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Validation of the rainfall-runoff SCS-CN model in a catchment with limited measured data in Zimbabwe

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An evaluation of available opportunities to revive irrigation on a long abandoned irrigation scheme in a dry region of Zimbabwe is presented by assessing water availability at catchment level. The aim is to enhance the livelihoods, income and nutrition of the communities that depend on the irrigation scheme through a sustainable management of revitalised irrigation infrastructure and ensure food security. Runoff generated in the catchment, with potential to flow into the dam that supplies water to the scheme, is estimated using the Soil Conservation Service curve number (SCS-CN) model. The model simulates runoff at catchment level using daily rainfall data. An overview of the methodology and the various steps followed are provided. Daily rainfall and dam water levels are the only measured data available for the catchment. The dam water levels are used to determine the dam water volumes using rating tables. The dam water volumes are used to calculate the daily water inflows into the dam and these are compared with simulated water discharge rates obtained from the model. The plotted hydrographs of both simulated and measured values coincided very well in shape with great precision validating the SCS-CN model for simulating runoff in ungauged catchments.

Key words: Irrigation, water availability, curve number, water balance, runoff, dam level.

INTRODUCTION

Water is the principal resource that helps agriculture and society to prosper (Taffa, 2002; Molle, 2008). Precipitation is the main source of water, but it is effective precipitation (rainfall that is not lost to interception, evapotranspiration, or infiltration) that is of immediate importance to a farmer. This effective precipitation results in runoff, which is defined as a fraction of precipitation that makes its way to water-bodies as surface flow. Water discharged into a river is the runoff from the catchment drained by the river, (Taffa, 2002; Durrans, 2003). Runoff is then harvested and used for irrigation and other competing uses.

The assessment of water availability at catchment level is realised by quantifying runoff generated in the catchment (Daniel et al., 2011). The knowledge of catchment runoff gives an outlook of water that is available to replenish water bodies in the catchment, and therefore very important in the management of both potable and agricultural water. Furthermore, its quantification gives indications on the opportunities to harvest rain water (Welderufael et al., 2009).

A catchment is a hydrologic-ecological unit composed of interrelated parts and functions. With the social and economic development, human activities and the dramatically changing land use have affected catchment runoff generation and flow paths (Xia et al., 2005). The changes in runoff characteristics induced by intensive human activities are important in understanding the effects of land use/cover change on the hydrological processes of catchment surface (Liu et al., 2004; Zepp et al., 2005; Liu and Li, 2008). Most catchments in developing countries do not have runoff information as

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they are ungauged.

The study was conducted in the Tugwane Dam Catchment (TDC) of the Runde River Catcment in Masvingo Province, Zimbabwe. The TDC is the drainage area of the Tugwane Dam which supplies water to Rupike Irrigation Scheme (RIS) and other competing multiple uses downstream. The TDC is a rural catchment where water is mainly used for agricultural and domestic purposes. The study simulates the rainfall-runoff relationship of the TDC using the Soil Conservation Service curve number (SCS-CN) model (SCS, 1972), to evaluate the quantity of water discharged into Tugwane Dam, as the catchment is not gauged to record runoff. The model is validated by comparing the simulated water discharge rates with measured daily water inflow values for 27 selected days of the 2007 to 2008 rain season. The main aim is to assess water availability in the TDC and assess the applicability of the SCS-CN model in estimating runoff in the region.

The SCS-CN model was selected because it considers the physiographic heterogeneity of the catchment (for example, topography, soil, and landuse) to simulate the rainfall-runoff relationship at catchment level (Liu and Li, 2008; Hawkins et al., 2009). The model has been widely used with success, providing consistently useful results (Walker et al., 2000; Soulis at al., 2009; D'Asaro and Grillone, 2010). The model is not only used for runoff estimation, but also for water resources management and urban storm water modeling because of its versatility (Durrans, 2003; Liu and Li, 2008; Hawkins, 1993; Greene and Cruise, 1995; Mishra et al., 2005; Tsihrintzis and Hamid, 1997; Lewis et al., 2000; Sharma et al., 2001; Chandramohan and Durbude, 2001; Sharma and Kumar, 2002; He, 2003).

MATERIALS AND METHODS

Data sources and description of the study area

A variety of data that includes satellite imagery, soil classification map, digital elevation model (DEM) and meteorological data obtained from Rupike Weather Station was used in the study. A 30 m resolution DEM was used to delineate the catchment boundaries and derive the river network. Satellite imagery was used to generate the landuse/landcover map of the catchment, and the results were compared and rectified using Google Earth imagery. The soil classification map was obtained from the SOTER soil database.

