Rainfall-Runoff Modelling Using SCS-CN and Geospatial Techniques in the Mubuku Catchment, Uganda

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Abstract – Climate change is a major factor which impacts on rainfall extremes and drought extremes all over the world. In this research the study area Mubuku River basin, faces such extremity of rainfall every year resulting in huge volume of sediment transportation to the river. Thus, as an initial step, the rainfall runoff quantity has been thoroughly carried out according the nature of the topography, soil and rainfall intensity. Techniques such as SCS method and geospatial tools are applied in determination of runoff quantity of the study area. Five years of rainfall data from 2020 to 2024 was used and respective runoff quantity has been computed. The highest runoff computed of 45568 m^3 for the year 2024 and the lowest runoff of 28672 m^3 computed for the year 2020. It was also observed a gradual increase of runoff throughout the five years in the study area.

Key Words*: *SCS method, Curve Number, Rainfall, Runoff, GIS, hydrologic soil

1. INTRODUCTION

The climate is a major determinant of water conditions through its influence on the hydrological cycle (Vörösmarty et al., 2000). Changes in climate patterns can impact water systems through shifts in temperature, rainfall, and extreme weather events (Intergovernmental Panel on Climate Change [IPCC], 2021). Changes in climate patterns like increases in global temperatures (Stocker et al., 2013), shifts in precipitation regimes (IPCC, 2021), and more frequent/severe extreme weather events (IPCC, 2021) can directly impact surface and groundwater systems. Altered rainfall and flooding patterns modify watershed hydrology and influence runoff volume/quality (Barnett et al., 2005). Rainfall-runoff is a mathematical model which directly relates with the basin characteristics such as slope, soil type, stream density and size of the basin (K Deepa, M Krishnaveni, 2012). Rainfall extremes result in flooding which further results in pollution of surface and subsurface water contaminations, spreading of water borne diseases and transportation of sediments to surface water bodies, further resulting in reduction of storage capacity of the reservoir. On the other hand drought extremes result in reduction in soil moisture condition, decline of water table and reduction of agriculture of a country. Thus, it is essential to monitor any regions or basin or watershed the extremes of those hazards, in order to manage the environment in a sustainable way. There by the economy of a region or country can be saved.

