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Estimation of Runoff in the High Humid Foot-Hill Areas of Arunachal Himalayas Using SCS-CN Method

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Abstract: The present study estimates runoff trend of extreme events of different seasons (pre-monsoon, monsoon and post-monsoon) in Dikrong river catchment which is located in the foot-hills of Arunachal Himalaya. The river catchment is characterized by the monsoon dominated hydrologic regime. For the purpose daily statistics of rainfall and discharge were collected from the various sources of state Government of Arunachal Pradesh, Itanagar, and Government of Assam, Guwahati used for testing the validity of SCS-CN method in Dikrong river catchment of high humid areas of Arunachal Himalayas. It is found that this method is suitable for the correct assessment of daily runoff (RO). The fluctuation in predicted RO are found more than the observed RO with an over estimation during high rainfall intensity and under estimation in the period of low rainfall regime.

Keywords: runoff, SCS-CN method, Arunachal Himalaya, Dikrong river catchment, discharge, monsoon

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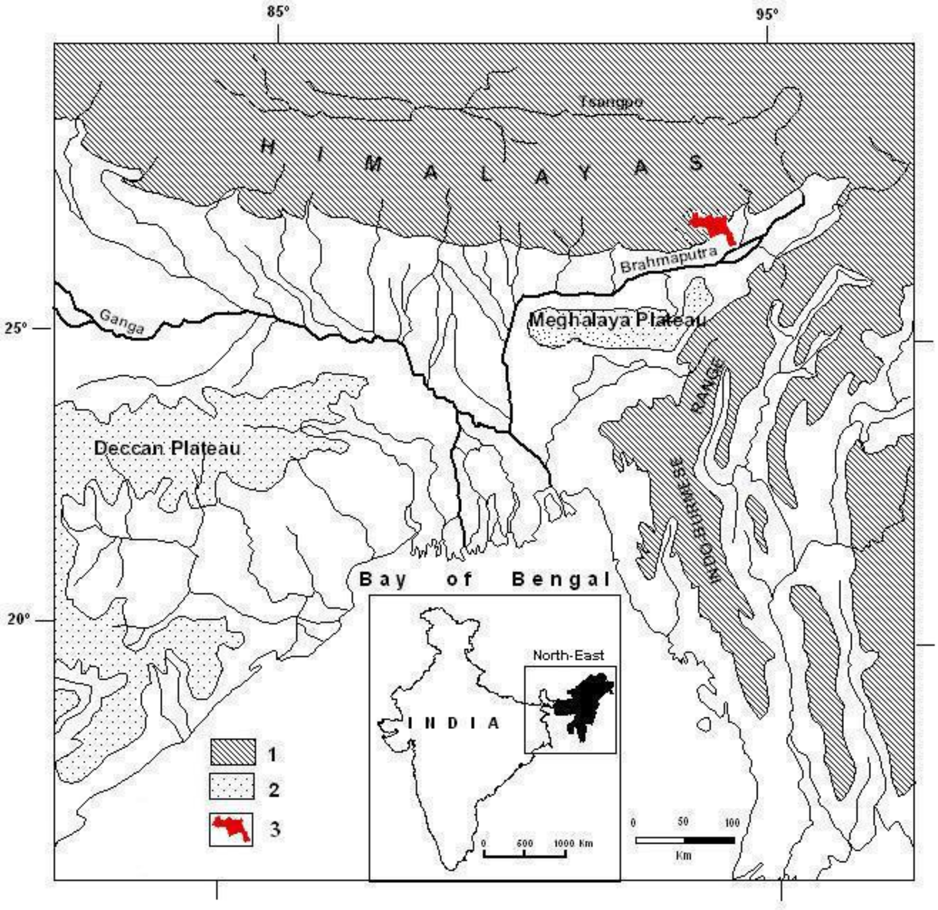
I. INTRODUCTION

SCS-CN method is universally accepted method and there are numerous studies on estimation of runoff using this method all over the world (Al Huda, 2013), because this method implicitly based on universally available land surface (hydrological soil group and land use) and meteorological (rainfall) attributes of the area, it is widely used because of its flexibility and simplicity (Ebrahimian et. al, 2009; Laura et. al, 2011). The runoff trends of a river basin associated with the hydro-meteorological conditions like rainfall and temperature of the area (Jung and Chang, 2011). The SCS-CN method developed by Soil Conservation Service-USDA (1972) and widely used for estimation of runoff based on the land use/land cover of the watershed. It is based on two phenomena, initial accumulation of rainfall represent interception, depression storage, and infiltration before the start of runoff. So it is assume that the actual moisture retention by the soil (P-Ia-Q) with the potential maximum retention {Sm ≥ ((P-Ia-Q)} equals to the actual runoff (Q) and the potential maximum runoff {Q=P-Ia [where (P-Ia) ≥ Q]} (Das, 2009; Singh and Syiemlieh, 2010).