Also used were daily dam water level recordings and the associated rating tables obtained from Zimbabwe National Water Authority (ZINWA). Daily rainfall data recorded over a period of 20 years (1992 to 2011) was obtained from Rupike Weather Station which is within the catchment.

The TDC (31°01'-31°07' E, 20°31'-20°36' S) is a part of the Runde Catchment in Southern Zimbabwe. Its catchment area is 43.2 km^2 and receives an annual average rainfall of 600 mm. Rainfall which is highly variable, mainly occurs during the summer season, that is, from November to March. The average altitude of the TDC is 774 m. Figure 1 is a map portraying the location, elevation and shape of the TDC. The broad and compact shape of the catchment makes it have long and few tributaries as illustrated in Figure 1. It is a generally flat catchment with isolated rocky hills covered with mixed forests, and there is also presence of thickets and bush-lands with underground grass. The soils are sandy loamy soils formed on granite rocks. This type of soil has high infiltration rate but also get saturated very quickly allowing rapid runoff (Schulze, 2007). Rainfed agriculture is the main economic activity practiced in the catchment. The RIS itself is outside the catchment. The peasant farmers in the catchment also keep some domesticated animals such as goats and cattle.

The SCS-CN model and method

The SCS-CN model, developed by the United States Soil Conservation Service (SCS, 1972), estimates runoff volume (Q_r) and runoff depth (Q) of individual rainfall events. The model is based on direct estimation of runoff, soil characteristics and landuse, vegetation cover and antecedent moisture conditions (AMC) (Durrans, 2003; SCS, 1972; Hawkins, 1993). The SCS derived the following equation to calculate Q:

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

where, Q is the runoff depth (mm), P is the daily rainfall (mm), and S is the maximum retention capacity of soil calculated as the difference between P and Q (mm). Q is the depth of water that flows over the ground surface or through the ground directly into water bodies after a rainfall event.

Equation 1 is only valid when $P >$ the initial abstractions (I_a) (i.e. $P > 0.2S$). I_a is calculated as $I_a = 0.2S$. $P = 0$ when $P \leq 0.2S$ (Durrans, 2003; Chow et al., 1994). The I_a is the total abstractions that occur before any runoff takes place.

The use of Equation 1 requires an estimate of the maximum retention capacity (S). The S is a function of the curve number (CN) and is calculated using Equation 2, (SCS, 1972; Williams and LaSeur, 1976):

$$S = 254\left(\frac{100}{CN} - 1\right), \text{ in mm} \tag{2}$$

The model allows the calculation of Q produced by a rainfall event (P) over a complex soil-vegetation surface identified by the CN. The CN reflects the runoff potential of an area.

The Q_r of a rainfall event is equal to the product of the Q and the land surface area on which the rainfall occurred, i.e. the drainage basin area (SCS, 1972; Chow et al., 1994). Thus, the Q_r is calculated as:

$$Q_r = \left(\frac{Q}{1000}\right)A, \tag{3}$$

where, Q_r is the runoff volume (m^3), Q is the runoff depth (mm) and A is catchment area (km^2).

Determination of the composite CN

The S, also called the maximum soil water holding capacity, is calculated using Equation 2 which requires the CN of the catchment. The CN, a dimensionless runoff coefficient which is a function of vegetation cover, soil type and soil antecedent moisture condition (AMC), was developed for small basins (≈ 25 km^2) with

