IRAQI JOURNAL OF CIVIL ENGINEERING (2020) 014–002

IRAQI Academic Scientific Journals

Available online at https://www.iasj.net/

Journal homepage: https://www.iasj.net/iasj?func=issues&jId=141&uiLanguage=en

Incorporating GIS Technique and SCS-CN approach for runoff estimation in the ungauged watershed: A case study west desert of Iraq.

***Hadeel Qays Hashim*[a], *Khamis Naba Sayl*[a]**

[a] *Dams & Water Resources Department, Engineering College, Anbar University, Ramadi-31001, Iraq*

A R T I C L E I N F O

Article history:
Received 21 / 04 / 2020.
Received in revised form 01 /07/ 2020
Accepted 05 /07/ 2020

Keywords:
Runoff
Geographic information system GIS
SCS-CN
West desert of Iraq
GIS Technique

A B S T R A C

Estimation of runoff in an ungauged watershed is a significant part in the process of the water resources management. In the Iraqi western desert, the accessibility reliable surface runoff knowledge is scarce, that affects a critical difficulty for the hydrologic engineers. Estimation of surface runoff quantity in valleys of interrupted flow is significant to mobilize the deficiency water resources and manage valleys flow accurately. The incorporation of the Soil Conservation Service Curve Number (SCS-CN) approach with the geographic information system (GIS) was applied for estimating runoff volume of Wadi Hijlan, Fahamy, and Zgadan. The amount of runoff of the maximum storm were 7388700 m^3, 12750000 m^3 and 9851590 m^3 for Hijlan, Fahamy and Zgadan respectively. In addition, the results showed acquired via the SCS-CN technique, revealed that the runoff depth fluctuated from 12.5 mm to 20.3 mm for (48mm) the maximum storm of rainfall through 2018-2019. The present strategy can be used for planning and development other valleys in the western desert of Iraq.

1. Introduction

Water is the greatest natural gift to humanity; it becomes a limited resource that demands to be preserved by water resources management. Precise runoff estimation is critical for water resource management, and difficulty for hydrological planners and engineering (Gajbhiye et al., 2013). Runoff is among the main factors used in the control of the watershed and it is the drainage of water precipitated into a stream in the watershed, after both sub-surface and surface losses have been achieved (Dubayah et al., 1997). The Rainfall-Runoff is very dynamic in a catchment, affected by specific characteristics of storms and drainages (Seth et al., 1997-98). Runoffs are erratic with the high amounts and a short period in all valleys of the west desert of Iraq. The western desert of Iraq covers an extensive part of the Iraqi region. It has many misfit valleys that offer the drainage network (Sulaiman et al., 2019). Due to social and economic constraints, most of these valleys are ungauged and the lack of data about runoff (Sulaiman et al., 2019). It has given rise to seek procedures for the estimation of runoff volume from the ungauged watershed.

Many researchers tried to predict and model surface runoff behavior using numerical and empirical techniques. All these models require more focused empirical methods to estimate surface runoff accurately (Schulze, 1994; Hunghes, 1995; Anderson, 1997). In addition, different spatial interpolation methods were used to acquire representative runoff over the entire watershed. A watershed is an ecological unit that contributes surface runoff and has definite properties such as, shape, size, slope, geology, vegetation, drainage, soil, land use, geomorphology and climate. Therefore, the process of conversion the rainfall to surface runoff is extremely nonlinear, complex and shows temporal and spatial unevenness via many characteristics. Representing the physical process that happens in the course of such a transformation in a simplified manner and calibration is time-consuming and complicated. Simulating the latter process is very complex and need numerous data for the application purpose (Abhijit et al., 2014). The process of collecting such data is very difficult, expensive and time-consuming (Nayak,2003). Some methods are available for estimating the ungauged runoff volume in the basin. Owing to its versatility and easiness, the SCS_CN technique is the most commonly used approaches. Most researchers incorporated the GIS with the curve number method have been shown to be rapid, reliable runoff estimation. In that technique land cover / land use classes are incorporated in GIS to calculate curve number CN value with the hydrological soil

* *Corresponding author.* E-mail address: Hadeel_ded@uoanbar.edu.iq

group (HSG). The calculated weighted curve number can be used to measure runoff over the entire watershed.

