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Research Article

Runoff assessment by Storm water management model (SWMM)- A new approach

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Abstract
The present study investigated the storm wise runoff collected in farm pond with the runoff estimated by Storm Water Management Model (SWMM) and Soil Conservation Service (SCS-CN) models. The SWMM and SCS-CN models estimated runoff depth storm wise. The runoff depths correspond to the catchment area given the runoff volume from the catchment. The runoff depth estimated from the Storm Water Management Model and Soil Conservation Service model was compared against the depth of runoff estimated from the Water balance model. For small rainfall depths, the runoff estimated from the Storm Water Management Model was at par with the actual runoff volume stored at the pond. It is necessary to know the watershed runoff contribution to the river or streams due to rainfall in order to determine environmental risk or flood potential. In larger rainfall depth, the runoff volume estimated from the SWMM model was less than the stored runoff volume at Farm Pond. The Soil Conservation Service Model gave better results for larger rainfall depth compared to Storm Water Management Model. SWMM was able to simulate runoff depth for small rainfall depths of 2mm. The peak runoff depths were produced by rainfall depths of 35.5mm. Initial abstractions of the study area for antecedent moisture content i.e. AMC I, AMCII and AMCIII are 53.2, 23.91 and 10.43mm, respectively. The comparison showed that both SWMM and SCS-CN models gave better runoff quantification results.

Keywords: Dynamic model, SCS-CN, SWMM, Runoff, Watershed

INTRODUCTION

The watershed, a geographically dynamic unit that contributes runoff to a common outlet. It has been recognised as a fundamental unit for planning and implementing defensive, curative, and ameliorative programmes. Successful management requires a thorough understanding of a watershed's hydrological behaviour. The watershed management planning focuses on flood control strategies in the catchment/watershed region. The two most critical hydrologic responses to rainfall events that occur across drainage systems are surface runoff and sediment losses. Rainfall-generated runoff is crucial in a number of water supply planning and management practises, including flood control and its management, Irrigation scheduling, Design of irrigation and drainage network, hydro power generation etc. There are a variety of software programmes that can model urban flooding. The first computerised models of urban storm drainage were created in the late 1960s, and various models have been used since then (Zoppou, 2001; Mitchell, 2001). Design models, flow prediction models, and planning models are the three types of models (Rangari *et al*., 2016, Hunter *et al*., 2007). Modelling of urban floods became simpler with the implementation of Graphical User Interface (GUI) software such as SWMM, HEC-HMS, HEC-RAS, MIKE FLOOD, and others.

The SWMM achieves catchment responses to peak flow and runoff volume, which are the most essential catchment responses in urban drainage planning (Shaik and Agrawal, 2019). This software produced readily understandable outputs. GIS tools such as ArcGIS, QGIS, and others have made the process of collecting data for direct input into the model much easier (Hashemyan et al., 2015). When evidence is sparse, the availability of DEM allows for a more comprehensive simplification of reality in simulations. Using experimental techniques, scientists performed a scientific review and assessment to quantitatively research and forecast precipitation runoff and proposed a model for estimating runoff and evaluating possible runoff production sites in the research area. Because of its accuracy and performance, the SCS-CN experimental approach was used. By preparing CN, the runoff production potential of the region was determined (Panahi, 2013). Morphometric characteristics for each catchment was manually determined using topographic maps and then automatically determined using a pre-processed DEM based on SRTM data and GIS scripting capability. An updated SCS dimensionless unit hydrograph was used to model the transition of excess rainfall into a direct runoff, and flow rates obtained by automatic methods were marginally higher than those obtained manually. The findings demonstrated that the accuracy of real runoff prediction is heavily dependent on the consistency of input data (soil, land usage, rainfall, etc.) and that there are only small variations as opposed to the time and energy saved by automated techniques (Zlatanovic and Gavric, 2013). Rainfall runoff and anthropogenic activity measurement was done in an urban watershed using SWMM. In densely urbanised catchments, the most significant variables in the study area are land use and land cover (Patil and Chaudhary, 2014). Flood modelling is primarily used to investigate all facets of flood in the urban environment, including the effects of heavy rainfall on the drainage of urban sub-catchments and the different socio-economic aspects of the flood (Rangari *et al.*, 2018). It was using the US EPA's Storm Water Management Model in a metropolitan setting using an RS and GIS-based solution. At 1:10,000 scales, the Cartosat-1 PAN+IRS-P6 LISS-IV merged product was used to map land cover in parts of the Surat district. The DEM of the study region was powered by a Cartosat stereo pair. The average runoff coefficient on the urbanised subcatchment areas directly connected to the drainage network was 0.92, compared to 0.88 on those urbanised sub-catchment areas lacking direct access to stormwater drainage, according to a dynamic rainfall-runoff simulation based on three days of rainfall (Gambi *et al.,* 2011). The current research focused on estimating runoff using the Storm Water Management Model (SWMM) and the Soil Conservation Service Curve Number Model to address the above problem. The study is unique in that it evaluates the SWMM for agricultural watersheds.