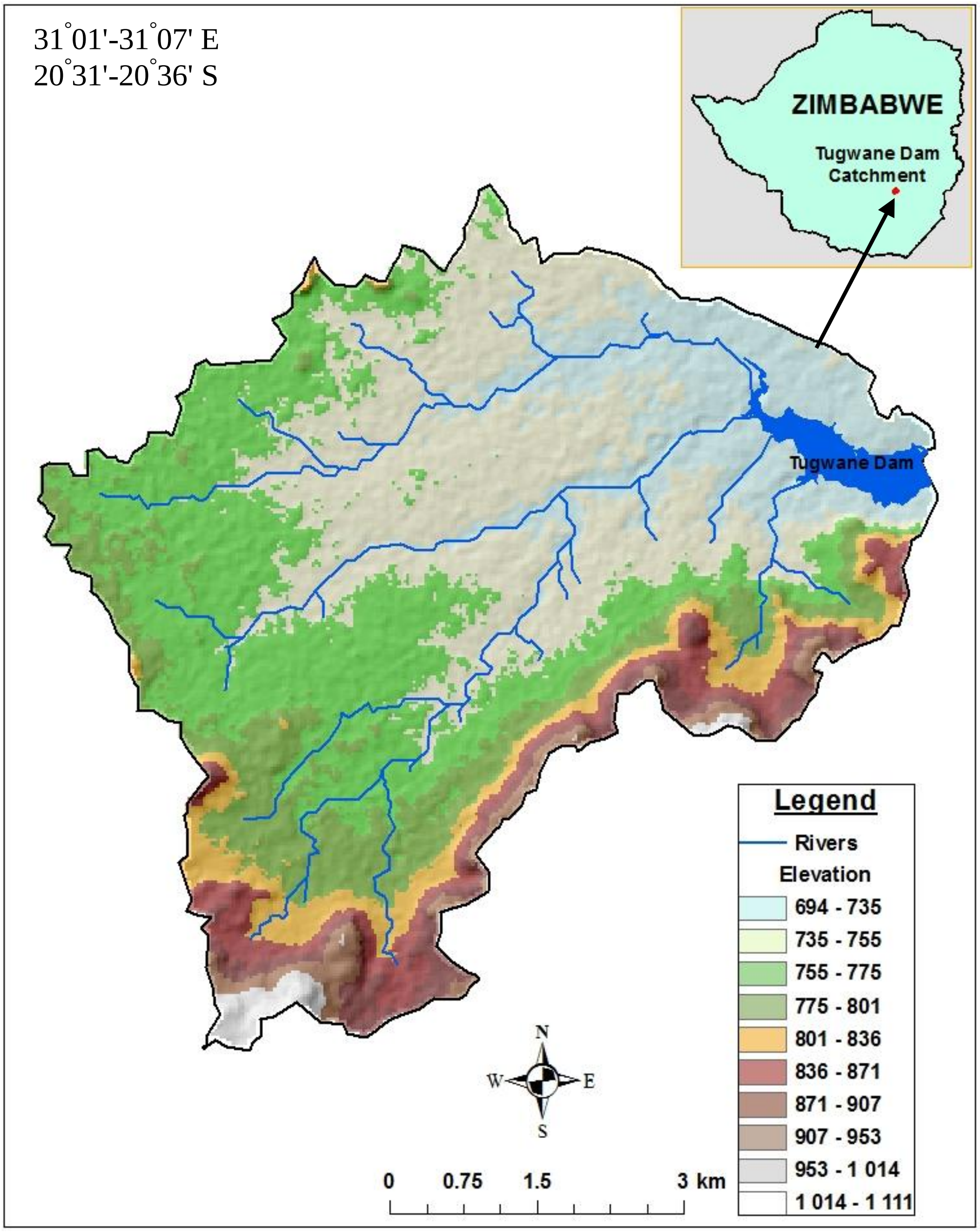

Figure 1. Location, shape and elevation of Tugwane Dam Catchment.

homogenous soil types and landuse because under such conditions it is easier to calculate the *CN* (Durrans, 2003; Hawkins, 1993, 2009; Williams and LaSeur, 1976; Liu and Li, 2008; D'Asaro and Grillone, 2010). The TDC, however, has various landcover types as shown on Figure 2, a condition that compels calculating a composite *CN*. *CN*s for different landcover categories were tabulated by the SCS and are found in literature.

The catchment has one soil type, sandy loam soil, which is moderately shallow, greyish brown, with course grained sands, formed on granite rocks. The soil type is categorised according to one of the hydrological soil groups (A, B, C, and D). The hydrological soil group is used to identify the *CN* of each landuse category using the tables provided by the SCS. The sandy loam soil type of the TDC is classified as belonging to group C as shown in Table 1 (Schulze, 2007).