2. LITERATURE REVIEW

Water resources management is a critical aspect of sustainable development, particularly in regions where agriculture and domestic water supply are heavily reliant on rainfall (Govindaraju, et al, 2024). Assessing water availability by evaluating the relationship between rainfall and runoff is therefore of paramount importance for effective watershed management, flood prediction and control of soil erosion. Rainfall-Runoff (RR) modelling is therefore needed to predict the responses of a watershed to precipitation events. There are so many methods of modelling that are used in hydrology such as SCS-CN, SWAT, SHE, WaSIM and VIC Models among others (Yoshe, 2025), (Solomon Eniyew, et al, 2024). In this study, the Soil Conservation Service-Curve Number (SCS-CN) method has been employed because of its simple and requires minimum input data. The method is based on the concept of curve numbers (CN), which represent the runoff potential of a watershed based on Soil Type, Land Use and Land Cover (LULC), Antecedent Moisture Conditions (AMC) (Chen, J., Hill, A. and Urbano, L. 2010). In the domain of flood management, this methodological approach significantly enhances forecasting, the establishment of early warning systems, and the design of flood control infrastructure. Additionally, it facilitates the identification of areas susceptible to flooding. Furthermore, the methodology contributes to water harvesting and the management of land use to promote sustainable agricultural practices. It is predominantly employed to evaluate the impacts of climatic variations on water resources. This method was formulated by the United States Department of Agriculture (USDA) and is recognized as one of the most extensively utilized techniques for estimating direct runoff resulting from precipitation (USDA, 1972), (USDA, 1985) and was originally modelled for conditions prevailing in the US. Since then, it has been adapted to conditions in other parts of the world (Govindaraju, et al, 2024). Notwithstanding the advancements made by certain regional centers in developing supplementary criteria, the fundamental concept remains widely applied globally. The method is well established because of its stability and ability to incorporate various factors contributing to runoff, including both spatial and non-spatial data sets such as daily and monthly precipitation. Its ability to be integrated with GIS, RS and lately AI tools make the method more reliable. We use GIS, RS and AI because field measurements are laborious and time consuming. Spatial data has made it practical to accurately calculate runoff (Ayushi Trivedi, 2021). However, advancements in geospatial technology help to include these variables for evaluating runoff from bigger watersheds. (Yoshe, 2025) Since conventional methods are time consuming and very demanding, combining GIS and RS aids spatial analysis(Deepa, K et al, 2017). Several studies have obtained CN and runoff with RS and GIS. Researchers conclude that these approaches are flexible, popular, faster and reliable (Yoshe, 2025) (Abhijit M.Zende et al, 2014) notes that with increase in the availability of finer spatial resolution information for GIS and RS data on vegetation, it's possible to use the method for large areas with enhanced accuracy. The key advantages of this method is its seamless integration with GIS and RS techniques and this has revolutionized the accuracy and efficiency of the model (Shashi Poonam, 2022). Integration of GIS and RS in RR modelling have become indispensable in hydrological studies due to their ability to manage, analyses and visualize spatial data. GIS facilitates the extraction of critical watershed parameters such as slope, land cover, and soil type, which are essential for runoff estimation. In the context of this method, GIS enables the spatial mapping of CN values, thus improving the precision of runoff estimations. RS provides satellite imagery of the earth's environment that helps to estimate runoff and potential floods. GIS is also used as an efficient tool to prepare input data obtained from RS. It can offer data for inaccessible locations with huge spatial and temporal variability (Solomon Eniyew, et al, 2024), (Yoshe, 2025). Studies have shown that SCS method is particularly effective in the data scarce regions, making it suitable for applications in developing nations like Uganda. Ugandan models have targeted urban settings and developed river watersheds, leaving a gap in rural watersheds. Elkassar, G. et al, posits that alterations in land use accompanying urban expansion lead to increased surface runoff and a concomitant rise in flood risk. If inadequately managed, surface runoff may inflict damage on property and infrastructure while also contributing to the silting of water resources (Elkassar, G. et al 2017). Mubuku River basin is located in South-western Uganda, is characterised by high rainfall intensity, steep slopes, and diverse land use practices. In such a basin, SCS-CN method can be particularly useful given its complex topography and varying land use patterns. These factors make it prone to issues such as soil erosion, flooding, and water resource degradation. This region has endured floods due to natural and human interventions. Steps to reverse these challenges such as tree planting to boost soil and water management efforts are not successful as anticipated.

3. STUDY AREA

The study will focus on the Mubuku River basin in Uganda, situated within the Rwenzori Mountains region. This basin encompasses a defined geographical area, including its tributaries and associated water resources within its catchment area(Bua,B.;Ojirot, 2014). The spatial extent of the study will be based on the coordinates of the Mubuku River basin, which generally range between approximately 0.311°N to 0.375°N latitude and 29.783°E to 29.953°E longitude. These coordinates outline the boundaries of the basin and include its tributaries and water resources as shown in figure 1.

