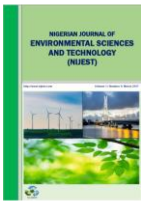
Nigerian Journal of Environmental Sciences and Technology (NIJEST)

www.nijest.com

ISSN (Print): 2734-259X | ISSN (electronic): 2734-2603

Vol 6, No. 1 March 2022, pp 207 - 213



Estimation of Runoff from River Asa Watershed Using SCS Curve Number and Geographic Information System (GIS)

Olaniyan O. S.[1], Ayemu A. I.[2], Adeyokunnu A. T.[3], Ojo E. O.[4] and Afolabi, L. A.[5]

[1,2]Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo-State, Nigeria

[3]Department of Civil Engineering, Ajayi Crowther University, Oyo, Oyo State, Nigeria

[4,5]Department of Civil Engineering, Osun State College of Technology Esa-Oke, Nigeria

Corresponding Author: *adeyokunnuat20@gmail.com, at.adeyokunnu@acu.edu.ng

https://doi.org/10.36263/nijest.2022.01.0265

ABSTRACT

The study aims to determine the runoff depth using Soil Conservation Service Curve Number (SCS-CN) method in Geographical Information System (GIS) environment. For River Asa Watershed, the SCS Curve Number method has been adopted for estimating the runoff depth using Rainfall data from 1987-2018. Land use and change cover map were used for the classification of soil type, in order to determine the Hydrological Soil Group (HSG) using ArcGIS. The runoff was estimated from the rainfall runoff equation. The Antecedent Moisture Condition (AMC), potential maximum retention(s) and initial abstraction were computed. Thematic maps such as Soil and Land Use / Land cover and have been used in conjunction with hydrological data for determining hydrological soil Group (HSG) and Curve Number (CN) for land used and change cover classes over the watershed. The values of Hydrological Soil Group, Curve Number and Annual runoff depth varied (6.28-914.22) km^2, (65-100) and (16.50-144.89) x 10^6 m^3. The study shows that the high runoff depth was observed in Hydrological soil group (HSG), when compared with curve number (CN), this is due to dense vegetation cover.

Keywords: Watershed, Curve numbers, Runoff, DEM, ArcGIS, and Hydrologic Soil Group

1.0. Introduction

Most of the problem often encountered in hydrological studies is the need for estimating runoff from a catchment area for which there are records of precipitation with no records of runoff and stream discharge (Dhawale and Arun, 2013). An approach to solution of this problem is to compare runoff characteristics with those of watershed characteristics. SCS-CN has been generally adopted for water resource management, storm water modeling and runoff estimation for single rainfall events in small agricultural or urban watersheds. The SCS Curve Number and GIS model has also been adopted by many hydrological and ecological models to determine runoff (Fashae, 2011).

Researchers has worked extensively on River Runoff Analysis in an attempt to estimate Runoff depth pattern. Since river runoff show some common characteristics in areas of similar landform. The river channel as a subsystem and an important component of the river basing system deserves studying in some details to enhance river basin management. This is the reason for estimating river runoff along alluvial segment of River Asa before emptying into the Atlantic Ocean at the Lagos Lagoon by analyzing the river runoff characteristics and interrelationship among the runoff variables, (Ellliot *et al.*, 2012).

2.0. Methodology

2.1. Study area

The River Asa originates from the Oyo State, South-Western Nigeria and it flows through Ilorin, capital of Kwara State. The major tributaries of Asa River is River Awon. River Asa is approximately 56km long, with maximum width of 100m. the river Asa catchment area is approximately 1037 km^2 between latitude 8^{0}36'N and 8^{0}24'N, longitude 4^{0}36'E and 4^{0}10'E (Idangunho, 2014).

River Asa watershed which has its source in Oyo State, South-West Nigeria and it flows through Ilorin, capital of Kwara State, Nigeria in a South-North direction forming a dividing boundary between the eastern and western parts of Ilorin metropolis, (Ketul *et al.*, 2017). It is situated in the transitional zone between the forest and savanna region of Nigeria i.e., between the very North and West coastal region (Google Earth 2018). The watershed has geographical area approximated to 929.74 km^2. The elevation of the watershed ranges 190-560m above mean sea level. Maximum and minimum annual temperature are 32.6 °C and 21.25 °C. (Adegboye and Alatise, 2013). The average annual precipitation over River Asa Watershed for the last Thirty-two (32) years is approximately 1288 mm. About 90% of this rainfall is received from April to November, and the major land use/land cover categories in the watershed are: shrubland, mosaic forest, deciduous closed tree cover and mosaic crop land, (Nhamo *et al.*, 2013).