When rainfall events occur in quick succession, the time period between storms may be too short for the soils to dry to their average or normal moisture conditions. When rain occurs on soils that are already wet, the net result is that runoff volumes and peaks will be higher than normal. The SCS-CN model accounts for this possibility by including the *CN*, a function of the antecedent moisture condition (AMC) (Durrans, 2003; Liu and Li, 2008). There are three AMC classifications; AMC I, AMC II and AMC III. Normal conditions correspond to AMC II. AMC I corresponds to drier

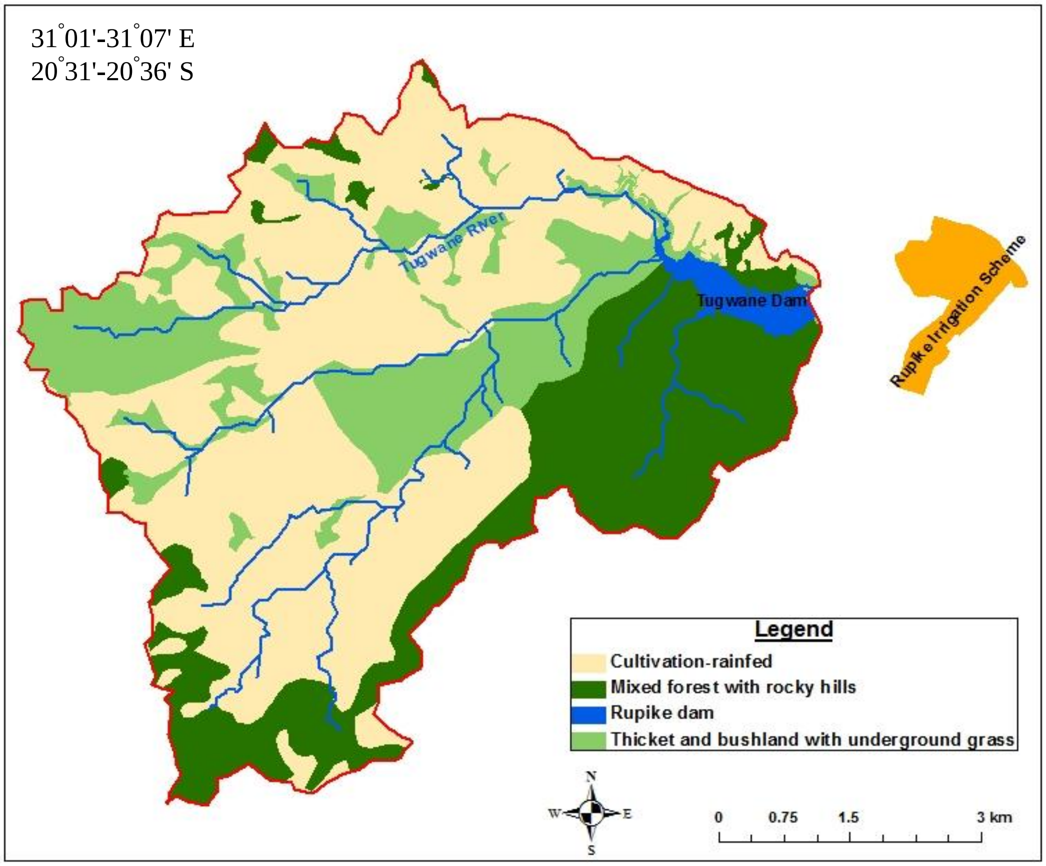

Figure 2 Landcover map of Tugwane Dam Catchment.

Table 1. Soil group of the Tugwane Dam Catchment.

Description	Hydrologic soil group	Antecedent moisture condition group
Moderately shallow, greyish brown, course grained sands, to sandy loams over reddish brown sandy clay loams formed on granite rocks	C	II

conditions, and AMC III to wetter conditions. According to the rainfall data recorded at Rupike weather station the AMC of the RDC soils were classified as condition II as illustrated in Table 1. The *CN* tables used to generate the *CN* for the TDC were taken from the tables elaborated by the SCS which already take into account the AMC II (Durrans, 2003).

*CN*s were assigned for the different types of land use/land cover and soil within the catchment as illustrated in Table 2. The composite *CN* is calculated as (SCS, 1972; Williams and LaSeur, 1976):

$$CN = \frac{\sum_{i=1}^{n} CN_i A_i}{A}, \qquad (4)$$

where, *CN* is the composite curve number of the catchment (dimensionless), *A* is the basin area (ha), CN_i is the curve number of each uniform plot of land within the catchment, and A_i is the area of each uniform plot within the catchment (ha).

The composite *CN* for the TDC is calculated as a weighted average of the individual landuse categories as indicated in Table 2.

Applying Equation 4, the composite *CN* for TDC is $\frac{359780.44}{4244.12} = 85$

According to Equation 2, the *S* for the TDC, at AMC II is calculated to be 44.8 mm as shown in Table 3. The I_a, calculated as $I_a = 0.2S$, is 8.9 mm. The I_a means that when rainfall is less than 8.9 mm, there is no runoff produced.

