

Urban Rainwater Harvesting Assessment in Sulaimani Heights District, Sulaimani City, KRG, Iraq



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ABSTRACT

Rainwater harvesting is the collection of rainwater and runoff from catchment areas such as roofs or other urban surfaces. Collected water has productive end-uses such as irrigation, industry, domestic, and can recharge groundwater. Sulaimani heights have been selected as a study area, which is located in Sulaimani Governorate in Kurdistan Region, North Iraq. The main objective of this study was to estimate the amount of harvested rainwater form Sulaimani heights urban area in Sulaimani City. Three methods for runoff calculation have been compared, the storm water management model (SWMM), the soil conservation service (SCS) method, and the runoff coefficient (RC) using daily rainfall data from 1991 to 2019. The annual harvested runoff results with the three different methods SWMM, SCS, and RC were estimated as 836,470 m³, 508,454 m³, and 737,381 m³, respectively. The results showed that SWMM method has the highest runoff result and could meet 31% of the total demand of the study area and 28% and 19% for RC and SCS methods, respectively.

Index Terms: Rainwater harvesting, Storm water management model, Soil conservation service, Runoff coefficient, Runoff, Sulaimani heights

1. INTRODUCTION

Water is crucial for urban sustainability and in maintaining the sustainability of the environment [1], [2]. The extreme urbanization, industrial development, and agricultural expansion lead to increase demand of water in many parts of the world [3], [4]. Urban area development continuously reduces the groundwater recharging areas and increases depletion of groundwater [5].

Rainwater harvesting (RWH) is the collection and concentration of rainwater and runoff from catchment areas such as roofs or

other urban structure and can be used for irrigation, industry, domestic, and for groundwater recharge purposes [6], [7], [8], [9]. RWH techniques have been used throughout time for the irrigation purpose by the ancient Iraqi people around 4500 BC [10], and it is an environmentally vocal decision to address issues brought out by large projects utilizing centralized water resources management approaches [11].

Many previous studies mentioned the use of RWH successfully as an effective and alternative water supply resolution [12], [13]. Patra and Gautam [4] conducted a study to assess the runoff coefficient (RC) method for RWH in Dhanbad city in India. The runoff results indicated that RH system is an economic option for where in the areas where rainfall is adequate and could supply part of the water demand of the city.

Zakaria *et al.*, 2013 [14], used Macro RWH at Koysinjaq (Koya), in Kurdistan Region based on Soil Conservation Service Curve Number (SCS-CN) method. The findings

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demonstrated that the macro-RWH method can be a new source of water to reduce the problem of water scarcity and to minimize the water shortages problem.

In a research conducted by Harb [9], different RWH techniques were evaluated to identify the most significant method for METU-NCC campus on the west of North Cyprus. The runoff from roofs, pervious and impervious areas were collected and utilized and applying in two approaches: Traditional SCS method and storm water management model (SWMM) RWHS for calculation of runoff volume and the findings could meet 41.2% of the campus irrigation demand.

In 2016, a paper published by Gnecco *et al.* [15] in which SWMM was used to investigate the effect of domestic RWH and storage unit effects on control efficiency. The study area was located in neighborhood in Albaro in Italy, where covers 6000 m². The survey of the land use data displays that 57% of the land cover was impervious surfaces and 33% of rooftops of the total area. The findings of the software pointed that RWH can be applied in urban water management and methods for assessment and optimization of runoff storage and use as potable water.

2. STUDY AREA

The Sulaimani heights are located in Sulaimani Governorate in Kurdistan Region, North Iraq. The latitudes are between

35°35' 55" and 35°36' 51" N and the longitudes are between 44°26'25" and 45°27'35" E. The area has a topographic with elevations ranged from 950 m to 1113 m. Sulaimani has a mean annual rainfall of 715 mm and has a mean daily temperature of 19°C [16]. Sulaimani heights spread over an area of 2.12 km² and containing 2899 units of various sizes. The study area consists of three subcatchments, as shown in Fig. 1, and the detail information about each subcatchment is shown in Table 1. According to the map from Sulaimani heights authority (Qaiwan Company), the area is divided into five zones, the green areas cover 17.14 % and the water pools cover 1.1% of the total area as shown in Fig. 2.

3. MATERIALS AND METHODS

3.1. Data Sets and Data Collection

3.1.1. Climatology data

The daily precipitation data for Sulaimani city from 1991 to 2019 were used from Directorate of Meteorology and Seismology of Sulaimani (DOMSOS). As there is no rain gauge station in the studied basins, therefore the closest meteorological station should be used; Sulaimani rain gauge in Ibrahim Pasha Street which is only 4 km away from the studied area that has an acceptable distance. Daily rainfall data were used to represent the basin rainfall for the study area [17].

