Using the SCS Curve Number Method for Rainwater Harvesting: A Case Study from Yenipazar, Turkey

Baris Kara[1], Gamze Baykurt[2]

[1]*Aydin Adnan Menderes University, Faculty of Agriculture, Department of Landscape Architecture,*
Aydin, Turkey
[2]*Student,Aydin Adnan Menderes University,Graduate School of Natural andAppliedSciences,*
Department of Landscape Architecture,Aydin, Turkey
Corresponding Author: B. Kara

ABSTRACT: Humans' survival depends on water as well as food and air. Only 0.3% of the water in the world is suitable for human consumption. Nowadays, it is more realized that water, which is not given importance by most of us, is a limited resource. The asphalting of urban areas and constructions lead to a decrease in groundwater recharge areas, and large amounts of quality rainwater falling on cities also flow into municipal drainage systems. These problems have turned rainwater harvesting (RWH) into a necessary practice in urban environments in recent years. Water scarcity is an important problem in many developing countries. Turkey is a country which also faces water scarcity, and this problem has become more serious in the country.

This study aims to investigate the possibility of using harvested stormwater as a park irrigation source by adopting the storage technique. In this study, the applicability of the Soil Conservation Service Curve Number (SCS-CN) method to rainwater harvesting was examined in the case study example of Yenipazar (Turkey).

Of the study area, 33.17% (3058.35 m^2) is comprised of pervious areas, 60.46% (5574.99 m^2) of impervious areas, and 6.37% (587.48 m^2) of other areas (structures, pools, etc.). Of 29 pervious areas, 36.03% are in a good (10 areas/1101.87 m^2), 39.72% are in a fair (9 areas/1214.79 m^2), and 24.25% are in a poor (10 areas/741.69 m^2) condition. For AMC I, AMC II, and AMC III conditions, the weighted CN values of the area were calculated as CN_I 75.53, CN_{II} 87.56, and CN_{III} 94.28, respectively. The amount of rainwater harvested in the area (calculated runoff) is 62.70 m^3. This amount corresponds to 8.99% of the total precipitation (697.55 m^3) in December 2020. The rainwater harvested in Yenipazar city park should be stored in the underground tank to be built in the area's northeast and used in the irrigation of the plants in the park by the drip irrigation method. Rainwater harvesting studies should be conducted using the SCS-CN method in urban open spaces in Yenipazar district, in other provinces of Turkey, or in different countries of the world, a drip irrigation system should be used in landscape irrigation, and drought-tolerant and/or less water-consuming plants should be preferred for planting. Using the SCS-CN method in rainwater harvesting will be an important tool in the fight against water scarcity in Turkey and other countries.

KEYWORDS: Water scarcity, water savings, stormwater, rainwater harvesting, runoff, SCS-CN method, park irrigation, Turkey.

I. INTRODUCTION

Water is necessary for the whole life[1, 2, 3]. However, less than 1% of the world's water is suitable for human use as fresh water in rivers, ponds, and lakes[4]. In 2006, the United Nations indicated that water scarcity affected every continent and approximately 1.2 billion people, making up almost one-fifth of the world's population living in areas of physical scarcity, were affected by water scarcity and warned that 500 million people were approaching this situation. Water scarcity is among the major problems that many societies will face in the 21st century[5]. Most developing countries are classified among the countries with water scarcity characterized by low and irregular precipitation resulting in a high risk of drought, in-season drought, and food safety problems[6]. When

the amount of water per capita is taken into account, Turkey is considered a country suffering from water scarcity with an annual amount of water per capita of 1519 m^3. According to the projections, it is stated that the annual amount of water per capita will decrease to 1120 m^3 with a population of 100 million in 2030[7] and Turkey will be a water-poor country[8, 9]. Because of the rapidly increasing world population and global climate changes, humanity has faced a major water scarcity problem in urban environments in the modern age[10, 11]. The world urban water demand is estimated to increase to 6.4 billion m^3 in 2050[12].