Geographic Information System (GIS) is designed to visualize, store and analyze the information about location and other environmental features (Adewale, 2012). The synthesis of data and mapping of the relationships between natural hazard phenomena and the elements at risk require the use of tools such geographic information system (GIS). The GIS has evolved in three broad application domains: the first is the use of GIS as an information database, the second is its use as an analytical tool, a mean of specifying logical and mathematical relationships among layers of maps to yield new derivative maps, and the third is its use as decision support system (Zerger, 2015). The map of the study area is presented in Figure 1.

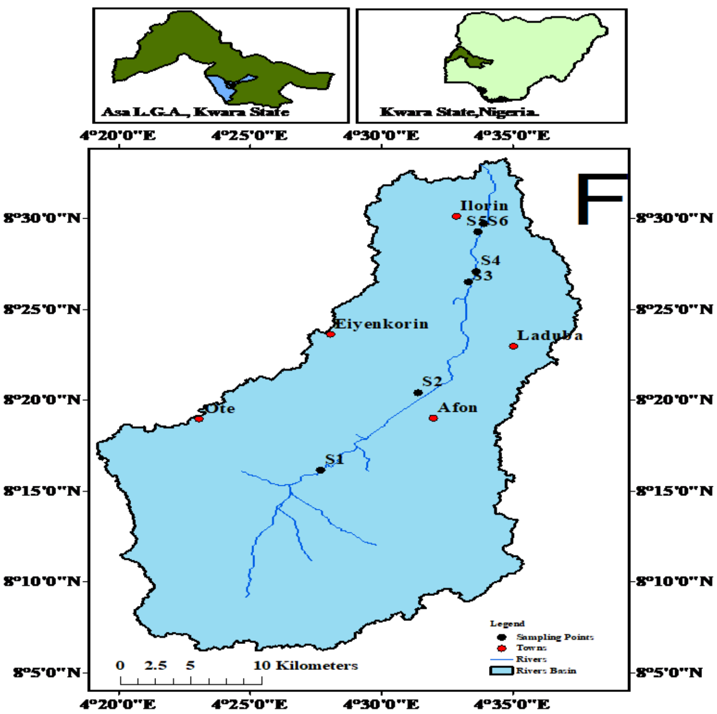


Figure 1: Location of study area on River Asa

2.2. Materials

Digital Elevation Model (DEM) with 30m resolution, Digital Soil Map (DSM), Land Use and Change Cover Maps from Shuttle Radar Topographic Mission (SRTM) were obtained and analyzed using 32 years rainfall data.

2.3. Soil group determination

Determination of hydrological soil group (HSG) of the particular soil. All soils are classified in one of four different categories-ranked A-D on the basis of their runoff potential:

- **Class A:** Soils mostly consist of deep, well-drained sands and gravels with low runoff potential and high infiltration and water transmission rates $k_{sat} \geq 0.3$in/hr e.g. sand, loamy sand and sandy loam.
- **Class B:** Soils have moderately fine to moderately coarse textures and are considered to have moderate infiltration rates when completely wet. $k_{sat} < 0.3$in/hr. e.g. silt loam or loam.
- **Class C:** Soils have moderately fine to fine textures with slow infiltration and water transmission rates.$0.04 < k_{sat} < 0.15$in/hr e.g. sandy clay loam.
- **Class D:** Soils are primarily clay soils or soils with clay pan that have slow infiltration rates when wet. $k_{sat} < 0.04$in/hr. e.g. clay loam, silty clay loam, sandy clay, silty clay or clay

Determination of the five-day antecedent moisture condition of the particular soil from the daily precipitation record. It is an index for basin wetness. One series of five-day precipitation totals is applied to the dormant season and a second series of five-day precipitation totals is used during the growing season.

Decision on the basis of the land cover, the cultivation treatment, the hydrologic condition of the soil, and the hydrologic soil group of the particular soil, the actual runoff curve number to use in determining daily runoff from precipitation.

Runoff depth for each storm event was computed using Equation 1 and 2. Annual runoff depth was computed by summation of individual storm runoff depth.

2.4. SCS curve number method

The rainfall-runoff equation used by the SCS Curve Number for estimating depth of direct runoff from storm rainfall as shown in Equation 1, while the potential maximum retention were computed using Equation 2.