In India especially in the high-humid areas where 'saturation excess' processes of runoff generation are more prevalent rather than 'infiltration' processes in the monsoon dominated hydrologic regime, there is a need of testing the validity of SCS-CN method to assess the runoff in such high rainfall conditions (Singh and Syiemlieh, 2011; Al Huda and Singh, 2012). For the purpose, present paper examines the daily runoff trend (event wise) and its associated factors and also evaluates the significance of the application of SCS-CN method taking into account Dikrong river catchment of about 1,556 sq. km area of which more than 80% is under the hill topography with an average annual rainfall of 3,294mm.

Study Area:

Dikrong river catchment is located in the foot-hills of Arunachal Himalayas and lies between 26˚55´N to 27˚22´N latitudes and 93˚13´E to 94˚0´E longitudes (Fig.-1) with its transitional characteristics of its location as it falls under Inter Tropical Convergence Zone (ITCZ) where climate is monsoonal in this part of Asian region. Being its location in the loop of Eastern Himalayas, it is more humid and has different hydrological characteristics than the other parts of North-East Region of the Country. Geologically, the catchment is located in the lower fault line which divides the river catchment into two topographic features: (i) the lower piedmont hills where erosion processes are prevalent and (ii) alluvial plains of depositional processes where frequent floods are experienced (Joshi and Shahid, 2002). However, the flood responses are more related to piedmont hill- topography and land use of its upper part that influence the water flow and discharge of river channels.

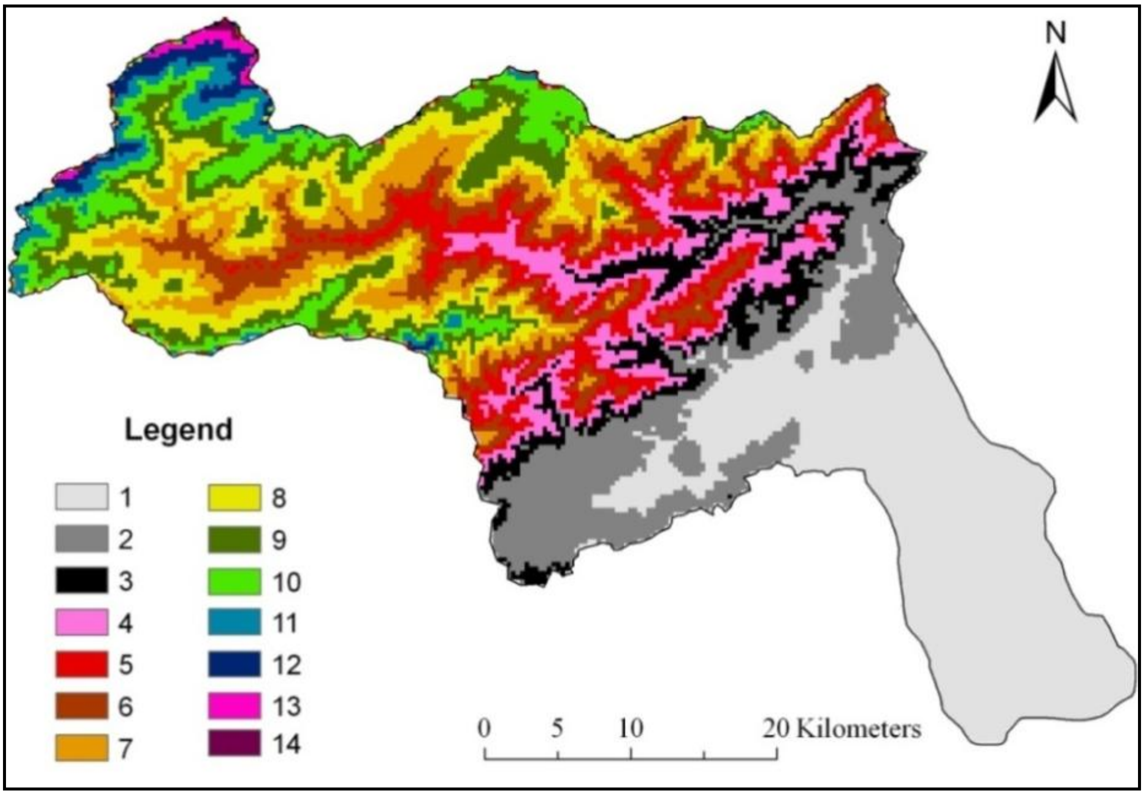


1=Areas above 1600 m a.s.l., **2**= Areas of 900 to 1600 m a.s.l. **3**= Study Area