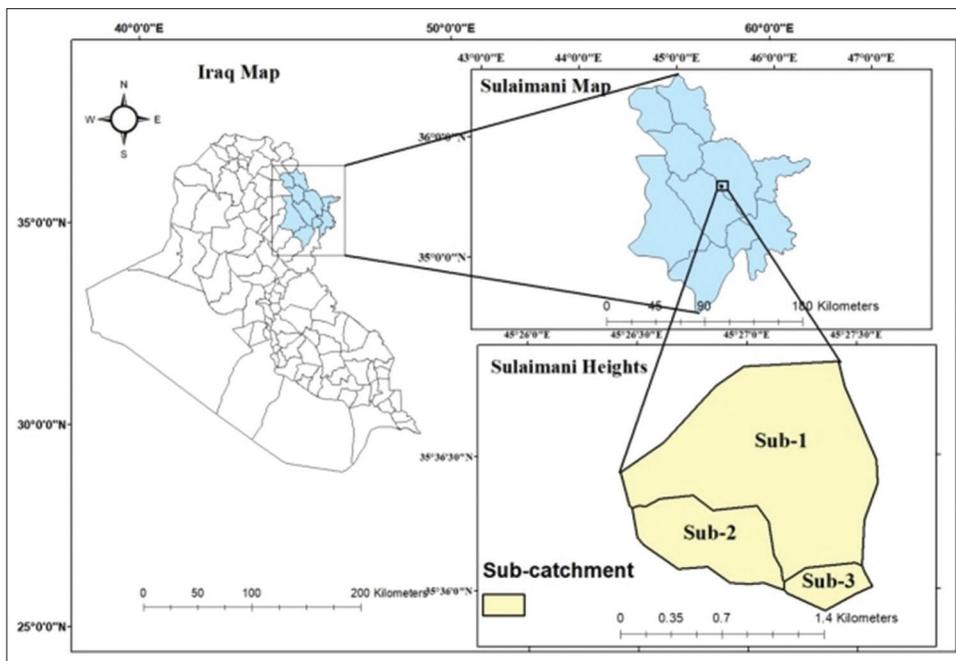


Fig. 1. Location of Sulaimani heights on Sulaimani map.



Fig. 2. Land use of Sulaimani heights.

TABLE 1: Detail information of the study area

Parameter	Value
Elevation – m	915–1113
Area km ²	2.12
Zone No.	5
Subcatchment No.	3
Residential No.	2899
Mean annual rainfall – mm	715
Mean daily temperature – °C	19

Other climatology data which have effect on the volume of the runoff should be also considered [9]; the monthly average wind speed and pan evaporation data from 1991 to 2019 were obtained from the Directorate of Meteorology and Seismology of Sulaimani.

3.1.2. Soil classification

To find the common soil characteristics of the study area, the Harmonized World Soil Database Viewer (HWSD) version 1.21 and soil map of the area were used. The software is adopted by cooperation of the Food and Agriculture Organization of the United Nations (FAO), the Chinese Academy of Sciences (CAS), the International Institute for

Applied Systems Analysis (IIASA), the International Soil Reference and Information Centre (ISRIC), and the Joint Centre of the European Commission (JRC). The coordinates of the study area were pointed on the HWSD viewer software and the dominant soil group was found to be Chromic Vertisols with 100% light clay to be the most prominent soil textures. Therefore, the dominant soil texture is clay and hence this satisfies the Hydrologic Soil Group D [18].

3.2. SWMM

SWMM is widely utilized software throughout the world in associating of urban runoff quantity and quality [19]. SWMM is a rainfall-runoff simulation model developed by the US Environmental Protection Agency to assist and support local storm water management in minimizing the runoff discharges. SWMM can forecast a single event or long-term (continuous) simulation set of model outputs parameters and inputs of runoff quantity and quality from primarily urban areas [20], [21], [22], [23], [24].

In accordance with the subcatchment properties, the average monthly surface runoff can be calculated through SWMM

software, to estimate monthly results from the SWMM software, the dates of simulation should be manipulated from the Options tab and the software run gives runoff depth, infiltration depth, and runoff volumes in the form of a table.

SWMM uses the Manning equation to express the relationship between flow rate (Q), cross-sectional area (A), hydraulic radius (R), and slope (S) in all conduits [21], [25].