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

where,
P = total rainfall (mm).
S = watershed storage (mm),
Q = actual direct runoff (mm),

The equation has one variable P and one parameter S, S is related to curve number (CN) and is shown in Equation 2:

$$S = \frac{25400}{CN} - 254 \tag{2}$$

where CN is a dimensionless parameter and its value range from 1 (minimum runoff) to 100 (maximum runoff). It is determined based on hydrologic soil group, land use, land treatment, and hydrologic conditions.

2.5. Geographic information systems, GIS and Antecedent Moisture Condition (AMC)

Antecedent moisture condition of the rainfall-runoff event under consideration refers to the moisture content present in the soil at the beginning. It is well known that initial abstraction and infiltration are governed by AMC.

The Antecedent moisture, defined as the summation of the 5-day rainfall before runoff-producing storm. Three levels of AMC are recognized by SCS which are as follows: AMC-I: Soils are dry but not to wilting point. Satisfactory cultivation has taken place, AMC-II: Average conditions, AMC-III: Sufficient rainfall has occurred within the immediate past five days. Saturated soil conditions prevail. The conditions are grouped with different for the dormant season and for the growing season, the grouping is presented in Table 1.

Table 1: Classification of antecedent moisture condition

AMC Type	Total Rain in Previous 5days	
	Dormant Season	Rainy Season
I	Less than 13mm	Less than 36mm
II	13 to 28mm	36 to 53mm
III	More than 28mm	More than 53mm

2.6. Land use and change cover map of River Asa watershed

Land use and vegetation cover of River Asa basin for the year 2009 was obtained from Global Land Cover and Climate Change Initiatives respectively and reclassified using ArcGIS. Nine (9) land use and change cover classes were categorized in the watershed based as given in Figure 2 and Table 3. The classes are surface area, deciduous, Grassland, Mosaic Cropland, Mosaic Vegetable, Open Water, Shrubians, Urban Area Mosaic Forestation. It is important you list the nine (9) land use class before showing it in the map).

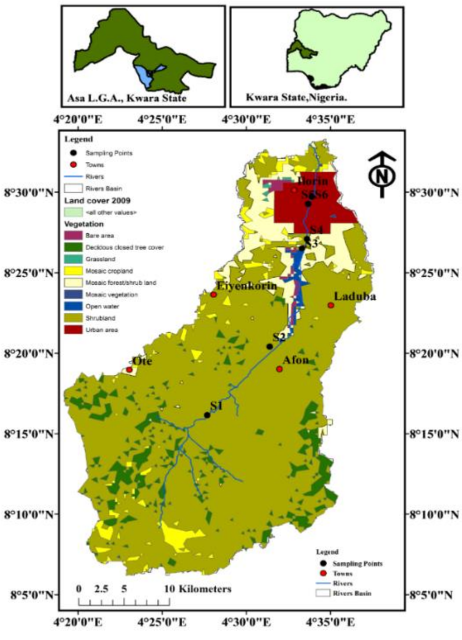


Figure 2: Land use and change cover of River Asa watershed

The following procedures were adopted namely:

1. Antecedent moisture condition is decided from the previous 5 days rainfall
2. According to AMC condition, potential maximum retention (S) and initial abstraction (Ia) is calculated.
3. From Equation (1) Runoff depth is calculated and annual runoff is estimated.
4. Runoff volume is calculated by multiplying runoff depth with study area

3.0. Results and Discussion

3.1. Classification of hydrological soil group

Soils are classified into four classes A, B, C and D based on the ground slope, infiltration, and other characteristics. The important soil characteristics that influence the hydrological classification of soils are effective depth of soil, average clay content, infiltration characteristics and the permeability as follow: group A: low runoff potential, group B: moderately low runoff potential, group C: moderate high runoff potential and group D: high runoff potential.

There are three (3) soil classes which possessed similar top soil characteristic, they can be called poorly to well graded sand distributed at the watershed as shown in Figure 3 and Table 2.