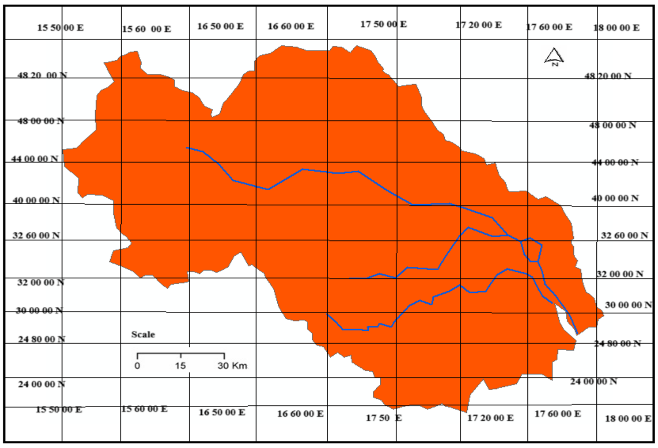

Figure 1 Mubuku River Basin Uganda

The Mubuku River basin in southwestern Uganda provides essential water resources that local communities depend on (Elkassar, G. et al 2017). The basin supports livelihood activities such as agriculture, livestock rearing, and domestic water usage (MWE, 2018). The Mubuku river basin area is about 256 km^2. The temperature data indicates average warming of 1.3°C between 1980-2020. The study area has three rainfall stations located in around such as Fort portal, Kasesee, and Mubuku respectively. The slope topography of the study area is in the form of mild slopes distributed all over the study area. The basin was divided into two sub-basins based on the river network.

4. METHODOLOGY

The methodology adopted in this research has been depicted in figure 2. The step-by-step procedure has been explained as below.

Step 1 – Thematic maps of landuse type, Landuse conservation practice, hydrologic soil group, hydrologic condition was prepared in ArcGIS software. The rainfall data procured from three rain gauge stations underwent spatial interpolation via the spline method. Monthly rainfall records spanning five years (2020-2024) were gathered from the Uganda Meteorological rainfall data center. The Thiessen polygon method was employed to ascertain the average distribution of rainfall across the entire study area, as depicted in Figure 3. The satellite imagery utilized for the land use and cover map of the study area was sourced from the website: www.EarthExplorer.usgs.gov.

Landsat 8 satellite imagery was acquired in TIFF format and subsequently reclassified utilizing supervised classification methodologies within the ArcGIS environment. Five classes of landuse pattern have been classified namely, built up land, water bodies, small crop growing region, pasture land, fallow row crop growing etc. The extracted land use map of the study area has been presented in figure 5.

Figure 2 Methodology flow chart of Rainfall-Runoff

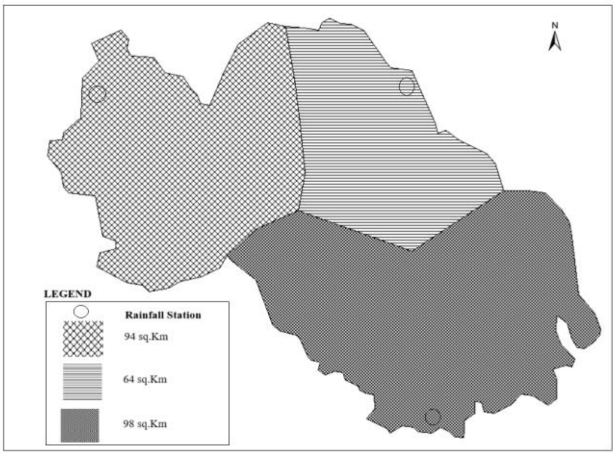

Figure 3: Thiesson Polygon for Rainfall Distribution

Hydrologic Soil Group Map

The spatial distribution of soil layers comprises 13% clay and 87% sand, exhibiting either loamy sand or sandy loam textures. Furthermore, the saturated hydraulic conductivity within the least transmissive layer, extending from the surface to 35 cm, ranges from approximately 32 micrometers per second to 38 micrometers per second. Figure 4 illustrates the presence of hydrologic soil groups within the study area.