Fig.-1: Location of the Study Area

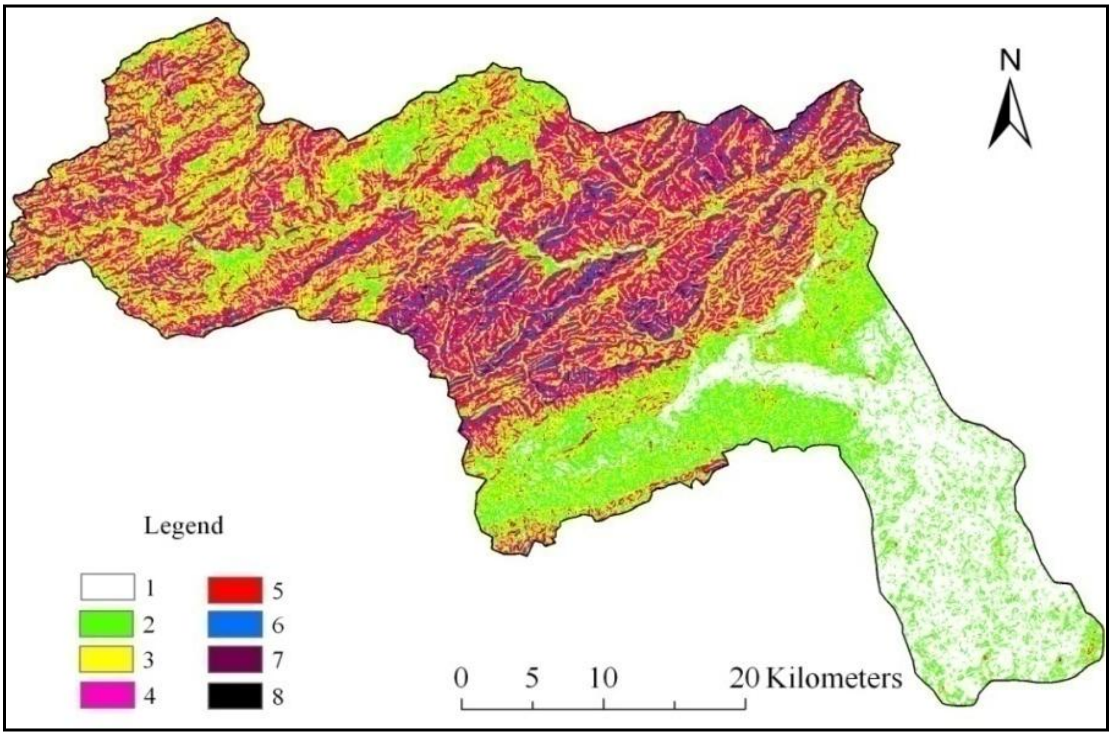
The length of the main river is recorded 145 km with an average slope of 5-15% with the perimeter of 264 km. Topographically, hill slopes are steep covering an area of about 61.54% with its narrow flat valleys located in the upper parts of the river catchment (Fig.-2 and 3). Such topography helps in accelerating the saturation processes and fast flow while the lower part is gentle plain accommodating about a quarter part of the catchment (27.01%) with sediment deposition. Average temperature is recorded 15.15°C in January (moderately cold) and 26.96°C in July (Hot). Sometimes rainfall is high during pre-monsoon period (April) but July is the peak of monsoon when it precipitates up to 602 mm to 986 mm. Post-monsoon showers which occur from October onwards are helpful for soil recharge and vegetation growth. Due to thick fertile soils (1.2 m to 1.8 m) having 200 mm of water retention capacity and high nutrient contents promote vegetal growth (NBSS & LUP, 2004).