Several approaches are used for estimating surface runoff in the ungauged watershed. One of these approaches is the SCS-CN technique established by the United States Department of Agriculture hydrologists (USDA, 1972; Pradhan et al., 2010; Shadeed & Al Masri, 2010. SCS-CN method is commonly used worldwide, it offers useful and reasonable results for average conditions, it is very simple to understand and requires few effort (Jasrotia, A.S. et al. 2009). The SCS depends on just Curve Number (CN), that is based on other essential catchment characteristics like soil type (HSG) and land use/land cover (LULC). While CN may have a theoretical range of 0-100, it is more likely in practice to be within 40-98. Of this purpose, SCS is commonly used in management of water resources, modeling of storm water and estimation of surface runoff (Sayl et al.,2017; Sayl et al., 2019, Sayl,2020, Chandrmohan & Durbude, 2001; He C., 2003; Liu X. & Li J., 2008).

Geospatial data is considered as an aid tool to offer a source of input data in runoff estimation. The capability of the geographic information system (GIS) to identify data related to a particular location and has the ability to handle and process the geospatial data. The application of GIS in the field of hydrological modeling can handle appropriately the spatial variability (Cheng Q. et al., 2006). Several studies such as (Thomas, 2009; Tsheko, 2007; Sharma and Kumar, 2002; Pandey et al., 2004; Jain et al., 2006; Sayl et al.,2017; Sayl et al., 2019) have revealed that the temporal parameters and the spatial hydrological variables can be used to estimate properly runoff using GIS and geospatial data and they concluded that GIS is effective tool assistance in improved watershed management.

The aim of current study is to estimate the surface runoff volume utilizing the SCS-CN approach with ArcGIS for the ungauged area.

2. Study area

The present research was done in the Iraqi western desert. Such study area is situated near the city of Haditha, Al Anbar as seen in Figure 1. The research study area includes some valleys like Hijlan, Fahamy, and Zgadan. It lies between 33° 50' 0" N to 34° 20' 0" N latitudes and 41° 40' 0" E to 42° 20' 0" E longitude with a whole area of about 1953.1 km^2 and the area of each wadi are: Fahamy 1020 km^2, Hijlan 447.8 km^2 and Zgadan 485.3 km^2, respectively. Haditha meteorological station situated in the study area but it did not contain a gauge for runoff measurement.

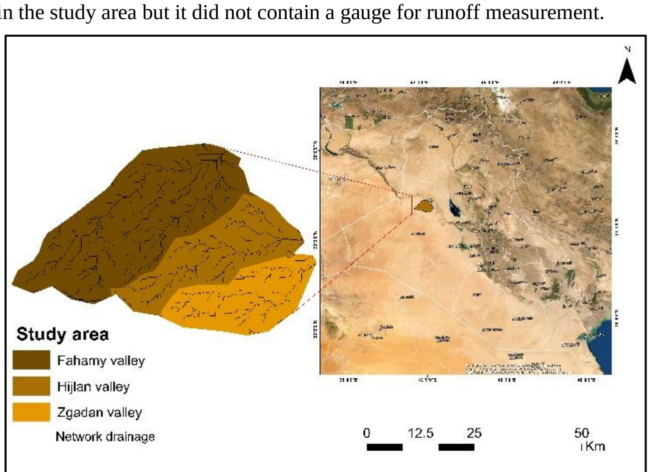

Fig. 1 Study area

Iraqi western desert climate is extremely dry and hot in summer, and cold in winter. The maximum temperature difference is about 36° C; the average annual rainfall is 115mm; approximately 50 % of rainfall is received in winter, 35 % in spring, and 15 % in autumn. The low humidity and high temperature led to large evaporation reach to 3000 mm per annum. The topography of the study area constitutes of alluvial Wadis. The elevation difference ranges from 117 m to 388 m above mean sea-level. The study area's most significant climate attribute is incredibly low and inconsistent rainfall.