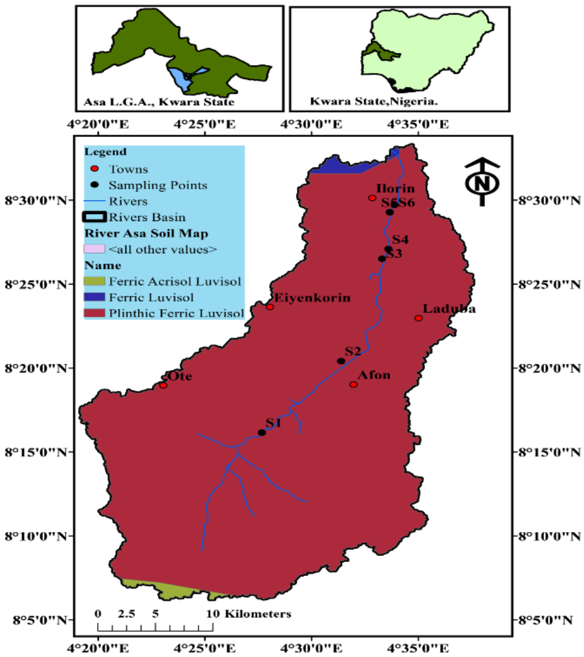


Figure 3: Soil map of River Asa watershed

From Table 2, River Asa watershed can be classified into one hydrological soil groups: Group B with infiltration rate (0.15-0.3) in/hr based on grade condition of the soil (poorly to well-graded sand).

Table 2: Soil class of River Asa watershed and their properties

Soil Class	Ms(sand) Top soil %	Ms(silt) Top soil %	Ms(clay) Top soil %	Ms (OC) Top soil %	Area Km^2	% of Area
Ferric Acrisol Luvisol	74.110	9.600	15.9	0.39	6.616	0.66
Ferric Luvisol	74.110	9.600	15.9	0.39	6.28	0.68
Plinthic Ferric Luvisol	74.110	9.600	15.9	0.39	914.32	98.66
Total					927.216	100

3.2. Computation of depth direct runoff

Curve Number was used to estimate the depth of direct runoff from the rainfall depth from drainage basin where no runoff has been measured. To create and detect the curve number values for each classified area; the hydrological soil group and the land use and land cover results were used.

The composite (Weighted) curve number was found by using the following equation, (Patil *et al.*, 2012); (Sahu and Eldho, 2012):

$$CN = \frac{\sum A_i \times CN_i}{\sum A_i} \quad (3)$$

where,
CN is the composite curve number (summation of Curve number for all vegetation classes over the drainage area),
A_i is the area for each land use and change cover.
CN_i is the curve number for each land use and change cover.
$\sum A_i$ is the Area of watershed

The composite curve number for the study area (River Asa watershed) using land use and cover of 2009 is:

$$CN_{ii} = \sum \left(\frac{A_1 \times CN_1}{A_1} + \frac{A_2 \times CN_2}{A_2} + \frac{A_3 \times CN_3}{A_3} + \frac{A_4 \times CN_4}{A_4} + \frac{A_5 \times CN_5}{A_5} + \frac{A_6 \times CN_6}{A_6} + \frac{A_7 \times CN_7}{A_7} + \frac{A_8 \times CN_8}{A_8} + \frac{A_9 \times CN_9}{A_9} \right)$$

$$CN_{ii} = 69.57$$

$$CN_i = \frac{4.2 \times CN_{ii}}{10 - (0.058 \times CN_{ii})} = 48.99$$

$$CN_{iii} = \frac{23 \times CN_{ii}}{10 + (0.13 \times CN_{ii})} = 84.02$$

Table 3: Curve number for 2009 land use and land cover on River Asa watershed

S/No	Land use/ Land cover	Soil Group	AMC	Curve No	Area (Km²)	Perc. of Area (%)
1	Bare area	B	II	86	6.39	0.69
2	Deciduous closed tree cover	B	II	66	65.72	7.07
3	Grassland	B	II	69	1.19	0.13
4	Mosaic cropland	B	II	69	35.67	3.84
5	Mosaic forest/shrub land	B	II	65	70.95	7.63
6	Mosaic vegetation	B	II	69	0.16	0.02
7	open water	B	II	100	6.39	0.69
8	Shrub land	B	II	69	699.40	75.23
9	Urban area	B	II	85	43.88	4.72
	Total				929.74	100.00