MATERIALS AND METHODS

The study was carried out at the Agriculture Engineering College and Research Institute in Kumulur, which is near Pallapuram village in the Trichy district of Tamil Nadu. Kumulur campus covered an area of 280 acres. Kumulur has latitude, longitude and altitude are $10^0 55'$ 29.34”N and $78^0$49’35.61”E, respectively, and is 70 metres above mean sea level. This area's average annual rainfall was 857.09 mm. For the runoff calculation analysis, a farm pond near the campus's main gate was used. Real runoff obtained at a farm pond was opposed to the projected runoff volume. Farm pond was situated at $10^0$93’9” N and $78^0$82’49”E. (Fig.1).

Estimation of runoff by Storm water management model (SWMM)

To estimate surface runoff generated by rainfall over a sub-catchment, SWMM was used it is a nonlinear reservoir model. A sub-catchment was modelled as a rectangular surface with a uniform slope (S) and width (W) that drains to a single outlet channel in the model. The sub-catchment was modelled as a nonlinear reservoir to produce overland flow. The parameters obtained and calculated for the catchment area were controlled by SWMM's numerical methods, which use mass, energy, and momentum conservation concepts to explain rainfall-runoff processes. Net change in depth (d) per unit of time (t) is essentially the difference between inflow and outflow rates across the sub-catchment, based on mass conservation:

$$\frac{\partial d}{\partial t} = i - e - f - q \quad \dots\dots\dots (1.0)$$

where,
i, rate of rainfall + snowmelt, m/s
e, surface evaporation rate, m/s
f, infiltration rate, m/s
q, runoff rate, m/s

Estimation of runoff by Curve number model (CN)

The SCS-CN formula calculated the storm-wise direct runoff (depth) or rainfall excess. This approach was dependent on the watershed's potential optimum retention (S), which was determined by the watershed's wetness, i.e. antecedent moisture content (AMC), and physical characteristics.

$$Q = \frac{(P - Ia)^2}{(P - Ia + S)} \dots\dots\dots (3)$$

where,
Q is runoff depth, mm.
P is daily rainfall, mm.
S is potential maximum retention of soil, mm.
I_a is initial abstraction, mm
I_a is related to S for different soil types, I_a= 0.2S,

$$Q = \frac{(P - 0.2S)2}{P + 0.8S} \dots\dots\dots.(4)$$

The curve number for various land uses in a catchment was used to calculate the soil's overall possible retention. If ‘S' has units of mm, the following equation was used to connect CN and S.