3. Methodology and Data source

3.1. Data source

Table 1 – Data source and derived layer

Source	Data	Derived layer
USGS (United States Geological Survey)	Landsat 8 image of June 2019	Land use/land cover (LULC)
Meteorological station data	Rainfall data	Maximum storm
Field data	Soil samples	Soil texture

3.2. Methodology

The methodology of the present study area incorporates the ArcGIS with SCS technique in which the types of land use/land cover classes and soil map (HSG) are imported in the ArcGIS10.7, to product a correlation between the thematic maps generated and the hydrological soil groups HSG. The result of that relationship used in the estimation of associated CN and then estimating runoff depths (Ningaragy et al., 2016; Taha M. Taher, 2015). Figure 2 shows the detailed steps of this methodology.

Land use/ land cover (LULC) determines the function of the land as well as the natural feature of the land cover. LULC such as bare land, and urban support for high runoff production against soil infiltration (Fagbohun B. J, 2018). Higher absorption and infiltration levels are correlated with vegetation cover, and thus lower runoff. Land use/land cover is extracted in June 2019 from Landsat 8 satellite image using supervised classification in ArcGIS 10.7 platform.

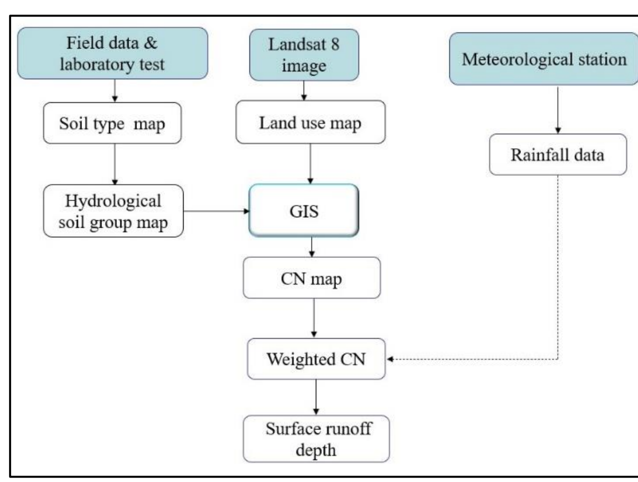

Fig. 2 Research methodology

There are 120 soil sample were collected by auger, its depths ranges between 20 to 40 cm from soil surface. The soil samples location was determined based on the type classes, which are generated from unsupervised classification of the research area. GPS device was utilized to locate the soil samples in situation. Sieve analysis and hydrometer tests were determined the percentage of clay, silt and sand depending on hydrologic soil classification of USGS. These data of classification were processed in ArcGIS 10.7 to generate digital soil map using spatial analysis model.

Al-Jabari et al., (2009) show that the SCS-CN approach is utilized in rural areas. CN value and Rainfall data are the main data for current approach. The SCS approach relies on the simplified relationship between runoff depth (Q) and (p) rainfall depth within a definition of CN (Shadeed and Al Masri, 2010). CN can be defined as $0 \leqslant CN \leqslant 100$.

The CN can be used to describe the runoff characteristics of certain soil land cover. The CN for the research area is calculated for each pixel, through the soil maps and LULC, after reclassified soil map into HSG. Table 2 shows the CN values based on the USGS classification scheme (D, C, B and A). The primary soil map is inserted in the ArcGIS 10.7 database. Allotted to an acceptable hydrological category of soil were added the various soil groups within that region.