For standard S.I units:

$$Q = \frac{1}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \quad (1)$$

Where, n is the manning roughness coefficient. The slope S stands for either the conduit slope or the friction slope (i.e. head loss per unit length), depending on the flow routing method used. The R is hydraulic radius, which is fraction of area to wetted parameter of the conduit or the channel.

3.3. Traditional SCS Method

SCS method is another suitable method for this case, as it includes all types of abstractions in the runoff calculation and the parameters needed for runoff estimation. The runoff volumes will be estimated based on SCS-CN method. CN method is thoroughly used for estimating direct runoff volume for a particular rainfall event [26], [27]. For the SCS, 1972 (SCS-CN) method, the CN(I) stands for dry condition, CN(III) stands for wet condition and tabulated CN is equal to CN(II), for normal (average) conditions, and can be modified for dry and wet conditions, as explained by Chow *et al.* [28] through the following Equations 2 and 3 [29]:

$$CN(I) = \frac{4.2 * CN_{II}}{10 - 0.058 * CN_{II}} \quad (2)$$

$$CN(III) = \frac{23 * CN_{II}}{10 + 0.13 * CN_{II}} \quad (3)$$

The expression used in SCS method for estimating runoff can be calculated through Equation 4 [18]:

$$Q = \frac{(P - I_a)^2}{\{(P - I_a) + S\}} \quad (4)$$

Where, Q is the accumulated storm runoff in (mm); P is accumulated storm rainfall in (mm), S is potential maximum retention of water by the soil, I_a is initial quantity of interception, infiltration, and depression which can be quantified through Equation 5.

$$S = \frac{25400}{CN} - 254 \quad (5)$$

While the data needed to calculate the runoff volume are present, SCS method is also used to compute the runoff volume. The runoff depth from subcatchments is calculated using CN and rainfall depth. After the runoff depth is calculated, the volume of the runoff from each subcatchment is computed by multiplying the area of each subcatchment as shown in Equation 6.

$$V = R * A \quad (6)$$

Where, V is the volume of runoff (m^3); R is the rainfall-runoff (m); and A is the area of the subcatchment (m^2).

3.4. Assessment of RC

RC for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface [30].

The R_c takes into account any losses due to evaporation, leakage, surface material texture overflow, transportation, and inefficiencies in the collection process [17]. The RWH potential or volume of water received from a given catchment can be obtained using the following Equation 7 [17].

$$V_r = R A_c R_c \quad (7)$$

Where, V_r the monthly volume of rainwater, R is average monthly rainfall depth, A_c is area of the catchment, and R_c runoff coefficient.

To calculate the monthly runoff produced for each subcatchment, R_c s (Equation 7) is used. The average R_c for the different types of areas was selected [31], for the areas of constructed concrete and asphalt, the R_c was selected as 0.65, 0.075 for green area, and 0.9 for water bodies.

The flowchart in Fig. 3 shows the steps followed for the calculation of runoff using the mentioned three methods.

3.5. Water Demand

To determine domestic water demand for indoor and outdoor household purposes, the standard average daily water demand per capita (Sulaimani water supply directorate) which is (250 l/capita/day) is used to calculate the average monthly demand for the study area [32]. Harvested rainwater should be treated before using for drinking purpose [33]. In accordance with the study area, there are 2899 residential and the average of 5 members in a household counted to estimate the total water demand for the study area. The total population of the study area calculated and the total daily water demand found for Sulaimani Heights. Using the map of the study area, the areas for each type of vegetation group for the study area

are calculated in AutoCAD and the irrigation months were selected with the amount of water for each m² of vegetation area. Thus, the monthly demands for the study area calculated by multiplying the number of days of the month and then by the total daily demand. The results of water demands are shown in Tables 2-5.

4. RESULTS AND DISCUSSION

The results from the three models are shown in Table 6 which shows that the SWMM method has the largest annual runoff volume of 836,470 m³, Rc method results with 737,381 m³ and SCS method with 508,454 m³ for the average annual rainfall of 719 mm. Table 7 and Table 8 represent the monthly and annual water demand, respectively, with the corresponding percent demand met.

The results showed that SWMM method has the highest runoff result and could meet 31% of the total demand of the study area and 28% and 19% for Rc and SCS methods, respectively. Comparison between respective runoff results

clearly demonstrates that the runoff results are influencing by the serial urbanization [34].

