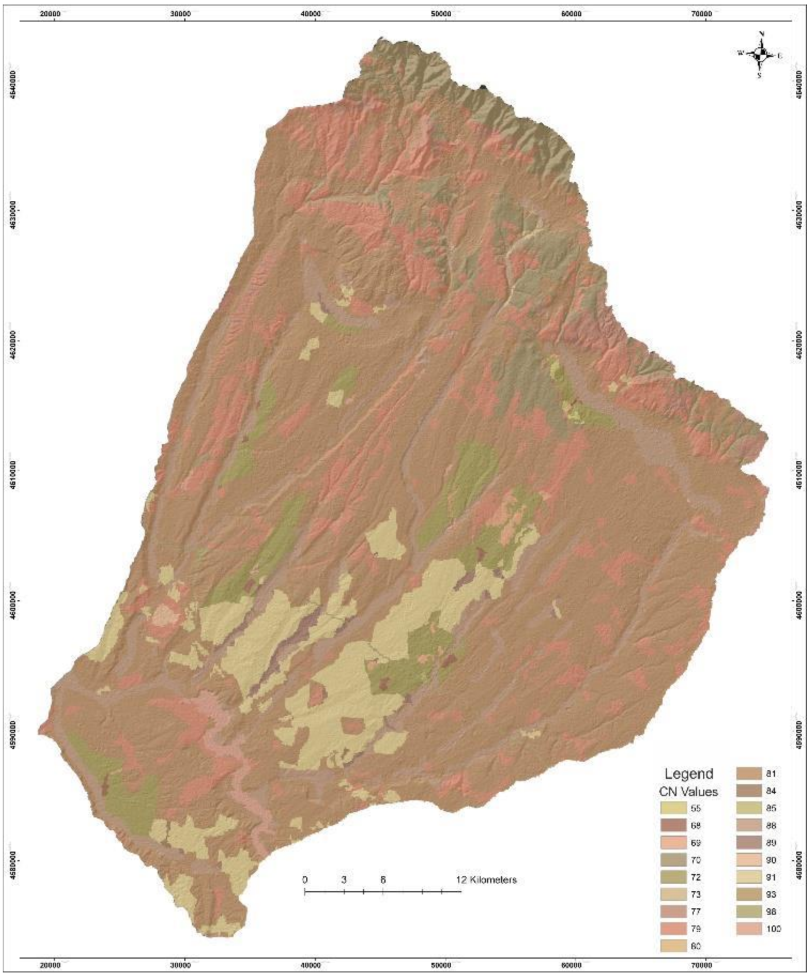

Figure 5. Map showing the CN values generated according to land use cover and hydrological soil groups

CNI, CNII and CNIII values for the basin were calculated from CN formulas (Table 6).

Table 6. CN values calculated for Lüleburgaz Sub-basin

Basin	CNI	CNII	CNIII
Lüleburgaz Sub-basin	63.44	80.51	90.48

The SCS-CN method was used to calculate the average surface runoff for the catchment over the last five years, resulting in a determination of 73.3 mm. Then, these calculated flow data were compared with the flow measurements of Lüleburgaz Current Observation Station located at the outlet of the basin.

The data between 2013-2017 for the flow observation station in the basin were evaluated, and the total flow and calculated base flow graphs were drawn with 3 methods (Local Minimum Method, Fixed Interval Method, Sliding Interval Method) determined by Pettyjohn and Henning (1979). The flow and base flow graph of Lüleburgaz station for the period 2016-2017 is shown in Figure 6. In the average of the three methods, the base flow was found to be approximately 223x106