Land use / land cover pattern of Dikrong river catchment is dominated by forest (75% areas are under dense and open forests) in the upper parts and agricultural and abandoned land (12% of total area) in the lower parts of the catchment (Fig.-4). Soils are fine loamy and coarse silty which have high faction of sand helping in retaining more water to regulate runoff. As a result, runoff has also been recorded in the dry weather of winter seasons in spite of less rainfall and moderate PET conditions (Al Huda and Singh, 2014).



Abbreviations: Elevation in meters **1**.0 – 200 **2**. 200 - 400 **3**. 400 - 600 **4**. 600 - 800 **5**. 800 – 1,000 **6**. 1,000 – 1,200 **7**. 1,200 – 1,400 **8**. 1,400 – 1,600 **9**. 1,600 – 1,800 **10**. 1,800 – 2,000 **11**. 2,000 – 2,200 **12**. 2,200 – 2,400 **13**. 2,400 – 2,600 **14**. Above 2,600

Fig. 2: Digital Elevation Model (DEM) of Dikrong River Catchment



Abbreviations: Slope in percent; **1**= Very Gentle (2- 4), **2**= Gentle (4-10), **3**= Moderate (10-20), **4**= Moderately Steep (20-35), **5**= Steep (35-60), **6**= Very Steep (60-100), **7**= Most Steep (100-175), **8**= Extremely Steep (above 175).

Fig-3: Slope Variations in the Dikrong River Catchment

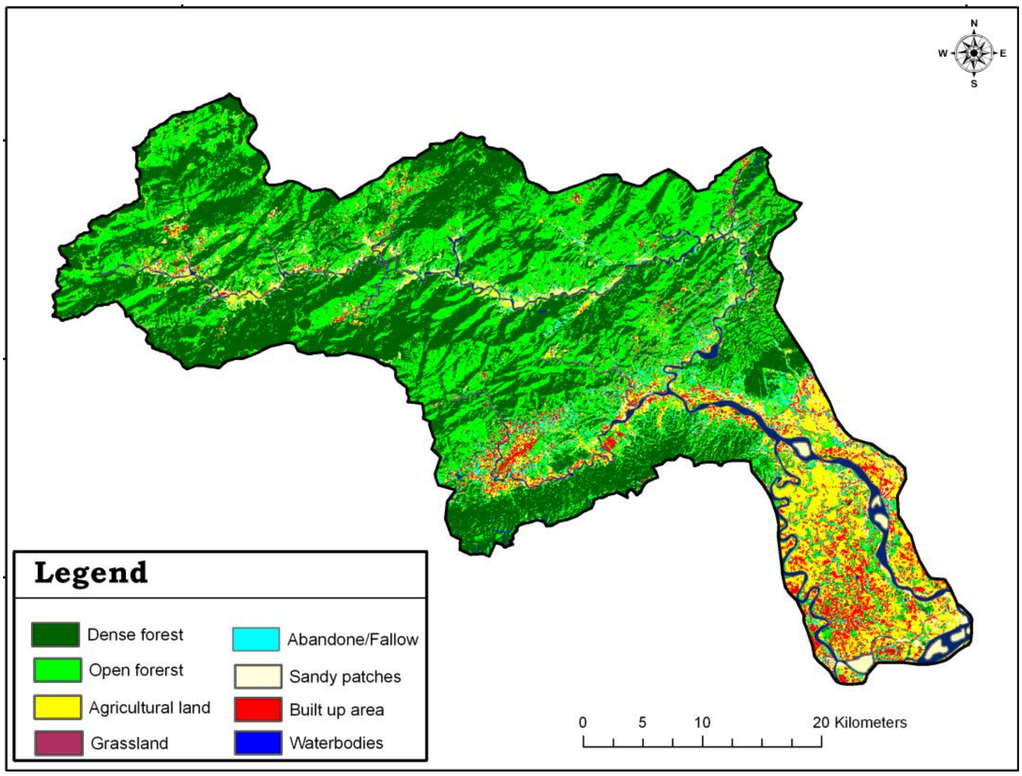


Fig.-4: Land use/Land Cover Pattern (2006)

Methods and Material Used:

The SCS-CN (Soil Conservation Service- Curve Number) has developed the widely used method (SCS-CN, 1972) for estimation of runoff based on the land use/land cover of the watershed. With the help of this SCS-CN method, runoff components were assessed for Dikrong River Catchment.

The following procedure was adapted to SCS-CN method.

(i) Choice of CN based on given combination of land use and hydrologic soil conditions for prevailing Antecedent Moisture Conditions (AMCs), as Initial Abstraction (Ia) equals to 0.2 time of potential saturation (S) for AMC-II (normal conditions), otherwise assign weight (Wi) for AMC-I and AMC-III given in Table- 1 and 2.