Many countries know that water resources have become more critical[13]. The increased use of water in urban areas pushes cities and water managers to look for alternative renewable water resources[14]. In this context, rainwater is regarded as an important water resource with continuity[15]. Severe droughts, concerns about the environmental impact of the stormwater runoff, and increased water demands in recent years have increased the interest in rainwater collection systems. Rainwater harvesting (RWH) is one of these systems[16]. RWH is the practice of allowing and encouraging precipitation to flow from basin surfaces in a controlled manner, then storing the harvested water in a tank for future usage[16, 17, 18, 19]. RWH means that rainwater is used optimally where it falls. It is stored and is not allowed to infiltrate and overflow other places[17]. Rainwater collected as a result of RWH is used for groundwater recharge, in agricultural irrigation, in animal husbandry, in domestic use, and as drinking water and landscape irrigation[19, 20, 21, 22, 23]. RWH ensures savings of other water resources as an alternative water resource[24, 25], increases water quality[1, 24], reduces soil erosion and stormwater runoff[15, 17, 19, 26, 27]., reduces the damage of floods[17, 19, 25, 26, 28], mitigates the effects of drought[1, 17], and saves money[29]. With these aspects, RWH has a great potential to be a sustainable way of coping with the hydrological challenges posed by the urban environment[30, 31, 32, 33, 34]. However, very little attention has been paid to the urban dimensions of rainwater harvesting[35]. There are two methods for rainwater harvesting, including rooftop rainwater harvesting [36, 37].and surface runoff harvesting [1, 3, 37].

Runoff is the most important component of the water cycle and refers to the flow of precipitation or its discharge from a catchment area through a channel[38]. Runoff is one of the most important hydrological variables used in water resources studies[39, 40], in the planning and design of hydraulic structures and in the water's evaluation

yield potential of a basin[41]. Runoff is also important for the feeding of dams as a water resource and anti-flood design of the drainage network in cities[38]. The formation and amount of runoff depend on the characteristics of precipitation, such as intensity, duration, and distribution[40]. RWH is based on the use of surface runoff, and thus, it needs runoff producing and runoff receiving areas[36]. Infiltration is another important component of the hydrological cycle and divides precipitation into surface runoff and inflowing to the soil[42, 43].

Because of the impact of global climate change, the increase in the impervious surfaces of modern cities[44, 45], and the failure of drainage systems in extreme precipitation events, precipitation causes large volumes of runoff in urban environments, andthere is an increase in severe flood events[46, 47, 48].

. Floods cause significant damage to buildings and put public-private infrastructure and people's lives at risk. It is essential to reduce runoff in order to decrease the flood risk and reduce the cost of drainage systems in urban environments. Traditional rainwater management approaches convey runoff to surface water bodies, and collect and treat it[49]. Therefore, RWH may play an important role in collecting and reducing the surface runoff and increasing the volume of water that enters the ground[50, 51, 52].

Many factors should be known to investigate the relationship between rainfall and runoff. While some of these factors are related to meteorological characteristics, some of them are related to the physical characteristics (slope, impermeability, etc.) of the recipient surface of rainfall[53]. Various models have been developed to calculate the runoff resulting from a precipitation event. The Soil Conservation Service Curve Number (SCS-CN) method is one of these models, called rainfall-runoff modeling[54, 55, 56, 57, 58, 59, 60]. The SCS-CN method was initially designed for non-small-scale agricultural watersheds, and then it was used in non-agricultural watersheds such as mining sites[61] and even in urban areas[62]. Because of its flexibility [63, 64, 65, 66]and simplicity[63, 64, 66, 67, 68], the use of the CN parameter only [61, 69]and the fact that it can be easily applied to water collection features such as soil type, land use/treatment, surface condition, and antecedent moisture condition (AMC)[61, 65, 70, 71, 72], it is commonly used in hydraulic engineering and environmental impact analysis studies in the USA and other countries[61, 66, 73].

The SCS-CN method uses a series of simple equations with input data such as land use

type, precipitation, hydrologic soil groups (HSG), curve number (CN), and AMC[38, 65, 74, 75, 76]. Soils are classified according to HSG to show the minimum infiltration rate obtained for bare soil after prolonged wetting[54]. There are four HSGs; A, B, C, and D[38]. While soils with high infiltration rate and low runoff potential are group 'A' soils, soils with very low infiltration rate and high runoff potential are group 'D' soils[40, 64, 74]. Important soil properties that affect the hydrological classification (HSG) of soils are effective soil depth, average clay content, infiltration properties, and permeability [66](Table).

The CN value depends on land surface characteristics and hydro-soil conditions[39]. The CN value varies between 0 and 100[38, 50, 72, 77, 78]. While CN values approaching 0 indicate that the surface is permeable (S infinity) and the runoff potential is low, CN values approaching 100 indicate that it is an impermeable surface (S=0) and the surface has high runoff generation capabilities[38]. With the increase in the CN value, the surface runoff volume increases to the same extent[39].