TABLE 2: Total daily domestic water demand in Sulaimani heights

Sub. No.	No. of residence	Population	Water demand (m ³ /day)
1	2541	12,705	3176
2	358	1790	448
3	0	0	0
Total	2899	14,495	3624

TABLE 3: Vegetation area and type of each subcatchment

Subcatchment	Green area (m ²)	Crop type	
		Ground cover area (m ²)	Trees and bushes area (m ²)
Sub-1	447,182	302,080	145,102
Sub-2	50,087	42,070	8017
Sub-3	127,650	108,400	19,250
Total area (m ²)	624,919	452,550	172,369

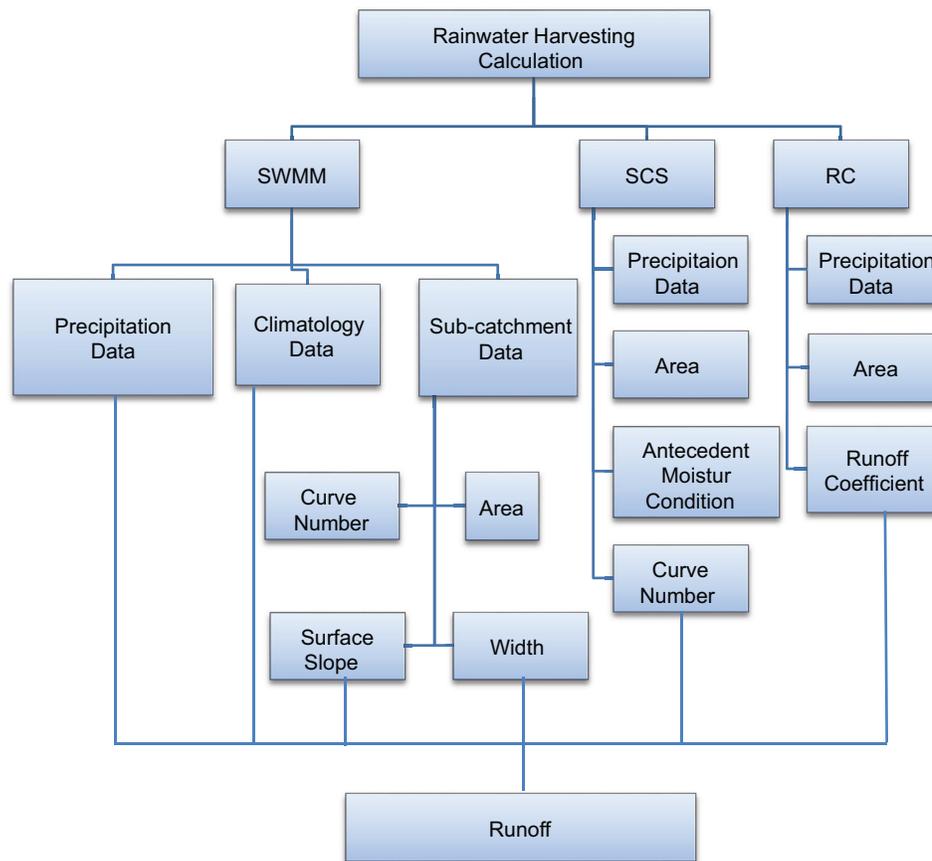


Fig. 3. Flowchart summary for runoff calculation methods.

TABLE 4: Total monthly irrigation water demand in Sulaimani heights

Crop type	Month of irrigation	Irrigation period (day/month)	Required water per (m ²) (L/day)	Water demand (m ² /month)		
				Sub-1	Sub-2	Sub-3
Ground cover	May	15	12	54,374.40	7572.60	19,512.00
	June	30	16	144,998.40	20,193.60	52,032.00
	July	31	16	149,831.68	20,866.72	53,766.40
	August	31	16	149,831.68	20,866.72	53,766.40
	September	30	16	144,998.40	20,193.60	52,032.00
	October	15	12	54,374.40	7572.60	19,512.00
Trees and bushes	May	15	8	17,412.24	962.04	2310.00
	June	30	12	52,236.72	2886.12	6930.00
	July	31	12	53,977.94	2982.32	7161.00
	August	31	12	53,977.94	2982.32	7161.00
	September	30	12	52,236.72	2886.12	6930.00
	October	15	8	17,412.24	962.04	2310.00