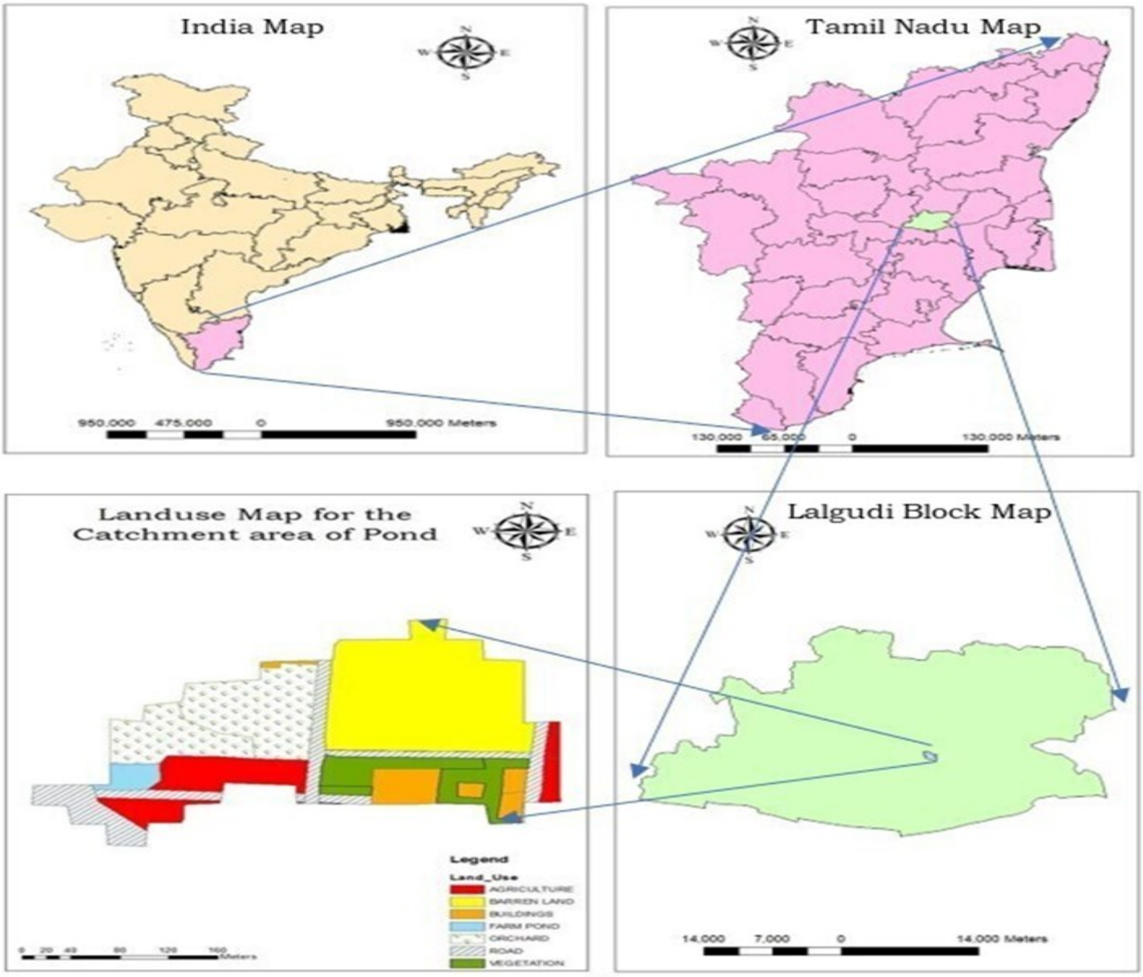

Fig. 1. *Map showing study area of Kumulur campus, near Pallapuram village in the Trichy district of Tamil Nadu.*

$$CN = \frac{25400}{254 + S} \dots\dots\dots(5)$$

Soil infiltration rates differ greatly and are influenced by both subsurface permeability and surface infiltration rates. Based on the minimum infiltration rate obtained for bare soil after extended wetting, soil in the study region was categorised into four Hydrologic Soil Groups: HSGs A, B, C, and D. The hydrologic soil group was used to calculate the curve number for each ground cover. The research area's soil texture was sandy loam. The new research field was designated as hydrologic soil group A. (HSG-A). The curve number corresponds to HSG-A was referred from USGS guidelines (Table 1).