Daily rainfall data from Rupike Weather Station recorded for a period of 20 years (1992 to 2011) is used to calculate *Q* and Q_r for each rainfall event applying Equation 3. The Q_r are used to calculate the monthly totals for the 20 years, which are then used to calculate the average annual Q_r which is 6 850 000 m^3 as shown in Table 3. Rainfall patterns often have inter-annual as well as inter-

Table 2. CNs for Individual Landuse Categories for TDC.

Landuse category	Soil types	Area (ha)	CN_i	Area × CN
Thicket and bushland with underground grass	Sandy loam	908.18	79	63572.6
Mixed forest with rocky hills	Sandy loam	1105.7	83	80716.1
Cultivation, rainfed	Sandy loam	2230.24	88	173958.72
Total		**4244.12**		**359780.44**

Table 3. CN, S and P values for the TDC.

Catchment	Area (ha)	*CN*	*S* (mm)	I_a (mm)	Q_r (m^3/year)
TDC	4244.12	85	44.8	8.9	6 850 000

decadal time scale variations, therefore average yearly Q_r values calculated over a period of less than 10 years could be misleading, (Mann and Park, 1997; Hu et al., 1998).

RESULTS AND DISCUSSION

The maximum water holding capacity of Tugwane Dam is 3 200 000 m^3. The simulated average annual Q_r of the catchment is 6 850 000 m^3. All the runoff produced in a catchment does not reach the catchment outlet as some is trapped by wetlands, caves, and some is lost through evaporation. However, with an annual average Q_r of 6.85 M m^3 there is enough runoff produced in the catchment to replenish the Tugwane Dam.

The average annual water consumption for RIS is 890 000 m^3. Subtracting the annual water consumption from the annual runoff there will still be 5.96 M m^3 of runoff with potential to replenish the dam considering its holding capacity of 3.2 M m^3. Although part of the water is used for irrigation and other uses downstream, these figures indicate that there is sufficeint water in the catchment to sustain the water use cycle per year. The remaining water in the dam should be able to maintain the dam ecosystem and sustain fishing. The results also indicate that water for irrigation is a small fraction of total water available in the dam. The dam is capable of much larger water supplies than current rate of withdrawals. With regards to policy it can be concluded that the underutilisation of the water resources available in the dam provides possibilities of promoting multiple water uses as well as expanding irrigations for further downstream users.

Model verification

In order to validate the SCS-CN model output, a sample of daily rainfall data of 27 rainfall events that occurred in the catchment during the 2007 to 2008 rain season were used to estimate daily runoff volume and discharge rates, respectively, as indicated in Table 4. The validity b and feasibility of the model was verified by comparing the hydrographs of the simulated and measured water inflows into the dam as shown in Figure 3.

Measured dam water levels were used to determine daily dam water volumes, using rating tables. The dam water volumes were then used to determine daily inflows and outflows by calculating the difference in dam water volumes between two successive days, that is, the difference of water volumes between two successive days gives the amount of water flowing in or out of the dam. When the value is negative it means that there has been no inflow into the dam and the water level actually diminished showing that there was outflow of water (water release) from the dam. But when the value is positive it means that there has been either inflow into the dam and the water level increased, or there was no outflow from the dam and the dam level/volume remained the same. When there is neither inflow nor outflow the discharge value is zero as indicated by Table 4.

The SCS-CN model only calculates *Q* and Q_r and not runoff discharge rate. Therefore, using the calculated *Q*, the daily runoff discharge rate (peak runoff rate, P_r) was calculated using the SCS triangular unit hydrograph (SCS-TUH) as follows (SCS, 1972; Sherman, 1932, 1941; Huggins and Burney, 1992; Hrissanthou, 2005):

$$P_r = \frac{0.278\,(AQ)}{T_b}, \tag{5}$$

where, P_r is the peak runoff rate (m^3/s), *A* is the area of the basin (km^2), *Q* is the runoff depth (mm), and T_b is the base time, (h). The calculated P_r for the selected rainfall events were used to estimate the P_r in 24 h (daily P_r) in m^3, as indicated in Table 4.