TABLE 5: Total demand in the three subcatchments

Month	No. of days	Water demand (m ² /month)			Total water demand (m ³ /month)
		Sub-1	Sub-2	Sub-3	
January	31	98,456	13,888	0	112,344
February	28	88,928	12,544	0	101,472
March	31	98,456	13,888	0	112,344
April	30	95,280	13,440	0	108,720
May	31	170,242.6	22,422.64	21,822	214,487.28
June	30	292,515.1	36,519.72	58,962	387,996.84
July	31	302,265.6	37,737.04	60,927.4	400,930.06
August	31	302,265.6	37,737.04	60,927.4	400,930.06
September	30	292,515.1	36,519.72	58,962	387,996.84
October	31	170,242.6	22,422.64	21,822	214,487.28
November	30	95,280	13,440	0	108,720
December	31	98,456	13,888	0	112,344
Total	365	2,104,903	274,447	283,423	2,662,772

TABLE 6: The runoff volume results of the three methods

Month	Sum of average monthly rainfall (mm)	Volume of runoff by SWMM (m ³ /month)	Volume of runoff by SCS (m ³ /month)	Volume of runoff by Rc (m ³ /month)
January	119.43	150,040	76,912.01	122,350.48
February	116.84	149,720	90,680.95	119,697.14
March	105.11	124,320	69,667.31	107,680.31
April	96.53	111,190	53,480.01	98,890.49
May	41.84	33,620	25,415.88	42,863.13
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	44.43	41,920	53,829.71	45,516.47
November	81.84	87,510	58,195.91	83,841.27
December	113.76	138,150	80,271.92	116,541.83
Total	719.78	836,470	508,453.71	737,381

SWMM: Storm water management model, SCS: Soil conservation service, RC: Runoff coefficient

From the methods discussed previously, it appears that the traditional SCS method and assessment of RC are respectable to be a combined with more losses method since the initial

abstraction includes infiltration, evaporation, interception, and surface texture caused by these processes are calculated simultaneously [9], [35].

TABLE 7: Monthly water demand and corresponding percent demand met

Month	Percent of water demand met using SWMM (%)			Percent of water demand met using SCS (%)			Percent of water demand met using RC (%)		
	Sub-1	Sub-2	Sub-3	Sub-1	Sub-2	Sub-3	Sub-3	Sub-2	Sub-3
October	18	44	5	23	49	16	20	50	2
November	68	100	100	42	100	100	65	100	100
December	100	100	100	57	100	100	88	100	100
January	100	100	100	54	100	100	92	100	100
February	100	100	100	71	100	100	100	100	100
March	94	100	100	49	100	100	81	100	100
April	86	100	100	39	94	100	77	100	100
May	15	36	4	10	27	8	19	47	2
June	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0

SWMM: Storm water management model, SCS: Soil conservation service, RC: Runoff coefficient

TABLE 8: Annual water demand and corresponding percent demand met

Method	SWMM	SCS	RC
Runoff (m ³)	836,470	508,454	737,381
Annual demand (m ³)	2,662,772	2,662,772	2,662,772
Annual demand met %	31	19	28

SWMM: Storm water management model, SCS: Soil conservation service, RC: Runoff coefficient

In addition, in the SCS and Rc methods, the infiltration in the initial abstraction does not change with rainfall events variation on a subcatchment, conversely, it would stay the same before and during the rainfall event [9], [35]. Some parameters implied in the SWMM model but not computed in the SCS such as the depression storage, percent of impervious layer, the pervious roughness coefficient, and the soil drying time [9], [21], [24].

On the other hand, the SWMM model has flexibility to route runoff and external inflows through the drainage systems, and the abstractions such as evaporation and infiltration vary with changing rainfall events [20]. Due to these limitations, the SWMM model is established in the prediction of comparable runoffs [36].

The SWMM differs from the SCS and Rc approaches by that the SWMM model can perform helpful and time saver tool in designing large catchments and SWMM has better feasibility of determining peak flow and volume of runoff with in the nodes and pipes for designing urban drainage system [21], [24].

5. CONCLUSION

This research studied the feasibility of applying RWH techniques as a water resource that should be associated into the management of urban areas. RWH for different types of catchments such as roofs, roads, and open areas has been founded. Three approaches for runoff calculation were adopted, the SWMM, the traditional SCS method, and the RC. Daily rainfall data from 1991 to 2019 were used to obtain the monthly and annual volume. Moreover, to demonstrate the potential RWH system, the annual demand for the study area was found and compared with the total annual runoff volume using three methods, however, harvested rainwater harvested should be treated before using for drinking purpose.

For the estimated total yearly water demand in the study area of demand in the study area of 2,662,772 m³, the annual runoff results with the methods SWMM, SCS, and Rc were estimated of 836,470 m³, 508,454 m³ and 737,381 m³ respectively. The final results showed that SWMM method has the highest runoff result and could meet 31% of the total demand of the study area and 28% and 19% for Rc and SCS methods, respectively.

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