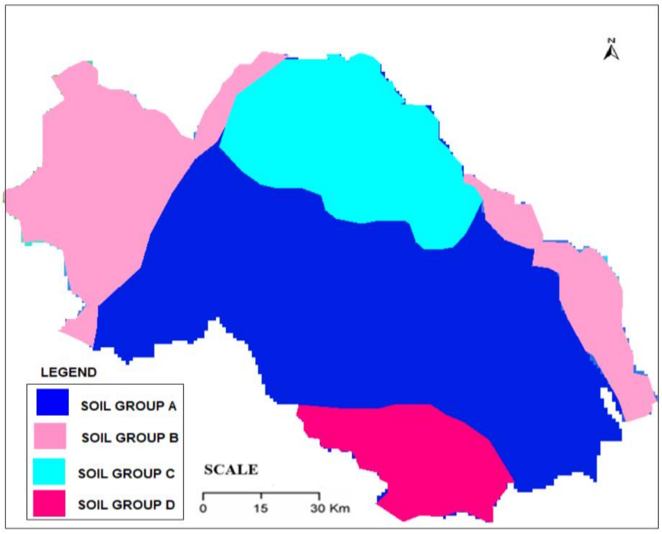

Figure 4. Hydrologic Soil Group Map

Landuse Map

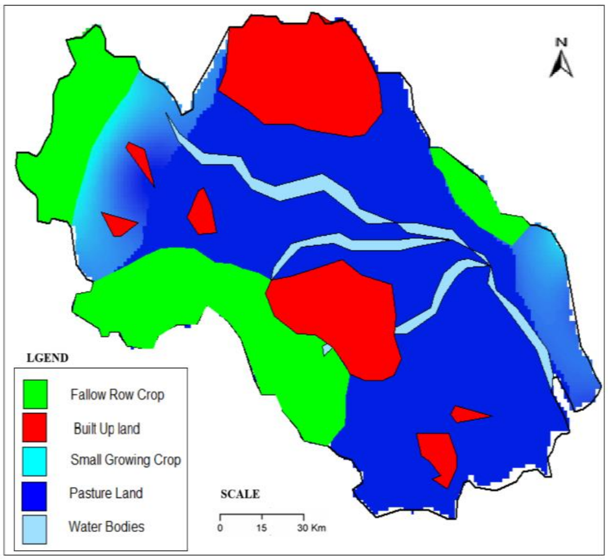

Figure 5. Land use map of the study area

Landuse map was prepared based on the classification of land use type, land treatment, and hydrological conditions in the study area catchment (Bhura CS et al, 2015) and (Wanielista, M.P. and Yousef, Y.A. 1993) . Finally, the soil-cover map was obtained by superimposing the land-use and the hydrologic soil group map which is presented in figure 6. Superimposing was achieved by assigning weights for soil groups such as 3 for group A, 2 for group B, 1 for group C and D. Also, for land use class, the weights assigned are 3 for fallow row crop and water bodies, 2 for small growing crop, 1 for pasture land and built-up land respectively.

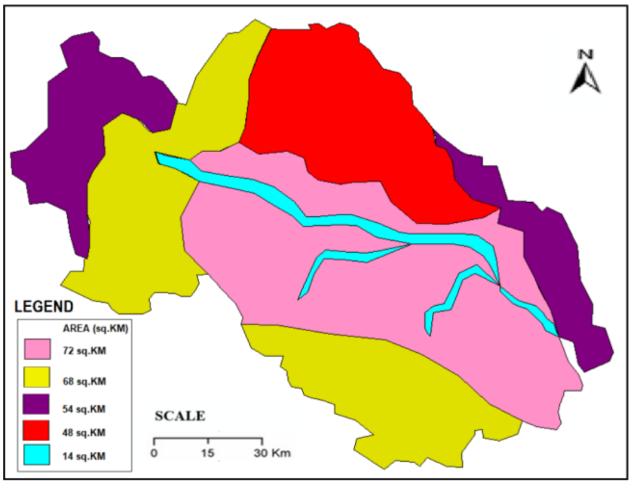

Figure 6. Super imposed area of Land use and soil cover map of the study area

Step 2 - The SCS runoff is articulated as the ratio of cumulative infiltration of rainwater (F) to the watershed storage (S), which equates to the ratio of actual direct runoff to effective rainfall (total rainfall - initial abstraction) (K Subramanya, 1972) and (Pandey, A. and Sahu, A.K, 2009). The general equation for the Soil Conservation Service model of curve number is computed as follows.

$$\frac{F}{S} = \frac{Q}{P - I} \quad \text{.... (1)}$$

The dimensions of F, S, Q and I are same and also the value of initial loss (Ia) is considered as 0.2S. The quantity of infiltrated rainwater after runoff begins can be expressed as:

$$F = (P\text{-}I) - Q \quad \text{.... (2)}$$

Thus,

$$Q = \frac{(P - 0.2S)^2}{(P+0.8S)} \quad \text{.... (3)}$$

Soil maps and land use datasets were employed to generate the Curve Number (CN). The value of S for specific watershed characteristics or land areas considered in the runoff computation is a function of the curve number (CN). The relationship between CN and S is delineated in equation 4.

$$CN = \frac{2540}{25.4 + S} \quad \text{.... (4)}$$

Where, S is the retention capacity of the soil (cm).