The antecedent moisture condition (AMC) is the previous relative humidity of pervious surfaces before the precipitation event[66, 79, 80]. Antecedent moisture is considered low when the previous precipitation is too little and high when there is significant precipitation before the modeled precipitation event[80]. The standard method used to define AMC is based on the amount of 5-day antecedent rainfall[50, 81, 82]. AMC is a very important factor to determine the actual CN value[40]. There are three levels of AMC applications: AMC I (dry/lower limit of soil moisture or upper limit of S), AMC II (moderate/normal conditions or average soil moisture content), and AMC III (wet/upper limit of soil moisture or lower limit of S)[61, 66, 83, 84, 85].

Weighted CN-I, II, or III is related to AMC I, II, or III[72] defined in the National Engineering Handbook Section 4: Hydrology (NEH-4)[85]. Weighted CN_{II} is an average condition, and CN_I and CN_{III} represent dry and wet conditions, respectively.

Previous Research on RWH

In Jordan, an arid to semi-arid country with water scarcity caused by climatic conditions such as drought and high solar radiation, and population pressure[86], attention is now focused on alternatives such as rainwater harvesting systems. Due to the lack of sewerage systems in many rural and urban areas of Jordan, it was indicated that rainfall collected from roads, parking lots, and roofs could increase the water supply for various domestic uses and help to fight against chronic water scarcity in the country[87].

[88] evaluated the use of rainwater. They revealed that the demand for other water resources could be reduced by half with the establishment of an integrated reuse system.

[89]modeled the operating policy of the University of Colorado's automatic irrigation systems and used the simulation model to predict rainwater runoff that could be used for irrigation. He stated that approximately 60% of the campus surfaces were impervious. The results showed that most of the rainwater could be used for the existing irrigation on the campus.

[90]developed a model for an individual residential area using harvested rainwater for landscape irrigation. They used this model, which evaluated the effectiveness of the in situ stormwater capture for landscape irrigation use, in cities in the USA, including Atlanta.

In this study, Yenipazar (Turkey) city park was evaluated in terms of RWH using the SCS-CN method, and recommendations were made concerning the use of rainwater to be harvested in a tank or pool in the park's irrigation. The reasons for selecting the SCS-CN method for this study are that it is a simplified method, it was developed to predict the runoff depth for rainstorms[61], provides good results, and is suitable for application in the study area[91, 92].

II. STUDY AREA

The study area is Yenipazar (Turkey) district city park. Yenipazar is a district of Aydın province, in the Aegean region in the west of Turkey (Figure 1). The climate of the district is Csa according to Köppen-Geiger climate classification. In the district, winters are warm, summers are very hot, and the arid climate (Mediterranean climate) prevails. Precipitation occurs mostly in the spring-winter months[93, 94]. While July is the driest month of the year with a mean precipitation of 3 mm, December is the rainiest month of the year with a mean precipitation of 93 mm. Yenipazar has a mean annual precipitation of 578 mm and a mean annual temperature of 17.58 °C[94]. Like many cities in Turkey, Yenipazar also faces a water scarcity problem for reasons such as climate change, limited precipitation, and improper use of water. The study area is 9220.82 m^2. The slope in the area is 2.5%. The cover types of the area consist of open space formed by lawns and impervious areas formed by paved surfaces. The area has a soil with moderately low runoff potential and moderate infiltration rate, silt loam or loam texture, and an HSG of B.
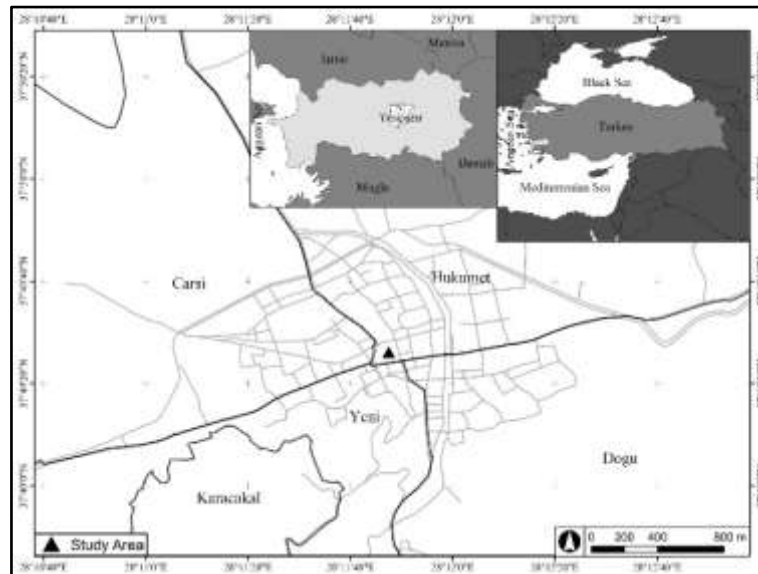
Figure 1. Study area.