Table 4: Runoff depth for River Asa catchment area from 1987 to 2018

Year	Annual Rainfall P (mm)	Annual Runoff R (mm)	Catchment A= (10^6 m²)	Runoff Percentage (%)	Volume = Runoff x Area (10^6 m³)
1987	1344.9	106.580	929.748	7.92	99.093
1988	1199.7	17.750	929.748	1.48	16.503
1989	964.9	28.590	929.748	2.96	26.581
1990	1044.2	26.250	929.748	2.51	24.406
1991	1483.1	88.620	929.748	5.98	82.394
1992	1515.85	95.490	929.748	6.30	88.782
1993	1393.9	54.190	929.748	3.89	50.383
1994	1450.8	143.500	929.748	9.89	133.419
1995	970.5	28.790	929.748	2.97	26.767
1996	1517.55	95.490	929.748	6.29	88.782
1997	1030.65	59.170	929.748	5.74	55.013
1998	1465.9	101.280	929.748	6.91	94.165
1999	1509.7	76.170	929.748	5.05	70.819
2000	1206.1	18.760	929.748	1.56	17.442
2001	1523.4	95.470	929.748	6.27	88.763
2002	1363.3	112.440	929.748	8.25	104.541
2003	1209.1	13.120	929.748	1.09	12.198
2004	981.8	28.790	929.748	2.93	26.767
2005	1038.7	26.350	929.748	2.54	24.499
2006	1487.3	76.100	929.748	5.12	70.754
2007	1529.9	97.690	929.748	6.39	90.827
2008	1395.9	59.160	929.748	4.24	55.004
2009	1465.9	155.840	929.748	10.63	144.892
2010	972	28.790	929.748	2.96	26.767
2011	1518.3	95.490	929.748	6.29	88.782
2012	970.8	28.790	929.748	2.97	26.767
2013	1038.4	30.910	929.748	2.98	28.739
2014	1487.3	76.170	929.748	5.12	70.819
2015	1521.63	95.490	929.748	6.28	88.782
2016	1519.75	107.620	929.748	7.08	100.059
2017	1038.65	30.320	929.748	2.92	28.190
2018	1062.31	10.240	929.748	0.96	9.521

4.0. Conclusions

- The results of ArcGIS showed that the weighted CN curve numbers for the Catchment area are 48.99, 69.57 and 84.02 for AMCI, AMC II and AMC III respectively.
- The average annual runoff depth is 65.91 mm and Runoff volume is 61.29 mm3
- Runoff volume is calculated for whole study area for watershed management purpose. Runoff volume helps to management of water from any location to in natural streams.

References

Adegboye, I.O. and Alatise, S.O. (2013). Temporal Variation of Rainfall and Temperature of River Asa, South-Western, Nigeria. *International Journal of Applied Engineering Research*, 8(3), pp. 90-102.

Adewale, P.O. (2012). Estimation of Surface Runoff Potential using SCS-CN method integrated with GIS. *Indian Journal of Science and Technology*, 8(28), pp. 1-5.

Dhawale, Z.O. and Arun, W. (2013). Runoff Estimation for Darewadi Watershed using RS and GIS. *International Journal of Recent Technology and Engineering*, 1(6), pp. 46-50.

Elliot, C.A., Alexander, R.O. and Trowsdale, S.O. (2012). A review of models of low impact urban storm water Drainage. *Environmental modelling and software*, 22(3), pp. 394-405.

Fashae, O. (2011). Riparian Vegetation and River Channel Morphology in the Alluvial Section of River Ogun, Nigeria. PhD Thesis. Department of Geography, University of Ibadan, Oyo-State.

Idangunho, F.O. (2014) Rainfall-runoff model using the SCS-CN method and Geographic Information Systems: A case study of Gomal Water-shed. *Water and Society II*, 17(8), pp. 159-170.

Ketul, S., Motiani, A.T., Indra, P. and Khalid, M. (2017). Application of SCS-CN method for estimation of runoff using GIS in Meshwo River Watershed in Dhansura - Aravalli district of Gujarat. *International Journal of Advanced Engineering and Research Development*, 4(4), pp. 2348-4470.

Nhamo, A.P., Luxon, O.A. and Chilonda, Z.R. (2013). Validation of rainfall-runoff SCS-CN model in catchment with limited measured data in Zimbabwe. *International Journal of Water Resources and Environmental Engineering*, 5(6), pp. 295-303.

Patil, J.P., Sarangi, A. and Eldho, T.I. (2012). Evaluation of modified CN methods for Watershed Runoff Estimation using GIS-based interface. *Biosystem Engineering*, 100(1), pp. 137-146.

Sahu, Z.K. and Eldho, T.I. (2012). An improved AMC-Coupled Runoff Curve Number Model. *Hydrological Science Processes*, 24(20), pp. 2834-2839.

Zerger, O.O. (2015). Rainfall-Runoff Estimation using SCS-CN and GIS approach in the Pappired Watershed of the Vaniyar Basin, South India. *Journal of modelling Earth System and Environment*, 4(3), pp. 17-25.

Cite this article as:
Olaniyan O. S., Ayemu A. I[2], Ojo E. O. and Adeyokunnu A. T., 2022. Estimation of Runoff from River Asa Watershed Using SCS Curve Number and Geographic Information System (GIS). *Nigerian Journal of Environmental Sciences and Technology*, 6(1), pp. 207-213. https://doi.org/10.36263/nijest.2022.01.0265