5. RESULTS AND DISCUSSION

The CN values corresponding to each soil hydrologic group, hydrologic condition, and associated land use classes are presented in Table 1. The weighted curve number for the area was determined using equation (5), yielding a Weighted CN value of 79.20. Consequently, the retention capacity S was calculated as 5.53 using equation (4). The results presented in Table 2 indicate a persistent increase in runoff depth within the study area. Runoff depth is directly proportional to the hydrologic soil conditions and land use patterns (S. K. Mishra, 2000). The volume of runoff is computed with respect to superimposed area coverage of land use pattern and hydrologic soil condition.

Table -1: Computation of Curve Number

Land use Class	**Land use Practice**	**Hydrologic Soil Group**	**Hydrologic Soil Condition**	**Area (Km^2)**	**Curve Number**
Small crop growing	Terraced farming	C	Poor	48	74
Pasture land	Contour farming	D	Poor	72	88
Fallow row crop growing	Straight row farming	B	Good	68	78
Built land	-	A	Poor	54	74
Water Bodies	-	B	Good	14	78

The Weighted Curve Number (CN_w)

$$CN_w = \frac{CN_1{*}A_1 + CN_2{*}A_2 + CN_3{*}A_3 + CN_4{*}A_4 + CN_5{*}A_5}{\text{Total Area}} \quad \text{.... (5)}$$

Table 2. Results of Runoff depth for the study area

Rainfall Year	2020	2021	2022	2023	2024
Rainfall Depth(mm)	114	134	142	153	180
Runoff Depth(mm)	111.88	131.87	139.87	150.86	177.85
Runoff Volume(m^3)	28672	33792	35840	38656	45568

6. CONCLUSIONS

The results of rainfall-runoff process using SCS method says that the study area is influenced by various factors, such as rainfall distribution, abstraction, slope, and hydrological soil types. The application of GIS tool played vital in extraction of rainfall distribution spatially, land use class coverage area and soil group area. The continuous increase of runoff depth in the study area warns the water managers and decision makers to give more attention in water resources management in aspect of soil erosion, water conservation techniques and land management.

REFERENCES

[1] Abhijit M.Zende, Nagarajan R, Atal K.R., “Analysis of Surface runoff from Yerala River Basin using SCS-CN and GIS”, International journal of Geomatics and Geosciences, Vol 4,No 3,2014.

[2] Ayushi Trivedi, MK Awasthi. “Runoff estimation by Integration of GIS and SCS-CN method for Kanari River watershed”. Indian Journal of Ecology 48 (6), 1635-1640, **2021**2021

[3] Barnett TP, Adam JC, Lettenmaier DP. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature. 2005 Nov 17;438(7066):303-9. doi: 10.1038/nature04141. PMID: 16292301.

[4] Bhura CS et al (2015), Estimation of surface runoff for Ahmedabad urban area using SCS–CN method and GIS, IJSTE. Int J Sci Technol Eng 1(11):2349–2784.

[5] Bua,B.;Ojirot,M.AssessingtheimportanceofriceasFoodandIncomeSecurityCropinPuti-putiSub-country, Pallissa District, Uganda. Am. J. Exp. Agric. 2014, 4, 532–540.

[6] Chen, J., Hill, A. and Urbano, L. (2010) A GIS-Based Model for Urban Flood Inundation. Journal of Hydrology, 373, 184-192.

[7] K Deepa, M Krishnaveni., “Suitable site selection of decentralised treatment plants using multicriteria approach in GIS”, Journal of Geographic Information System, Vol.4 No.3(2012), Article ID:19598,7 pages.