III. MATERIAL AND METHOD

The precipitation data used in the study were the daily precipitation data for December 2020 got from Aydın Meteorological Station Directorate. The soil data were obtained from Yenipazar District Directorate of Agriculture and Forestry. The plan with elevation points of the area was created as a result of the land measurements. The slope of the area was determined using this plan with elevation points. The study area was divided into two groups as pervious (lawns) and impervious (paved surfaces) areas, according to permeability status. Pervious areas were classified among themselves as poor condition (grass cover <50%), fair condition (grass cover 50% to 75%), and good condition (grass cover >75%) according to their infiltration levels (Figure 2). CN values were determined according to the HSGs of the cover types in the area[54]. Then, the weighted CN value of each cover type was calculated.

Runoff and SCS-CN Method
In this study, the SCS-CN method was used to calculate the surface runoff. The hypothesis of the SCS-CN method reveals the following equation [54, 80, 82, 95, 96, 97][Eq. (1)].

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

In which
Q=Runoff (mm),
P=Rainfall (mm),
S=Infiltration (mm),
Ia=Initial abstraction,

The Ia value is considered to be equal to 0.2S. Therefore, the SCS-CN model in Eq. (1) can be expressed as follows [54, 63, 98, 99, 100][Eq. (2, 3)].

$$I_a = 0.2S \qquad (2)$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad \text{(for P > 0.2S)}$$

$$Q = 0 \qquad \text{(for P ≤ 0.2S)} \qquad (3)$$

The parameter S can be expressed as a conversion of CN [50][Eq. (4)].
CN = Runoff curve number

$$S = \frac{25400}{CN} - 254 \qquad (4)$$

The HSG (as B) of the study area was determined based on soil data (Table 1).

Table 1. Main characteristics of the HSG[54].

HSG		Soiltextures	Runoffpotential	Infiltration	Watertransmission
A	Deep, welldrainedsoils	Sand, loamysand,	Low	High	>7.62
B	Moderatelydeeptodeep, moderatelywelltowelldrainedwithmoderatelyfinetomoderatelycoarsetextures	Siltloamor loam	Moderatelylow	Moderate	3.81-7.62
C	Moderatelyfinetofinetexture	Sandyclay loam	Moderatelyhigh	Low	1.27-3.81
D	Soilswhichswellsignificantlywhenwet, heavyplasticandsoilswith a permanenthighwatertable	Clayloam, siltyclayloam, sandyclay, siltyclay, orclay	High	Verylow	0-1.27

The CN values of pervious (lawns) and impervious (paved surfaces) areas were determined according to HSG B (Table 2).

Table 2. Runoff curve numbers for urban areas[54].

CoverType	Curvenumbersfor HSG			
	A	B	C	D
Open space (lawns, parks, golf courses,				
Poorcondition (grasscover<50%)	68	**79**	86	89
Faircondition (grasscover 50% to 75%)	49	**69**	79	84
Goodcondition (grasscover>75%)	39	**61**	74	80
Imperviousareas				
Pavedparkinglots, roofs, driveways, etc.	98	**98**	98	98

Weighted CN values were calculated according to AMC values (Table 3).

Table 3. Classification of antecedent moisture conditions (AMC)[61, 82, 101].

AMC Group	Soilcharacteristics	Fivedayantecedentrainfall (mm)	
		Dormantseason	Growingseason
I	Drycondition	<13	<36
II	Moderatecondition	13-28	36-53
III	Wetcondition	>28	>53

First, the weighted CN_{II} value corresponding to the average AMC (AMCII) of the area was calculated[61, 66, 83, 84, 85]. Then, the weighted CN_{II} value for AMC II was converted to weighted CN_I and weighted CN_{III} values for AMC I and AMC III [40, 61, 66, 102,103][Eqs. (5) and (6)].

$$CN_I = \frac{CN_{II}}{2.281 - 0.01281CN_{II}} \quad (5)$$

$$CN_{III} = \frac{CN_{II}}{0.427 + 0.00573CN_{II}} \quad (6)$$

CN: Runoff curve number
CN_I: Dry curve number (AMCI)
CN_{II}: Moderate curve number (AMCII)
CN_{III}: Wet curve number (AMCIII)