Although the simulated discharge rates are higher than the measured rates as shown in Table 3 the absolute error margins between the two sets of values range between 0 and 1.4 which are within the permissible limit, validating the SCS-CN model to estimate runoff in

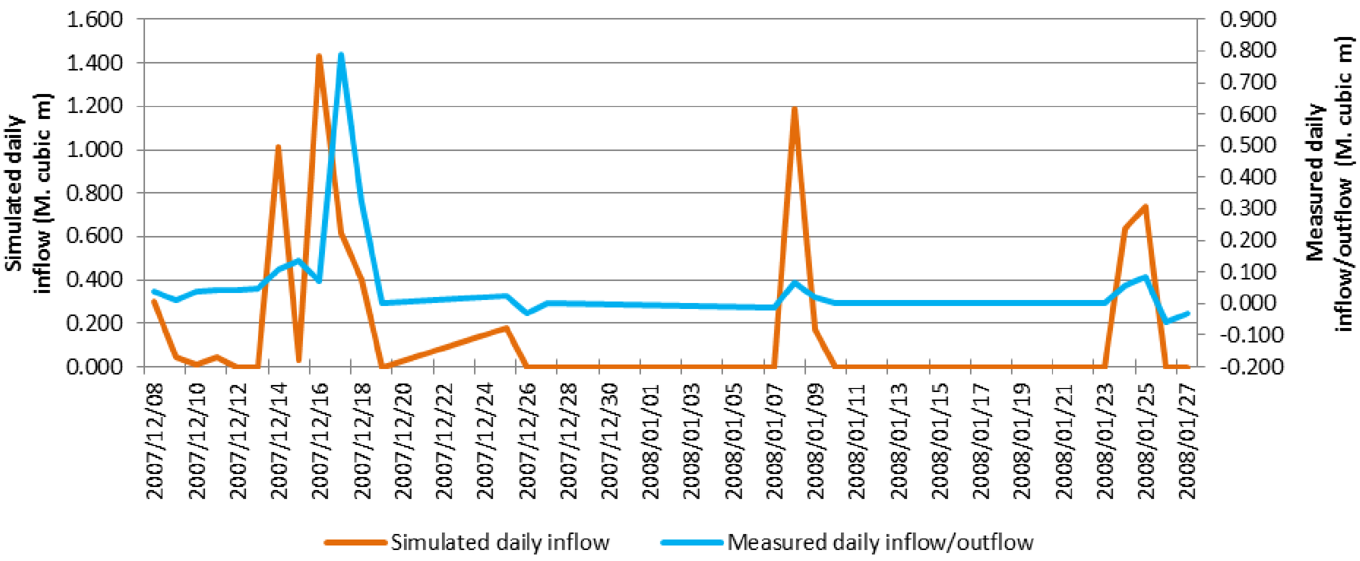

Figure 3. Relationship between simulated and measured daily water inflow.

Table 4. Comparison between daily simulated and observed daily dam inflows.

Day	Rainfall (mm)	Runoff volume (m^3)	Direct runoff (mm)	Simulated discharge (m^3/s)	Dam level (m)	Dam volume (10^6 m^3)	Measured daily inflow/outflow (10^6 m^3)	Simulated daily inflow (10^6 m^3)
08 Dec 2007	26.3	209031.0	4.84	3.45	94.85	0.772	0.040	0.298
09 Dec 2007	15.1	31971.4	0.74	0.53	95.00	0.812	0.013	0.046
10 Dec 2007	11.9	7821.6	0.18	0.13	95.05	0.825	0.041	0.011
11 Dec 2007	14.9	30040.4	0.70	0.50	95.20	0.866	0.042	0.043
12 Dec 2007	1.9		0.00	0.00	95.35	0.908	0.044	0.000
13 Dec 2007	3.4		0.00	0.00	95.50	0.952	0.048	0.000
14 Dec 2007	45.6	712126.1	16.48	11.76	95.66	1.000	0.107	1.016
15 Dec 2007	14	22017.4	0.51	0.36	96.00	1.107	0.136	0.031
16 Dec 2007	54.8	1001505.	23.18	16.53	96.40	1.243	0.073	1.428
17 Dec 2007	35.8	434403.4	10.06	7.17	96.60	1.316	0.790	0.620
18 Dec 2007	29.5	278936.6	6.46	4.60	98.40	2.106	0.319	0.398
19 Dec 2007	5.3			0.00	99.00	2.425	0.000	0.000
25 Dec 2007	21.9	125278.2	2.90	2.07	99.18	2.528	0.023	0.179
26 Dec 2007	7.2		0.00	0.00	99.22	2.551	-0.029	0.000
27 Dec 2007	6.2		0.00	0.00	99.17	2.522	0.000	0.000
07 Jan 2008			0.00	0.00	99.19	2.534	-0.012	0.000
08 Jan 2008	49.5	831952.6	19.26	13.73	99.17	2.522	0.065	1.187
09 Jan 2008	21.5	118473.5	2.74	1.96	99.28	2.587	0.018	0.169
10 Jan 2008	3.4		0.00	0.00	99.31	2.605	0.000	0.000
17 Jan 2008	6.4		0.00	0.00	99.10	2.482	0.000	0.000
18 Jan 2008	7.8		0.00	0.00	99.10	2.482	0.000	0.000
19 Jan 2008	3.2		0.00	0.00	99.10	2.482	0.000	0.000
23 Jan 2008			0.00	0.00	99.00	2.425	0.000	0.000
24 Jan 2008	36.2	444963.4	10.30	7.35	99.00	2.425	0.057	0.635
25 Jan 2008	38.8	515358.9	11.93	8.51	99.10	2.482	0.087	0.735
26 Jan 2008	6.6		0.00	0.00	99.25	2.569	-0.058	0.000
27 Jan 2008	0.6		0.00	0.00	99.15	2.511	-0.029	0.000