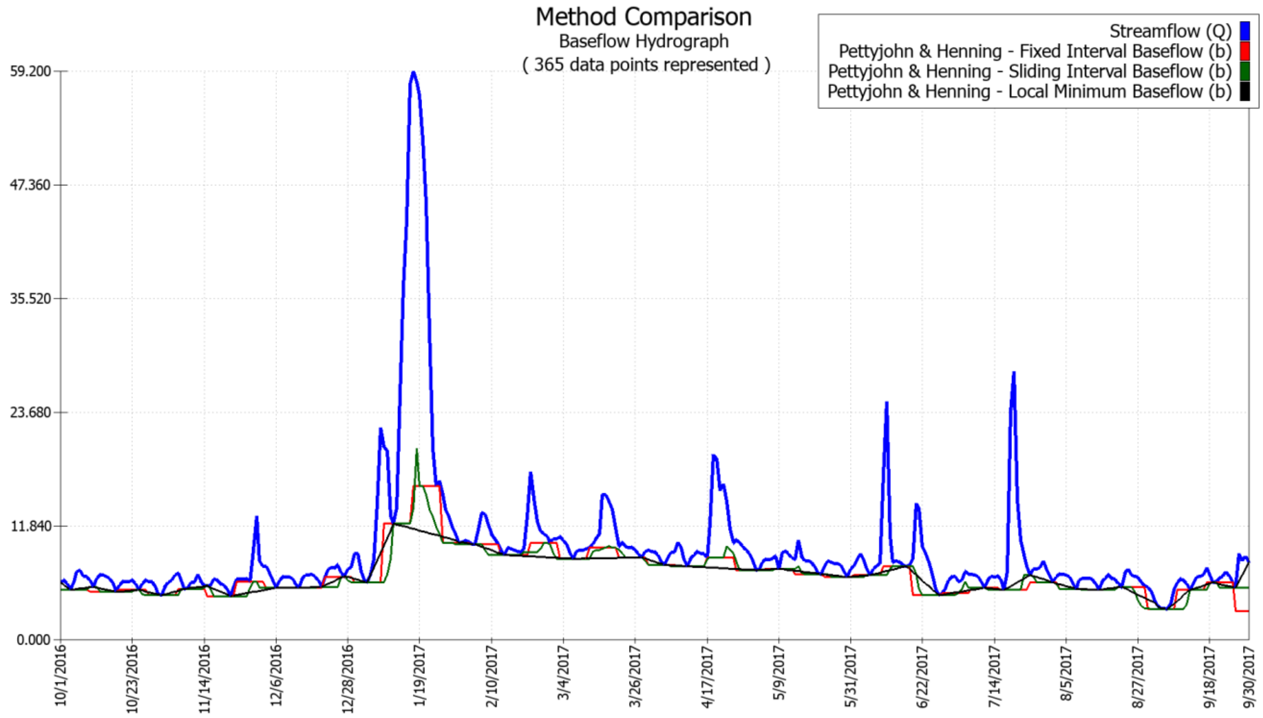

Figure 6. Total flow and base current graphs (Pettyjohn and Henning, 1979).

Table 7. Flow values measured at D01A008 Lüleburgaz station for the last 5 years (x$10^6$$m^3$/year)

Time	2013	2014	2015	2016	2017	Average
Total flow	371.25	427.88	268.68	241.38	366.16	335.07
Base flow	212.43	261.63	158.54	139.86	223.82	199.26
Surface flow	158.82	166.25	110.14	101.52	142.34	135.81

m^3/year and the surface flow was found to be 143x106 m^3/year (Table 7).

Conclusion

The Soil Conservation Service Curve Number (SCS-CN) method is extensively employed as a straightforward approach to the estimation of direct runoff volume resulting from a specific precipitation event. In this study, the runoff value was computed using the SCS-CN method and subsequently compared with the observed data recorded at the flow observation station. The findings from this study emphasize the effectiveness and accuracy of the SCS-CN method for determining surface runoff in ungauged watersheds. As a result, average precipitation in Lüleburgaz Sub-basin is calculated as 1250 x 10^6 m^3/year. At the flow observation station, the total runoff was measured to be 335 x 10^6 m^3/year, with surface runoff at 135.8 x 10^6 m^3/year. Utilizing the SCS-CN method, the average runoff was determined to be 157.6 x 10^6 m^3/year. Applying this method to the Lüleburgaz Sub-basin achieved an 86% accuracy rate when compared with actual flow data, validating its applicability in similar basins lacking streamflow observation data.

The study emphasizes the critical role of accurate precipitation data, hydrological soil group classifications, and land use cover information in enhancing the precision of the SCS-CN model. These elements are crucial in determining the Curve Number (CN) values, directly influencing the runoff calculations. Furthermore, the obtained findings highlight the necessity for a systematic yet site-specific revision of the traditional CN method. Adjusting the CN values to more accurately reflect local conditions can significantly improve the model’s performance. This study supports the notion that while the traditional CN method provides a solid foundation, adapting it to specific site conditions can yield better results in rainfall-runoff modeling.

The successful application of the SCS-CN method in the Lüleburgaz Sub-basin also provides a framework for future research and practical applications in water resource management, especially in regions facing water scarcity and quality issues. The model’s ability to predict runoff with high accuracy makes it a valuable tool for planning and implementing effective land and water management strategies.

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Author Contributions

MB: Conceptualization, Investigation, Writing-Original Draft Preparation, Writing-review and editing, Methodology- creation of models, Formal Analysis. **HH:** Writing-review and editing, Resources, Project Administration

Conflicts of Interest

The authors declare no conflict of interest.

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