IV. RESULTS
While 3058.35 m^2 (33.17%) of the study

area consists of pervious areas, 5574.99 m^2 (60.46%) and 587.48 m^2 (6.37%) of the study area comprise impervious areas and other areas (structures, pools, etc.), respectively. The sum of pervious areas and impervious areas is 8633.34 m^2. Of 29 pervious areas, 10 are in a good (1101.87 m^2/36.03%), 9 are in a fair (1214.79 m^2/39.72%), and 10 are in a poor (741.69 m^2/24.25%) condition. Among the pervious areas, the largest area was the area number 20 in a fair condition with 397.33 m^2, and the smallest area was the area number 26 in a poor condition with 6.49 m^2. While pervious areas in a good condition constituted 12.76% of the sum of pervious and impervious areas, areas in a fair condition made up 14.07% of them, and areas in a

poor condition constituted 8.59% of them. Impervious areas made up 64.58% of the sum of pervious and impervious areas (Table 4).

The CN was found to be 61 for the pervious areas in a good condition, 69 for the areas in a fair condition, 79 for the areas in a poor condition, and 98 for the impervious areas (Table 4).

While Area (%) x CN of the pervious areas in a good condition was calculated as 779, Area (%) x CN of the areas in a fair condition was 971, Area (%) x CN of the areas in a poor condition was 679, Area (%) x CN of the impervious areas was 6328, and Area (%) x CN of the sum of the pervious and impervious areas was 8756 (Table 4, Figure 2).

Table 4. Characteristics of pervious and impervious areas.

| Pervious areas	Area (m^2)	Area (%)	CN	Area (%) x CN	Condition
1	254.99				good
5	202.17				good
6	212.69				good
7	81.50				good
10	112.13				good
11	79.98	1101.87	12.76	61	779	good
12	46.92				good
13	43.75				good
21	52.72				good
28	15.04				good
2	71.69				fair
3	83.03				fair
8	17.08				fair
15	48.71				fair
17	258.35	1214.79	14.07	69	971	fair
19	24.21				fair
20	397.33				fair
22	146.70				fair
23	167.68				fair
4	76.75				poor
9	69.46				poor
14	36.91				poor
16	53.54				poor
18	25.85	741.69	8.59	79	679	poor
24	33.74				poor
25	7.54				poor
26	6.49				poor
27	383.15				poor
29	48.28				poor
Total pervious area	3058.35				
Total Impervious areas	5574.99	64.58	98	6328	
Total pervious and impervious areas		100		8756	
Other areas (buildings, ponds etc.)	587.48				
Total Area	9220.82				
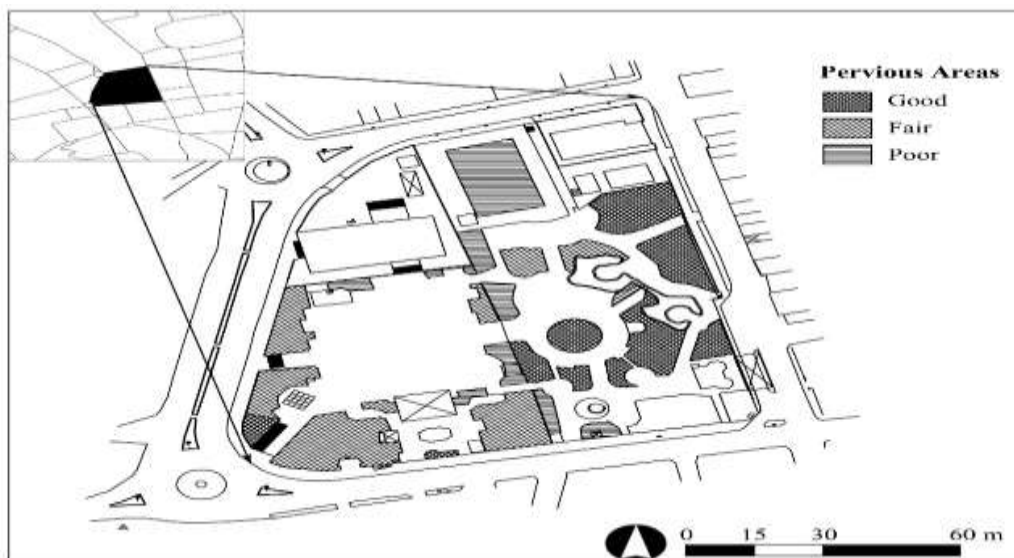
Figure 2. Pervious areas by infiltration levels.