(ii) Calculate weighted CN by assigning area as weighted for different land use/ land cover category

(Wi*CNi) i= 1, 2, 3,….., n … (1)

(iii) Add all weighted CNs to get one figure for whole watershed that is ∑(Wi*CNi)

(iv) Calculate effective available soil moisture within the soil profile, Se using SCS-CN formula

Se= (25400/CN)-254 … (2)

(v) Calculate the predicted direct runoff (RO in mm) using the SCS-CN formula

$Qp= \{(P-.2Se)^2/(P+.8Se)\}$ … (3)

It is suitable for US conditions. For Indian conditions while Ia=.3Se by Dhruvanarayan (cf. Das, 2009), the above rainfall-runoff equation may be written as

$Qp= \{(P-.3Se)^2/(P+.7Se)\}$ … (4)

Table-1: Runoff Curve Numbers for Land use Categories by its Hydrologic Soil Groups

Land use/Land Cover Description	Hydrologic Soil Groups			
	A	B	C	D
Cultivated land (Fallow, Row crops, small Grains) (i) Without conservation treatment (ii) With conservation treatment	 72 62	 81 71	 88 78	 91 81
Grassland and pastures (i) Poor conditions (ii) Good conditions	 68 39	 79 62	 86 74	 89 80
Jhum (good conditions)	30	58	71	78

Wood or forest land (i) Poor cover (ii) Dense cover	 45 25	 66 55	 77 70	 83 77
Plantation	30	55	65	75
Roads, settlement, dirt and hard surface	74	84	90	92

NB: Soil Groups refer to A= deep sandy, aggregated silts highly porous, B=Sandy loam with porous condition, C= Clay loam, shallow loam with less porous and D=Soils that swell significantly when wet, heavy plastic clays, shallow hard surface

Table-2: Conversion of CN from AMC II to AMC I and AMC III

CN at AMC II	Factor to CN at AMC II to	
	AMC I	AMC III
10	0.40	2.22
20	0.45	1.85
30	0.50	1.67
40	0.55	1.50
50	0.62	1.40
60	0.67	1.30
70	0.73	1.21
80	0.79	1.14
90	0.87	1.07
100	1.00	1.00

Sources: USDA-SCS (1972), Chow et al. (1988), Das (2009) and Singh and Syiemlieh (2010)

There are various methods for determination of error term of runoff distribution. The following three procedures were adapted to test the validity of SCS-CN method for the present study:
(a) Nash and Sutcliff (1970), $E=1-\sum(Q_0-Q_p)^2/\sum(Q_o-Q_{o\ mean})^2$
Very Good (0.75-1.0), Good (0.5-0.74), Fair (0.25-0.49), Poor (0-0.24), Unsatisfactory (<0.0)

(b) Root Mean Square Error method, $RMSE= \sqrt{\sum(Q_o-Q_p)^2/N}$, 0 is perfect fit, values half the standard deviation considered low

(c) Root Square Root Method, $RSR= \sqrt{\sum(Q_o-Q_p)^2}/ \sqrt{\sum(Q_o-Q_{o\ mean})^2}$
Very Good (0.00-0.50), Good (0.51-0.60), Satisfactory (0.61-0.70), Unsatisfactory (>0.70)

In order to make data standard, the daily statistics of rainfall of four consecutive years (2004-2006) were used for Itanagar station (that is centrally located in the study area). The concerned statistics were collected from the Rural Works Department, Government of Arunachal Pradesh, Itanagar. While daily discharge statistics of the same period of time were collected from the Water Resource Department, Government of Assam, Guwahati for Sisapather gauge station (that is at the mouth of river catchment). The four extreme hydrological events of different seasons (pre monsoon, monsoon and post-monsoon) were selected for the testing the validity of SCS-CN method in Dikrong river catchment.

The slope map was prepared by digitizing the contour map (using Survey of India topographical sheets of R.F. 1:50,000) and using Digital Elevation Model (DEM) technique in putting digitized map into GIS environment with its spatial resolution of 30m*30m. Moreover, the land use/ land cover statistics were generated from the satellite imagery (IRS-LISS-III).