Table 2– CN values based on HSG and Land use (Munyao, 2010)

Land use / land cover	Class A	Class B	Class D
Bare soil	77	86	94
Urban	61	75	87
Water	100	100	100
Farmland and grass	43	65	82

In fact, as the beginning of rainfall occurs, water flows into the soil until saturation retains its absolute retention. And the rate of runoff increases as upsurges of rainfall. It explains the presence of a large variation in the volume of the runoff from the same rainfall magnitude. The SCS-CN approach estimates the Q based on the fallowing equation (Munyao, 2010):

$$Q = \frac{(p - 0.2s)^2}{(p + 0.8s)} \qquad (1)$$

Q representing Runoff depth (mm)
P representing Rainfall depth (mm)
S representing potential maximum retention (mm)
Because S is widely variable, it can be extracted from equation 2 after knowledge of the CN.

$$S = \frac{25400}{CN} - 254 \qquad (2)$$

CN: the curve number of a hydrologic soil cover

$$I_a = 0.2S \qquad (3)$$

I_a: the initial abstraction mm
A weighted curve number CN_w can then be determined via equation 4.

$$CN_w = \frac{CN_i A_i + \cdots + CN_n A_n}{\sum_{i=1}^{n} A_i} \qquad (4)$$

CN_w: The Weighted CN , CN_i: CN of sub-areas
A_i : area of sub basin , n : the whole numeral of sub-basin
The runoff volume is computed via multiplying the surface runoff depth calculated from Eq.1 by the area of that watershed as equation below:

$$Runoff\ volume = Q * A \qquad (5)$$

Q: Runoff depth (m)
A: Watershed area (m^2)

4. Results and discussions

The land use/land cover carried out using supervised classification, classified the study area into four main categories of land cover: grass and agricultural (35%), residential (10%), barren land (50%) and water (5%) as illustrated in Figure 3.

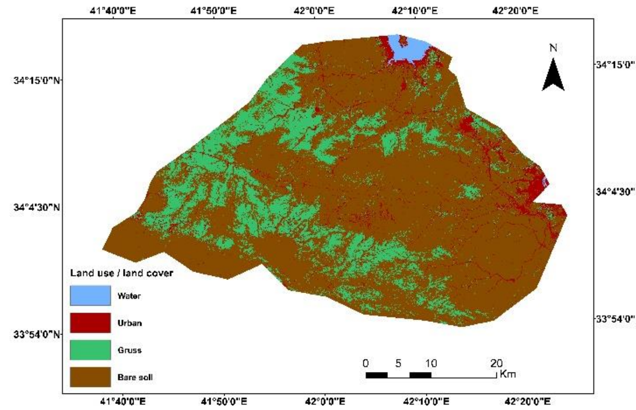

Fig. 3 Land use/ land cover map

In GIS, the final output of the current laboratory test results study, as input data, reflects the map of soil texture. The resulting soil texture map classified the research area into four types; silty loam, sandy loam, loam and clay loam as shown in Figure 4. The loam soil represents % 63 of the whole area, the clay loam soil 23%, the silty loam soil represents13 % and the sandy loam soil 1%.

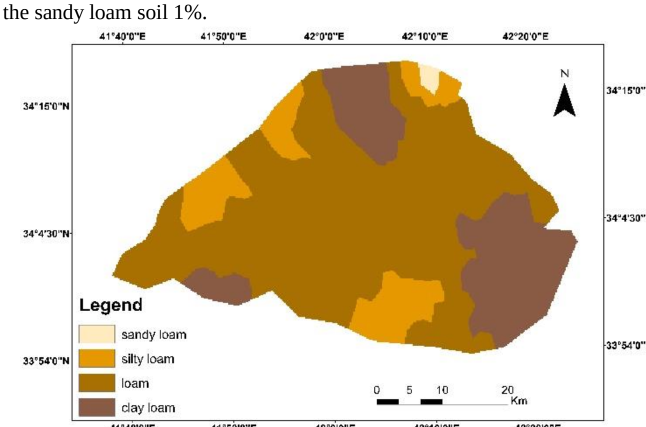

Fig. 4 Soil texture map

For the soil, the SCS ordered four hydrological classes, depending on the capacity for soil runoff (USDA, 1986). These classes are denoted as (D, C, B, and A), where class A takes the lowest potential surface runoff, while class D has the largest. Depending on the soil texture map, the research area is classified into three HSG as shown in Figure5. Table3 illustrate the HSG based on infiltration rate.