ungauged catchments.

The validity of the SCS-CN model in the region was done comparing the simulated daily discharge rates (inflows) with measured values. The plotted hydrographs of both simulated and measured inflow data coincided very well in shape as indicated by Figure 3. The simulated inflow hydrograph has higher values than the measured because the model estimates gross runoff, but it is not all runoff that reaches the catchment outlet, as a fraction of it is trapped by wetlands, ponds, caves, and etc. The hydrographs also show that the dam water volume rises during the subsequent day of a rainfall event, because the base time (T_b) of the catchment was calculated at 34 h. Base time refers to the time it takes for peak runoff to be reached, that is, the time it takes for every runoff from the furthest part of the catchment to reach the outlet (Durrans, 2003; Chow et al., 1994). Days that did not have runoff have nil values for both simulated and measured inflow data, validating the model for assessing water availability in ungauged catchment.

Conclusions

The study used the SCS-CN and the SCS-TUH methods to estimate runoff volume and runoff discharge rates of the TDC respectively. The discharge rates were used to validate the SCS-CN model as dam water volumes were the only measured data available for the catchment. The simulated runoff discharge rates produced results that were consistent with the measured inflow values. The comparative analysis conducted between the simulated and measured inflow values has shown that the SCS-CN model is a useful tool to estimate runoff and to assess water availability in ungauged catchments. The quality of the runoff estimates from the SCS-CN model strongly relies on the quality of the estimation of the *CN*, otherwise the results will not achieve the expected objective.

The methodology used has indicated that the model should be used only with 24 h rainfall durations (daily rainfall events). For example, the I_a for TDC, which is 8.9 mm, means that if rainfall is less than 8.9 mm there is no runoff. But if the runoff is calculated from monthly rainfall totals the runoff results will be erroneous because the monthly rainfall is cumulative. The total monthly rainfall is a result of the sum of rainfall events that occurred throughout that month, some of which would not have produced runoff. The monthly rainfall would give an impression that there was runoff yet some of the rainfall events did not produce runoff as they were below the 8.9 mm threshold.

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REFERENCES

Chandramohan T, Durbude DG (2001). Estimation of runoff using small watershed models. Hydrol. J. 24(2):45-53.

Chow VT, Maidment RD, Mays LW (1994). Applied Hydrology. McGraw Hill, New York, USA, p. 232.

D'Asaro F, Grillone G (2010). Runoff Curve Number method in Sicily: CN determination and analysis of the Initial abstraction ratio. Proceedings of the 4th Federal Interagency Hydrologic Modeling Conference, Las Vegas, Nevada (USA), 06/27/2010-07/01/2010.

Daniel EB, Camp JV, LeBoeuf JE, Penrod JR, Dobbins JP, Abkowitz MD (2011). Watershed modelling and its applications: A state-of-the-art review. Open Hydrol. J. 5:26-50.

Durrans SR (2003). Stormwater Conveyance Modeling and Design. Haestad Press, Waterbury, CT.

Greene RG, Cruise JF (1995). Urban watershed modeling using Geographic Information System. J. Water Res. Pl-ASCE, 121(4):318-325.

Hawkins RH (1993). Asymptotic Determinations of Runoff Curve Numbers from Rainfall-Runoff Data. J. Irrig. Drain. E-ASCE, 119(2):334-345.