II. RESULTS AND DISCUSSION:

The present analysis is based on extreme rainfall events of different season as chosen for the four years (2003-2006) for Dikrong river catchment. The weights were assigning as per the AMCs of soils for the river catchment. The CN III AMC were assigned to make calculation of Weighted Curve Number (WCN) for each land use/land cover categories, because the experiments were conducted during extreme rainfall time (monsoon season) for the river catchment (Table-3). After summing up WCN for each land use/land cover categories and using equation-2, the values of available soil moisture retention (S_e) had been calculated for the Dikrong river catchment. The important inferences from the analysis are as follows:

Table-3 depicts that more than 75% of the river catchment area under the forest cover. The high value of ∑WCN reaching upto 84.65 shows the absorption of rainfall (Se) of about 46.03 mm in the soil in Dikrong river catchment.

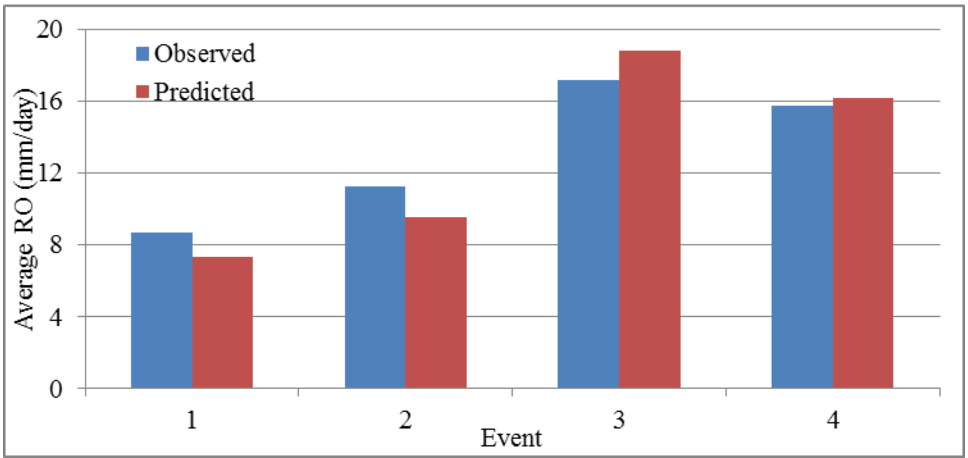
Table-3: Values of Weighted Curve Numbers (WCN) as per their Different Land use/Land Cover

Land use/Land cover	**Area (in ha)**	**Value CN II**	**Conversion Factor III**	**Value CN III**	**WCN**
Dense Forests	64396.80	66	1.25	82.50	34.14
Open Forests	54371.80	66	1.25	82.50	28.82
Agricultural Land	13391.90	92	0.94	86.48	7.44
Grass Land	2840.68	79	1.13	89.27	1.63
Abandoned Land	10793.70	86	1.1	94.60	6.56
Sandy Patches	1156.42	89	1.08	96.12	0.71
Build up Area	6335.63	84	1.13	94.92	3.86
Water Bodies	2338.79	95	1.04	98.80	1.48
			Weighted CN		84.65707
			S_e		46.03399

The per day predicted runoff depth was calculated high during 14-days duration event (4-17 June 2006) with 18.77 mm/day of runoff while minimum was calculated in 9-days duration event (9-17 April 2004) with 7.34 mm/day (Fig.-5 and Table-4).

Table-4: Comparison of Event wise Total Observed (O) and Predicted (P) Runoff of SCS-CN Method

Event	**Duration**	**RO Total (mm)**		**RO Per Day (mm)**	
		Observed	**Predicted**	**Observed**	**Predicted**
9-17th April 2004	9	78.12	66.03	8.68	7.34
24th June-14th July 2003	21	235.91	200.32	11.23	9.54
4-17th June 2006	14	240.27	262.81	17.16	18.77
6-12 October 2004	6	94.33	96.82	15.72	16.14



1=9-17th April 2004 **2**=24th June-14th July 2003 **3**=4-17th June 2006 **4**=6-12 October 2004

Fig.-5: Event wise per day Average Observed and Predicted Runoff

This method predicts even-based depth of runoff. However, it is applied here by using day as a unit of time duration of hydraulic events of high rainfall. The 9-days duration event in the pre-monsoon season (9-17 April 2004) predicts about 66.03 mm of runoff depth (Qp) while the observed runoff (Qo) was calculated 78.12 mm (Fig.-6 A). For 21-days rainfall duration event, starting from 24th June to 14th July 2003, predicts runoff depth (Q_p) of about 200.32 mm while observed runoff (Q_o) was calculated 235.91 mm (Fig.-6 B). The total predicted and observed runoff depth was calculated 174.90 mm and 240.27 mm respectively for 14-days duration of rainfall event in 2006 (4th June to 17 June). The average runoff depth was calculated 12.49 mm/day for predicted runoff and on the other hand, it is calculated 18.77 mm/day for observed runoff of this event (Fig.6