Table 3 – Properties of Hydrological soil group (Maidment, 1993)

HSG	Soil texture type	Direct runoff	Infiltration rate (mm/h)
A	loamy sand or Sandy loam, sand	Lowe	25.0
B	loam or Silty loam	Medium	13.0

C	Sandy clay loam	High	6.0
D	clay loam, Silty clay loam	Very high	3.0

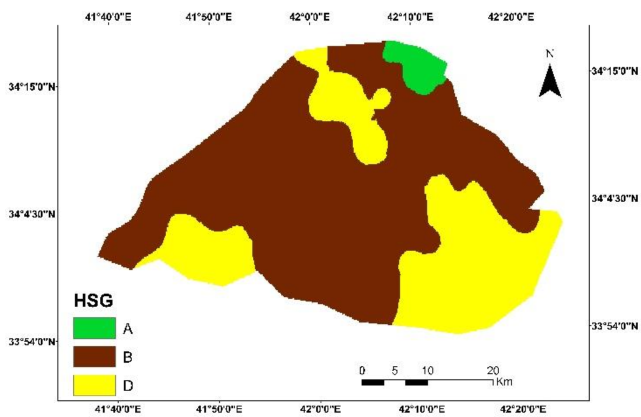

Fig. 5 Hydrologic soil group (HSG) map

In ArcGIS 10.7, the CN map procedure created the land use / land cover map and hydrological soil group map for each sub-watershed of different types. Figure 6 illustrates the curve number for each pixel of the research area. Depending on equation 4 and the data of Table 4, for the three wadis included in the study area the weighted curve number CN_w was determined to be: Al-Fahamy 79.9, Hijlan 83.6 and Zgadan 86.6.

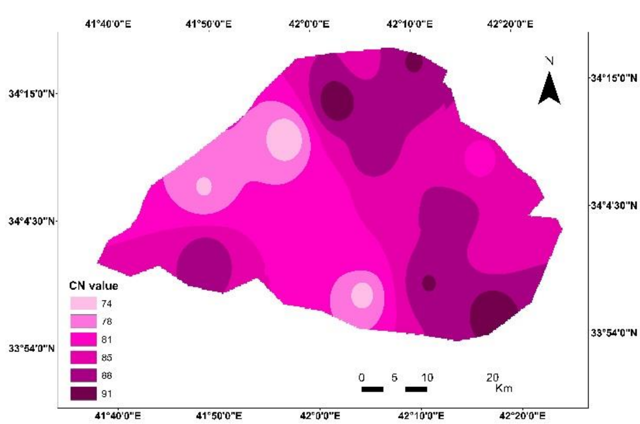

Fig. 6 CN value map

Table 4 – The CN values for each sub-area

Sub-watershed	Sub-area no.	Area (km^2)	CN value	CN*Area
Al-Fahamy	1	217	82	17794
	2	234	76	17784
	3	90	75	6750
	4	167	92	15364
	5	101	83	8383
	6	211	73	15403
		$\sum = 1020$		$\sum = 81478$
Hijlan	1	271	80	21680
	2	110	89	9790
	3	28	88	2464
	4	38.8	90	3492
		$\sum = 447.8$		$\sum = 37426$
Zgadan	1	218	83	18094
	2	61	85	5185
	3	86.6	93	8053.8
	4	51	90	4590
	5	68.7	89	6114.3
		$\sum = 485.3$		$\sum = 42037.1$

To obtain the runoff depth (Q) for the whole study area, Q was estimated for each sub-watershed depending rainfall data and CN value in the same sub-watershed based on equation 1, equation 2 was used to calculate the potential maximin retention (S). The initial abstraction I_a was obtained for each watershed according to equation 3 as shown in Table 5. That table illustrates all variables of the SCS-CN method. Figure 7 illustrates the runoff depths distributed for the whole research area based on the maximum rainfall occurs through (2018-2019). The values of the runoff depths range between (12.5 to 20.3) mm.