The wetness index of soil was specified as antecedent moisture content (AMC). The AMC was calculated using rainfall levels from the previous five days. Table 2 lists the AMC parameters.

The curve number ranges from zero for the most permeable or entirely saturated surface to 100 for an impervious (Concrete) surface. However, Table 3 displays the curve number values for various land use conditions and hydrologic soil classes. These values were only used for the antecedent moisture content (AMC) II, or average condition. Other AMCs' CN values were determined using the correction factors (i.e. I & III). After estimating the runoff depth (Q), the volume (m3) of the specific event can be determined using the given equation. The following equation is used to approximate the amount of runoff harvested.

$$V = \frac{Q * Ac}{1000} \dots\dots\dots(2.3)$$

where,

Q, Runoff depth, mm

Ac, Catchment area, m^2

Estimation runoff by water balance method

The catchment was chosen because it was near a Farm pond. The catchment's runoff was stored at the Farm Pond, which was established downstream of the catchment for each rainfall occurrence. During the study period, the water levels of the Farm Pond were measured daily and the pond water level was registered. For a water balance simulation analysis to measure inflow (runoff) to the reservoir, evaporation data from the study region is obtained for the entire study duration. During the study time, the maximum water level observed in the pond was 1.21m, with a volume of water deposited of 831 m^3. Throughout the research period (29 October 2015 - 11 December 2015), the water levels of Farm Pond were continuously tracked. The Farm Pond was shaped like a trapezoid. For Farm Pond, a depth-volume relationship was established in order to approximate the volume of runoff obtained at various water depths. Rainfall and evaporation were measured on a regular basis. In order to model watershed runoff, which was inflow into Farm Pond, the water balance model was used to approximate it.

$$S_t = S_{t-1} + Q_t + P_t - I_t - D_t - L_t - E_t \dots\dots\dots (3.0)$$

where,

S_t, storage for time t, m^3.

S_{t-1}, storage for time t-1, m^3.

Q_t, inflow, m^3.

P_t, precipitation onto reservoir (rainfall depth* Pond surface area), m^3.

I_t, irrigation amount, m^3.

D_t, flood control discharge, m^3.

L_t, other losses, m^3

E_t, pond evaporation (evaporation depth*surface area of pond), m^3

RESULTS AND DISCUSSION

Estimation of runoff by SWMM

SWMM was a distributed model, which ensures that a research area can be subdivided into as many uneven sub catchments as required to better capture how topography, drainage pathways, land cover, and soil characteristics influence runoff generation. The chosen study area has a basic geometry, and physical catchment parameters were calculated in the region. The research field is depicted in Fig.1. According to land use, the catchment area is divided into three subcatchments, S1, S2, and S3. S1 is bare earth (playground), S2 is an orchard, and S3 is farmland. The geometrical structure and topography state of each sub catchment are closely related to the physical parameter described. The field survey is used to estimate all physical parameters in this analysis. Rangari *et al.* (2018) divided the study area into nine sub basins by considering the drainage line. The same methodology has followed in the current study. In the present study research area's land use and land, cover trend is obtained from a 30 m Cartosat DEM. To describe the runoff from each sub catchment, the area of each sub basin is estimated and input into the storm water management model (SWMM). Changes in land cover form, the advance of peak runoff time, and rise in peak flow and overall runoff are all problems that the conventional planning model would cause. As seen in Fig. 2, after the planned holistic implementation of urban water ecosystem landscape storm water management system, peak flow and cumulative runoff would revert to predevelopment levels or even slow down peak rainfall. The results obtained had a similar trend with Shaik and Agrawal (2019). Because of the influence of storage sources and the outlet reservoir at the start of rains, the expected runoff hydrograph is close to zero. In general, maximising the combination of permeable (vegetation and porous) and impermeable (road, roof, and street) surfaces to maximise the amount of infiltrated water is one aspect of the assessment and application of landscape rainwater systems to establish a natural hydrological context. In terms of slope, the porosity, surface cover, rain penetration conditions to permeable areas should be given in such a way that permeable surfaces are placed in the flow path and have a high potential to maintain and percolate. Water collection and release mechanisms limit runoff rate and temporary storage, as well as the hydrograph's peak discharge. This arrangement, a typical example of a pool, is a good way to steer and regulate water. Runoff storage was focused on the efficient utilisation of rainwater supplies and runoff prevention to reduce peak flow.