C). The 6-days duration event in the post-monsoon season (6-14 October 2004) predicts of about 96.82 mm of runoff depth (Qp) while the observed runoff (Qo) was calculated 94.33 mm (Fig.-6 D). There are cases of over estimation of runoff usually at higher rainfall intensities and vice-versa.

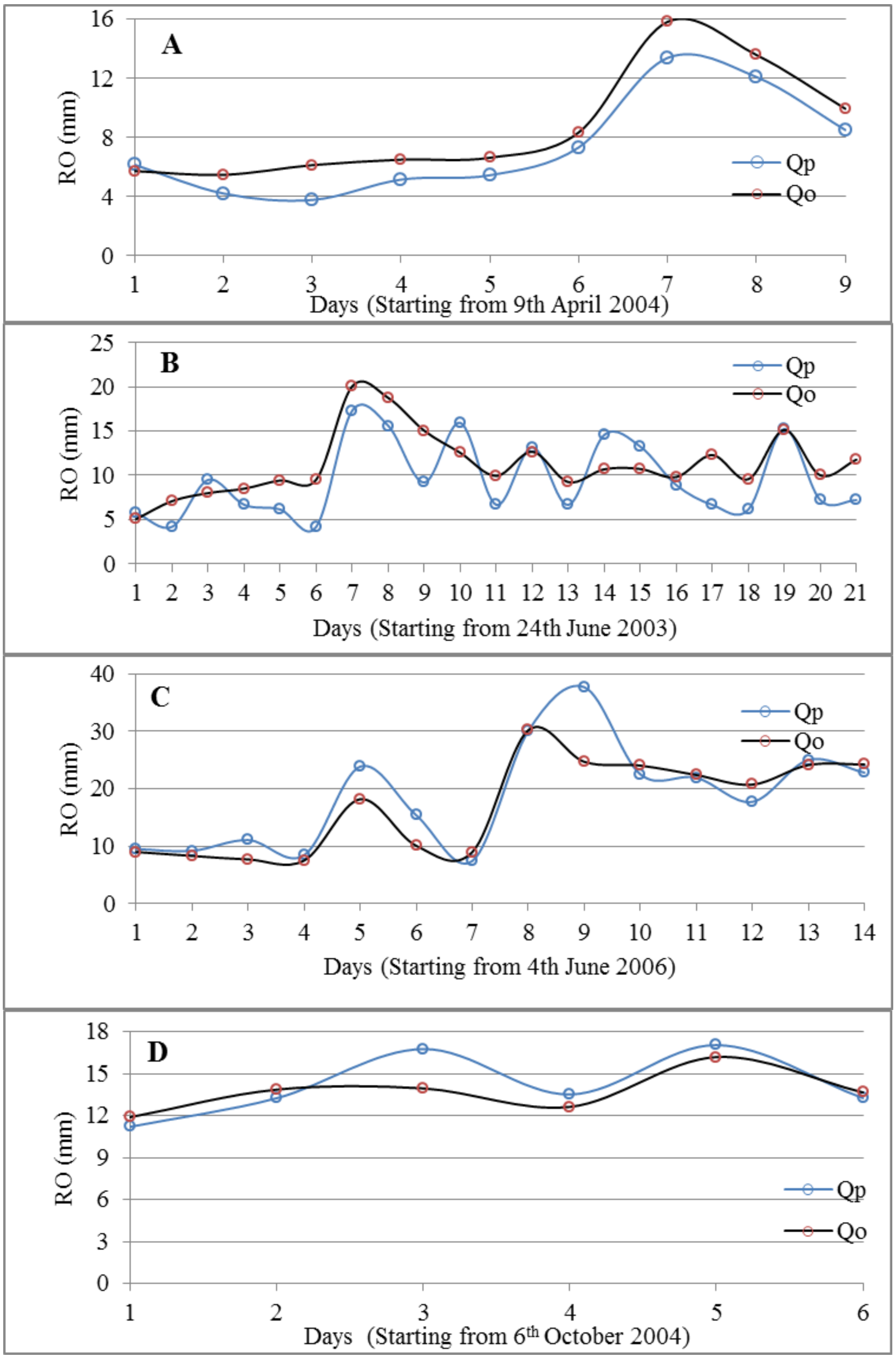


Fig.-6: Comparison of Predicted and Observed Runoff through SCS-CN method **A.** 9-17 April 2004 **B.** 24 June-14 July 2003 **C.** 4-17 June 2006 and **D.** 6-12 October 2004