Table 5 – Values of SCS-CN variables in study area

Sub-watershed	CN_w	S mm	I_a mm	Rainfall depth mm	Runoff depth Q mm	A km^2	Run-off M m^3
Al-Fahamy	79.9	63.9	12.78	48	12.5	1020	12.75
Hijlan	83.6	49.8	9.96	48	16.5	447.8	7.3
Zgadan	86.6	39.3	7.86	48	20.3	485.3	9.8

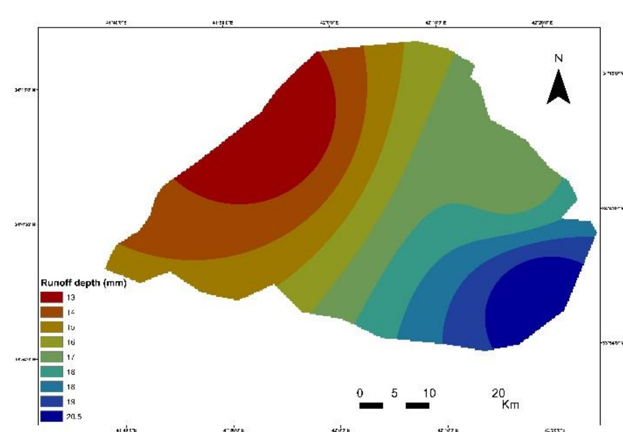

Fig. 7 Runoff depth map

It is not all rainfall transform into runoff. Rainfall parts are evaporated, captured on land and some permeated through the soil. Finally, the un-captured rainfall part causes runoff event. The analysis indicated that only 32 % of rainfall donates to runoff, whereas the residual 68 % donates to losses and interceptions.

The direct depth of runoff over the watershed of the study determined via equation 1. The amounts of water flow over the entire study area, are determined based on the runoff depths and the area of the same sub-watershed area (equation 5). Figure 8 shown the surface runoff volume for each wadi of the study area: Al-Fahamy, Hijlan and Zgadan 12.75, 7.3887, and 9.85159 million m^3, respectively.

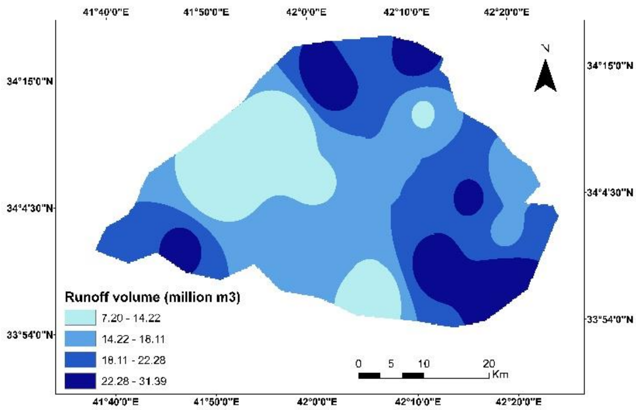

Fig. 8 Runoff volume map

The corporation of the SCS-CN approach with GIS technique could be applied in other valleys have the similar conditions. Runoff volume results require utilization in order to develop the area of study.