Estimation of runoff by SCS-CN model

The SCS-CN approach was used to calculate runoff depth using curve number (CN) values related to Land Use and soil data to determine CN values for the watershed that took into account the amount of infiltration rates of soils. United States Department of Agriculture Technical Release 55 (1986) provided the CN values

Table 1. Hydrological soil group according to the texture of the soil.

Hydrological soil group (HSG)	Soil texture
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay

Source: (United States Department of AgricultureTechnical Release 55,1986)

Table 2. Seasonal rainfall limits to determine antecedent moisture condition.

AMC Group	Total 5-day antecedent rainfall (mm)	
	Dormant season	Growing season
I	<12.7	<35.6
II	12.7-27.9	35.6-53.3
III	>27.9	>53.3

Source: (United States Department of Agriculture, Technical Release 55,1986)

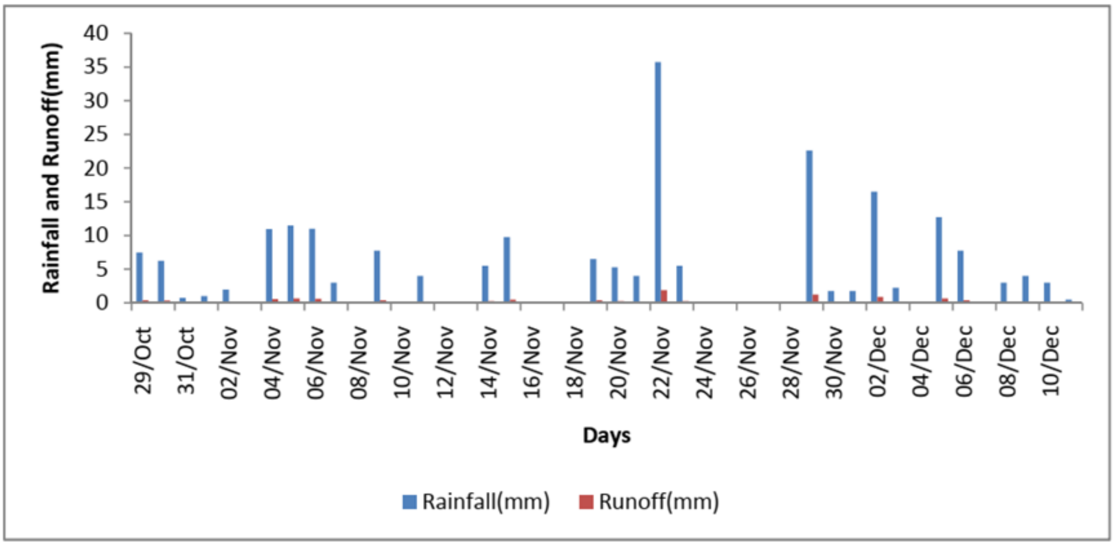

Fig. 2. *Runoff estimated from Storm water management model (SWMM).*

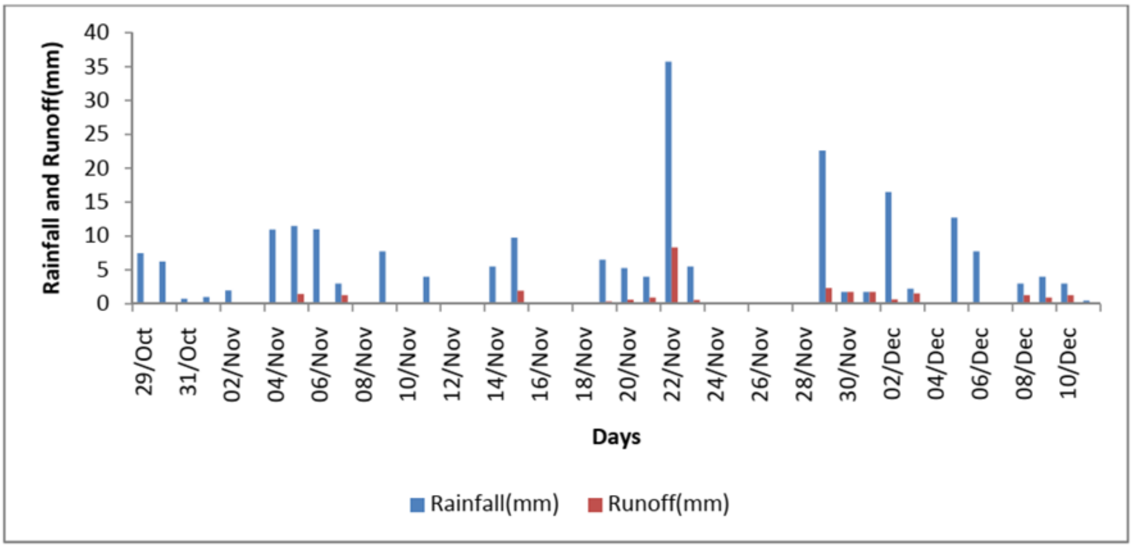

Fig. 3. *Runoff estimated from soil conservation service –Curve number model.*

for both forms of land uses and hydrologic soil classes. Soils were divided into hydrologic soil classes in this regard (HSGs). The HSGs were divided into four categories: A, B, C, and D, with A and D representing the highest and lowest infiltration rates, respectively. Table 3 shows the curve number for each Land Use and hydrologic soil region.

Estimation of runoff by SCS-CN model

The SCS-CN approach was used to calculate runoff depth using curve number (CN) values related to Land Use and soil data to determine CN values for the watershed that took into account the amount of infiltration rates of soils. United States Department of Agriculture Technical Release 55 (1986) provided the CN values for both forms of land uses and hydrologic soil classes. Soils were divided into hydrologic soil classes in this regard (HSGs). The HSGs were divided into four categories: A, B, C, and D, with A and D representing the highest and lowest infiltration rates, respectively. Table 3 shows the curve number for each Land Use and hydrologic soil region.

The SCS-CN model provided no runoff for smaller rainfall depths. The runoff depth caused by the rainfall depth of 35.5 mm was seen in the graph as the peak runoff depth. The research area was initially abstracted at 53.2, 23.91, and 10.43mm for AMC I, AMCII, and AMCIII. The initial abstraction was not filled due to inadequate rainfall depths.

Comparison SWMM, SCS-CN model and Water balance model

The observed runoff calculated at the Farm Pond was equivalent to the runoff estimated using the SCS-CN model and SWMM. Everyday water balance simulation tool was used to measure the observed runoff.