Hawkins RH, Ward TJ, Woodward DE, van Mullem JA (2009). Curve Number Hydrology: State of practice. ASCE publication, Reston, Virginia (USA), ISBN978-0-7844-1044-2.

He CS (2003). Integration of Geographic Information Systems and simulation model for watershed management. Environ. Modell. Softw. 18(8):809-813.

Hrissanthou V (2005). Estimate of sediment yield in a basin without sediment data. Catena 64:333-347.

Hu WCM, Mudrick SE (1998). Inter-decadal variations of annual precipitation in Central United States. Am. Meteorol. Bull. 79:221-229.

Huggins LF, Burney JR (1982). Surface runoff, storage and routing. In Hydrologic Modelling of Small Watersheds, edited by Haan et al., St. Joseph, Mich, ASAE. 5:169-225.

Lewis MJ, Singer MJ, Tate KW (2000). Applicability of SCS curve number method for a California Oak Woodlands Watershed. J. Soil Water Conserv. 55(2):226-230.

Liu GC, Tian GL, Shu DC (2004). Streamflow and soil moisture of agroforestry and grass watersheds in hilly area. Pedosphere 14(2):263-268.

Liu X, Li X (2008). Application of SCS Model in Estimation of Runoff from Small Watershed in Loess Plateau of China. China Geogr. Sci. 8(3):235-241.

Mann ME, Park J (1997). Global Scale Modes of Surface Temperature Variability on Interannual to Century Scale. J. Geophys. Res. 99:25819-25833.

Mishra SK, Jain MK, Bhunya PK, Singh VP (2005). Field applicability of the SCS-CN-based Mishra-Singh general model and its variants. Water Resour. Manag. 19(1):37-62.

Molle F (2008). Why enough is never enough: The societal determinants of river basin closure. Int. J. Water Resour. Dev. 24(2):2017-226.

Schulze RE (2007). Soils: Agrohydrological Information Needs Information Sources and Decision Support. In South African Atlas of Climatology and Agrohydrology, WRC Report 1489/1/06, Section 4.1, Water Research Commission, Pretoria, RSA.

Soil Conservation Service (SCS) (1972). SCS National Engineering Handbook, Section 4. Hydrology, Soil Conservation Service, US Department of Agriculture, Washington, DC.

Sharma D, Kumar V (2002). Application of SCS model with GIS database for estimation of runoff in arid watershed. J. Soil Water Conserv. 30(2):141-145.

Sharma TS, Kiran PV, Singh TH (2001). Hydrologic response of a watershed to land use changes: A Remote Sensing and GIS approach. Int. J. Remote Sens., 22(11):2095-2108.

Sherman LK (1932). Stream Flow from Rainfall by the Unit Graph Method. Eng. News Rec. 108:501-505.

Sherman LK (1941). The unit hydrograph and its application. Bull. Assoc. State Eng. Soc. 17:4-22.

Soulis KX, Valiantzas JD, Dercas N, Londra PA (2009). Investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability to a partial area experimental watershed. Hydrol. Earth Syst. Sci. 13:605-615.

Taffa T (2002). Soil and Water Conservation for Sustainable Agriculture. Mega Publishing Enterprise, CTA, Postbus 380, 6700 AJ Wageningen, The Netherlands.

Tsihrintzis VA, Hamid R (1997). Urban storm water quantity/quality modeling using the SCS method and empirical equation. J. Am. Water Resour. As. 33(3):163-167.

Walker SE, Banasik K, Mitchell JK, Northcott WJ, Yuan Y, Jiang N (2000). Applicability of the SCS curve number method to tile-drained watersheds. Ann. Warsaw Agric. Univ. (SGGW), Land Reclam. Warsaw, Poland, 30:3-14.

Welderufael WA, Le Roux PAL, Hensley M (2009). Quantifying rainfall-runoff relationships on the Melkassa Hypo Calcic Regosol ecotope in Ethiopia. Water SA, 35(5):639-648.

Williams JR, LaSeur WV (1976). Water yield model using SCS curve numbers. J. Hydraul. Div. Proc. Am. Soc. Civ. Eng. 102(HY9):1241-1253.

Xia J, Wang GS, Ye AZ (2005). A distributed monthly water balance model for analysing impacts of land cover change on flow regimes. Pedosphere 15(6):761-767.

Zepp H, Tang JL, Zhang B (2005). Methodological framework for a multi-scale study on hydrological processes and soil erosion in subtropical southeast China. Pedosphere 15(6):695-706.