conclusion

As no runoff measures are available inside the study area, the result should not have been compared with the calculated values in the current analysis. Nevertheless, the results of incorporating the SCS-CN approach with the GIS technique in Yemen, India, Palestine and many other countries indicate that a clear agreement exists between estimated and measured values. Such a method was applied for estimating the runoff volume of Wadi Hijlan, Fahamy, and Zgadan in the Iraqi western desert. Consequently, the results of the paper obtained from the current study offer a good estimate of the amount of runoff for the ungauged valleys. Depending on the calculated results, the research area is divided in three classes of HSG. The weighted CN for the wadis of the study area are Al-Fahamy 79.9, Hijlan 83.6, and Zgadan 86.6 and, runoff depths 12.5, 16.5 and 20.3 mm, runoff volumes 12.75, 7.38, and 9.85 million m^3, respectively. It would be reasonable to apply this approach current approach for planning purposes in other west Iraqi watersheds because of the inaccessibility of that regions and the unavailability of runoff measurement instruments.

REFERENCES

[1] Gajbhiye, S. K. Mishra and A. Pandey (2013). A procedure for determination of design runoff curve number for Bahmani watershed. IEEE International Conference on Advances in Engineering and technology (ICAET -2013). 23-25 January, pp 1-9.

[2] Dubayah, R and Lerrenmaier D. (1997). Combing Remote Sensing and Hydrological Modeling for Applied Water and Energy Balance Studies. NASA EOS Interdisciplinary Working Group Meeting, San Diego, CA.

[3] Seth SM, Kumar Bhism, Thomas T, Jaiswal RK (1997-98). Rainfall-Runoff Modelling for Water Availability Study in Ken River Basin Using SCS-CN Model and Remote Sensing Approach. Technical Reports, National Institute of Hydrology, Roorkee, No. CS/AR-12/97-98.

[4] Sulaiman S, Kamel A, Sayl K, and Alfadhel M (2019). Water resources management and sustainability over the Western desert of Iraq Environmental Earth Sciences (2019) 78:495. https://doi.org/10.1007/s12665-019-8510-y

[5] Schulze, R.E. (1994). Hydrology and Agrohydrology: A Text to Accompany the ACRU 3.00 Agrohydrological Modelling System. Water Research Commission, Report TT69/95, Pretoria.

[6] Hughes, D.A (1995). Monthly Rainfall–Runoff Models Applied to Arid and Semi-Arid Catchments for Water Resource Estimation Purposes. Hydrological Science Journal. 40 (6) 751-769.

[7] Anderson, N.J. (1997). Modelling the Sustainable Yield of Groundwater Resource in Riverbed Aquifers in Arid and Semi-arid Areas. MPhil to PhD Transfer Report. Department of Civil Engineering, University of London. London, England.

[8] Abhijit M. Zende1, Nagarajan R1, Atal K.R (2014). Analysis of surface runoff from Yerala River Basin using SCSCN and GIS. International Journal of Geomatics and Geosciences Volume 4, No 3.

[9] Nayak T R, and Jaiswaly R K (2003). Rainfall run off modeling using satellite date and G/S for Bebas river in Madhya Pradesh. IE(I) J., vol. 84, pp. 47-50.

[10] SCS (Soil Conservation services), 1972. Section 4: hydrology soil conservation service, ed. National engineering handbook. Washington, DC: US Department of Agriculture.

[11] Pradhan, R.; Pradhan, M.P.; Ghose, M.K.; Agarwal, V.S.; Agarwal, S (2010). Estimation of rainfall runoff using remote sensing and GIS in and around Singtam, East Sikkim. Int. J. Geomat. Geosci. 1(3), 467–476.

[12] Shadeed, S.; Al Masri, M (2010). Application of GIS-based SCSCN method in West Bank catchments, Palestine. Water Sci. Eng. 3(1), 1–13.

[13] Jasrotia, A.S., Majhi, A. & Singh, S (2009). Water balance approach for rainwater harvesting using remote sensing and GIS techniques, Jammu Himalaya, India. Water resources management, 23(14), pp.3035-3055.

[14] Sayl K N, Muhammad N S, El-Shafie A (2017). Robust approach for optimal positioning and ranking potential rainwater harvesting structure (RWH): a case study of Iraq. Arabian Journal of Geosciences, 10(18): 413. doi: 10.1007/s12517.