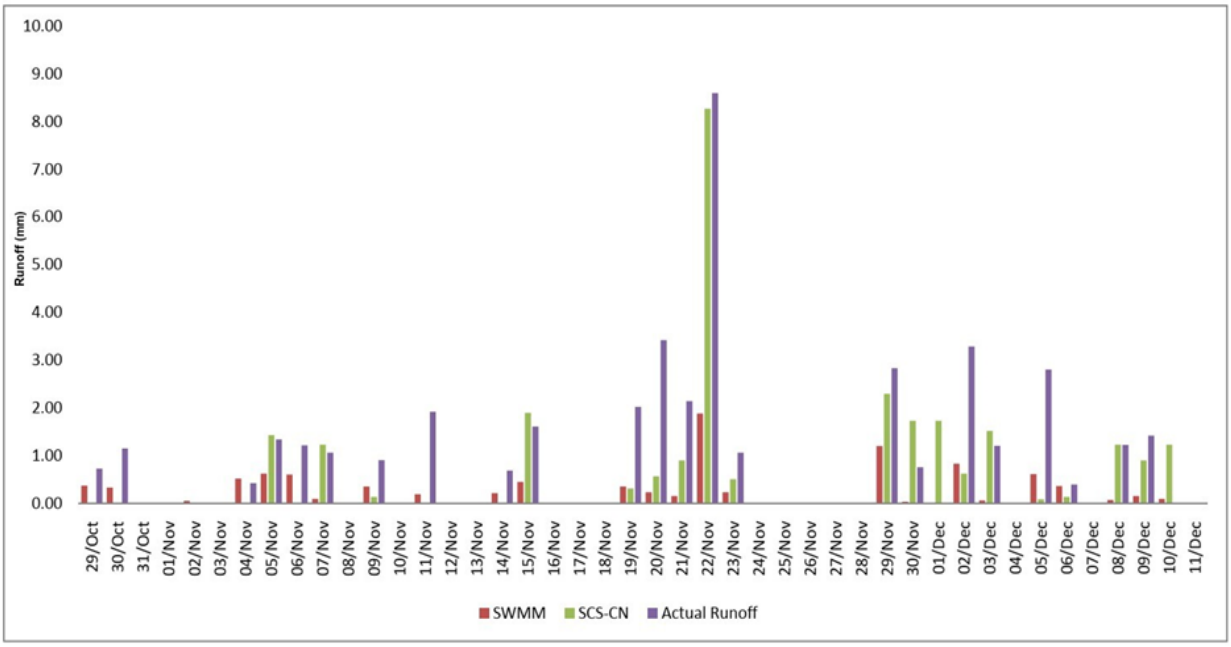

Fig. 4. *Comparison of runoff volume estimated from SCS-CN model, Water balance method and storm water management.*

Fig. 4 compares the predicted runoff depth from the SCS-CN model and SWMM to the observed runoff. It was discovered that the SWMM's runoff depth was comparable to the actual runoff measured. The volume of actual runoff obtained at Farm Pond exceeded the volume predicted by two separate models. Only for higher rainfall depths does the SCS-CN model yield runoff depth. In the study area, the SCS-CN model revealed a considerable depth of initial abstraction. The minimal rainfall occurrences were not enough to make up for the initial abstraction losses. The SWMM was a computer-driven simulation model that measured runoff based on depression storage and infiltration capability. The SCS-CN Model calculated runoff based on antecedent moisture conditions and the soil's possible optimum retention. For limited rainfall depths of 2mm, SWMM will simulate runoff depth. The depth of the simulated runoff from SWMM matched the actual runoff obtained at the pond. For the research region run off quantification, the SWMM and SCS-CN models performed better.

Table 3. Curve number for different land cover in the catchment.

Land cover	AMC II	Area(ha)
Bare soil	77	3.6
Orchard	57	3.0
Agriculture land	72	0.75
Weighed CN	68	

Conclusion

The highest water level recorded in the pond during the study period (29 October 2015 - 11 December 2015) is 1.21m and the corresponding volume of water stored was at pond 831 m^3. The actual runoff depth generated from the catchment collected at the pond was compared with runoff depth estimated by SWMM and SCS-CN model. The SWMM performed well in both low and high rainfall conditions. Finding these differences from the model made this work unique. Differentiating the computer model from the conceptual model with its drawbacks helps to improve model performance. The following conclusion can be made from the study :

Runoff depth was sensitive to changes in the input parameters of percentage impervious area, the width of the catchment and depression storage. This suggests that a slight change in any of these input parameters will significantly change the simulated runoff depth.

Application of SWMM for predicting storm runoff quantity was improved by taking into account the catchment''s antecedent moisture condition and the impervious depression storage value.

The SCS-CN model showed better results at high rainfall depth. At lower rainfall, the depth model was not resulting runoff due to consideration of initial abstraction.

Conflict of interest

The author declares that she has no conflict of interest.

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