[8] Deepak Kumar Tiwari, H. L. Tiwari and Raman Nateriya, 2021, Geomorphology-wavelet based approach to rainfall runoff modeling for data scarce semiarid regions, Kolar River catchment, India, Journal of Engg. Research Vol.10 No. (1B) pp. 29-40.

[9] Deepa, K.; Karthiga, A.; Rehana, K.; Rayen, V. Aquifer Mapping of Chennai city using GIS techniques. *Imp. J. Interdiscip. Res.* **2017**, *3*, 165–172.

[10] Elkassar, G. Establishment of Water Distribution Scheduling and Operation Strategy for Sustainability Management of Pilot Irrigation Scheme Mubuku Area-Uganda, “Application Case Study”. In Twentieth International Water Technology Conference IWTC20, Hurghada, Egypt, 18–20 May 2017; Negm, A.M., Ed.; Springer: Cham, Switzerland, 2019.R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press

[11] IPCC, 2021: Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 3–32, doi:10.1017/9781009157896.001.

[12] K Subramanya, “Engineering Hydrology” Ministry of Agriculture, Govt. of India,” Handbook of Hydrology”, New Delhi, 1972.

[13] Gupta, Abhinav, Mohamed Hantush, and Rao Govindaraju. "Evaluating a conceptual hydrological model at gauged and ungauged basins using machine learning-based limits-of-acceptability and hydrological signatures." (2024).

[14] Glotov, V. E., and L. P. Glotova. "Water runoff vs modern climatic warming in mountainous cryolithic zone in North-East Russia." *IOP Conference Series: Earth and Environmental Science*. Vol. 107. No. 1. IOP Publishing, 2018.

[15] Pandey, A. and Sahu, A.K. (2009) Generation of Curve Number Using Remote Sensing and Geographic Information System. Geospatial World.

[16] S. K. Mishra, “A modified SCS-CN based hydrologic model”, National Institute of Hydrology Report, TR(BR)-2, 2000.

[17] E Solomon, M Derege Tsegaye, Z Gebeyehu Abebe,, Combining geospatial information and SCS-CN for surface runoff estimation in Rib watershed, upper Blue Nile Basin, Ethiopia “, Geomatics, Natural Hazards and Risk 15 (1), 1-23, 2024.

[18] Shashi Poonam Indwar, Ankit Kumar, Rahul Jaiswal, R.V.Galkate and T. Thomas, “Rainfal-runoff modellings using SCS-CN and GIS Aprroach in the Tawa catchment of Madhya Pradesh, India, J. Indian Water Resour. Soc., Vol. 42, No. 3 & 4, Jul. & Oct. 2022.

[19] Matthew D. Stocker, Yakov A. Pachepsky, Robert L. Hill, and Gonzalo Martinez, "Escherichia coli Export from Manured Fields Depends on the Time between the Start of Rainfall and Runoff Initiation", Journal of Environmental Quality TECHNICAL NOTES & PRELIMINARY COMMUNICATIONS, Published September 6, 2018.

[20] Tassew, B.G.; Belete, M.A.; Miegel, K. Application of HEC-HMS model for flow simulation in the Lake Tana basin: The case of Gilgel Abay catchment, upper Blue Nile basin, Ethiopia. Hydrology 2019, 6, 21.

[21] USDA (1972) Soil Conservation Service, National Engineering Handbook. Hydrology Section 4. Chapters 4-10. Washington, D.C: USDA.

[22] Vörösmarty, C.J.; Green, P.; Salisbury, J.; Lammers, R.B. Global water resources: Vulnerability from climate change and population growth. *Science* **2000**, *289*, 284–288.

[23] www.EarthExplorer.usgs.gov

[24] Wanielista, M.P. and Yousef, Y.A. (1993) Stormwater Management. John Wiley & Sons, Inc., New York.

[25] AK Yoshe, "Assessment of anthropogenic and climate-driven water storage variations over water-stressed river basins of Ethiopia", Hydrology Research 55 (3), 351-379