[15] Sayl, K. N., Muhammad, N. S and El-Shafie, A. (2019). Identification of potential sites for runoff water harvesting. Proceedings of the Institution of Civil Engineers: Water Management 172 (3), 135-148. doi.org/10.1680/jwama.16.00109.

[16] H.J.Ningaraju, Ganesh Kumar S B , Surendra H J. (2016). Estimation of Runoff Using SCS-CN and GIS method in ungauged watershed: A case study of Kharadya mill watershed, India. International Journal of Advanced Engineering Research and Science (IJAERS).

[17] Taha M. Taher. (2015). Integration of GIS Database and SCS-CN Method to Estimate Runoff Volume ofWadis of Intermittent Flow. Arab J Sci Eng.

[18] Fagbohun B. J (2018). Integrating GIS and multi influencing factor technique for delineation of potential groundwater recharge zones in parts of Ilesha schist belt, southwestern Nigeria Environmental Earth Sciences (2018) 77:69.

[19] Sayl, K. N., Mohammed, A. S., and Ahmed, A. D. (2020). GIS-based approach for rainwater harvesting site selection. IOP Conf. Series: Materials Science and Engineering 737 (2020) 012246 doi:10.1088/1757-899X/737/1/012246

[20] Chandrmohan T and Durbude D G. (2001). Estimation of runoff using small watershed models. Hydrology Journal. Vol. 24 (2), pp. 45-53.

[21] He C. (2003). Integration of geographic information systems and simulation model for watershed management. Environmental Modelling & Software, 18(8), 809-813.

[22] Liu X. and Li J. (2008). Application of SCS model in estimation of runoff from small watershed in Loess Plateau of China. Chinese Geographical Science, 18(3), 235.

[23] Cheng Q., Ko C., Yuan Y., Ge Y. and Zhang S. (2006). GIS modeling for predicting river runoff volume in ungauged drainages in the Greater Toronto Area, Canada. Computers & Geosciences, 32(8), 1108-1119.

[24] Thomas, A., Chingombe, W., Ayuk, J., and Scheepers, T. (2009). A Comprehensive Investigation of the KuilsEerste River Catchments Water Pollution and Development of a Catchment Sustainability Plan. Report to the Water Research Commission. WRC Report No. 1692/1/10.

[25] Tsheko, R. (2006). Comparison Between the United States Soil Conservation Service (SCS) and the Two Models Commonly Used for Estimating Rainfall-Runoff in South-Eastern Botswana. Water SA. 32 (1) 29-36

[26] Sharma D, Kumar V. (2002). Application of SCS model with GIS data base for estimation of runoff in an arid watershed. Journal of Soil and Water Conservation, 30(2): 141-145.

[27] Pandey A, Sahu AK. (2004). Estimation of runoff using IRS-1 B LISS-II data. Indian Journal of Soil Conservation, 32(1): 58-60.

[28] Jain MK, Mishra SK and Singh VP. (2006). Evaluation of AMC-dependent SCS - CN - based models using watershed characteristics. Journal of Water Resources Management, 20(4): 531-555.

[29] Al-Jabari, S.; Abu Sharkh, M.; Al-Mimi, Z. (2009). Estimation of runoff for agricultural watershed using SCS curve number and GIS. In: Thirteenth International Water Technology Conference, IWTC13, Egypt.

[30] Munyao, John Ngila (2010). Use of Satellite Products to Assess Water Harvesting Potential in Remote Areas of Africa, International Institute for Geo-Information Science and Earth Observation Enschede, the Nwtherlands.

[31] USDA. (1986). Urban hydrology for small watersheds. Engineering Division of the Natural Resource Conservation Service, United States Department of Agriculture, Technical Release—55. Washington DC.

[32] Maidment David R (1993). HandBook of Hydrology. University of Texas at Astin, Texas USA.