For AMC I, AMC II, and AMC III conditions, the weighted CN values of the area were calculated as CN_I 75.53, CN_{II} 87.56, and CN_{III} 94.28, respectively. Precipitation was observed on December 8, 9, 11, 12, 13, 14, 28, and 29 in Yenipazar. The district received a total precipitation of 80.80 mm (697.55 m³) in December. The runoff (amount of the collected water) calculated in the area was 7.26 mm (62.70 m3). This amount constituted 8.99% of the total precipitation in December 2020 (Table 5).

Table 5. RWH calculations for Yenipazar district according to the SCS-CN method.

Date	P (mm)	AMC	Weighted CN	S (mm)	Q (mm)	Q (m³)	I_a=0.2S
1.12.2020	0	1	75.53	82.29	0	0	16.46
2.12.2020	0	1	75.53	82.29	0	0	16.46
3.12.2020	0	1	75.53	82.29	0	0	16.46
4.12.2020	0	1	75.53	82.29	0	0	16.46
5.12.2020	0	1	75.53	82.29	0	0	16.46
6.12.2020	0	1	75.53	82.29	0	0	16.46
7.12.2020	0	1	75.53	82.29	0	0	16.46
8.12.2020	9.3	1	75.53	82.29	0	0	16.46
9.12.2020	0.6	1	75.53	82.29	0	0	16.46
10.12.2020	0	1	75.53	82.29	0	0	16.46
11.12.2020	27.2	1	75.53	82.29	1.24	10.71	16.46
12.12.2020	5.8	3	94.28	15.41	0.41	3.52	3.08
13.12.2020	15.6	3	94.28	15.41	5.61	48.46	3.08
14.12.2020	0.6	3	94.28	15.41	0	0	3.08
15.12.2020	0	3	94.28	15.41	0	0	3.08
16.12.2020	0	3	94.28	15.41	0	0	3.08
17.12.2020	0	2	87.56	36.07	0	0	7.21
18.12.2020	0	2	87.56	36.07	0	0	7.21
19.12.2020	0	1	75.53	82.29	0	0	16.46
20.12.2020	0	1	75.53	82.29	0	0	16.46
21.12.2020	0	1	75.53	82.29	0	0	16.46

22.12.2020	0	1	75.53	82.29	0	0	16.46
23.12.2020	0	1	75.53	82.29	0	0	16.46
24.12.2020	0	1	75.53	82.29	0	0	16.46
25.12.2020	0	1	75.53	82.29	0	0	16.46
26.12.2020	0	1	75.53	82.29	0	0	16.46
27.12.2020	0	1	75.53	82.29	0	0	16.46
28.12.2020	6,.1	1	75.53	82.29	0	0	16.46
29.12.2020	15.6	1	75.53	82.29	0	0	16.46
30.12.2020	0	2	87.56	36.07	0	0	7.21
31.12.2020	0	2	87.56	36.07	0	0	7.21
Total	80.80				7.26	62.70	

V. CONCLUSIONS AND RECOMMENDATIONS

The results provide managers with basic information to evaluate the potential runoff and offer solutions to reduce the problems related to runoff[38].

Of the rainwater harvested in Yenipazar city park, 62.70 m^3 can be stored in an underground tank to be built in the area's northeast. The harvested water should be used in the irrigation of the plants in the park.

Rainwater harvesting can be done effectively in playgrounds, open areas, and parks[26]. Rainwater harvesting systems should be established in all existing and planned urban open spaces such as playgrounds, parks, and urban squares in Yenipazar district. The amount of rainwater that can be harvested in these areas should be calculated using the SCS-CN method, and the harvested rainwater should be used in the irrigation of the plants in the areas with the drip irrigation system. Elements of the Mediterranean flora that are drought-tolerant and need less water should be preferred in the planting of urban open spaces in Yenipazar. Rainwater harvesting practices should be done in other provinces of Turkey and other countries. It is necessary to use less water-consuming species of the Mediterranean vegetation that can use the rainwater harvested in the provinces in the Mediterranean region of Turkey and other countries in the Mediterranean belt in the most efficient way. Native plants with low water consumption should be used in the provinces of Turkey and other countries where rainwater harvesting practices will be done, and these plants should be irrigated by the drip irrigation system using less water.

The use of the SCS-CN method in rainwater harvesting can be considered an important tool in the fight against water scarcity. In this context, the results provide useful information for the further development of the RWH program in other arid and semi-arid regions of Turkey and the world.

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