Performance of SCS-CN Method:

Validity testing was pursued to analyze the results of different events. It is found that the Nash and Sutcliff (E) method and RSR method was more suitable for 9-days (9-17 April 2004) duration event when the R^2 was calculated 0.954 with r=0.976. There is no strong relationship between observed and predicted runoff for 21-days (24th June-14th July 2003) duration event because all the three testing methods shows very poor results with R^2 0.547 and r=0.739. Nash and Sutcliff and RSR methods found good with R^2= 0.792 and r=0.890 fort the 14 days-duration events of 4-17 June 2006 while relationships between predicted and observed runoff for 6 days duration events (6-12 October 2004) of post-monsoon season are very poor (Fig.-7 and Table-5).

Table-5: Performance of SCS-CN methods for Different Events in Dikrong River Catchment

Events	Nash and Sutcliff		Root Mean Square Error		Root Square Root	
	E		RMSE		RSR	
9-17 April 2004 (Pre-monsoon)	0.8	Very Good	1.56	Good	0.44	very good
24 June-14 July 2003 (Monsoon)	0.12	Poor	3.29	Low	0.94	Unsatisfactory
4-17 June 2006 (Monsoon)	0.7	Good	4.31	Low	0.55	Good
6-12 Oct 2004 (Post-monsoon)	0.16	Poor	1.23	low	0.92	Unsatisfactory

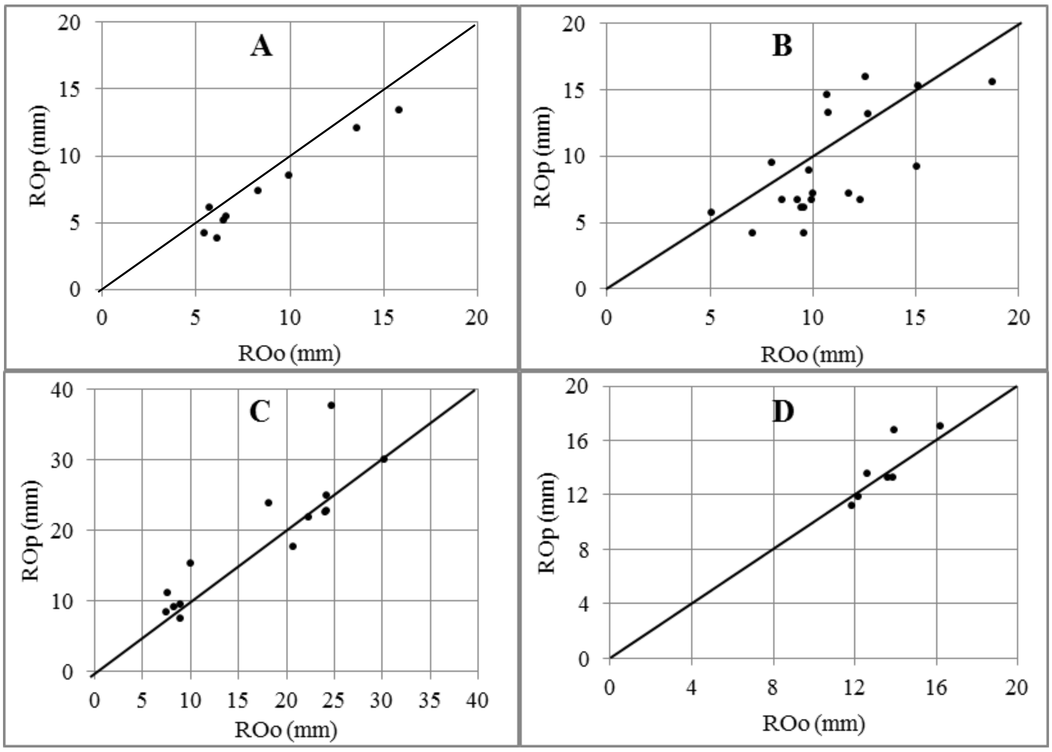


Fig.-7: Scatterness between Predicted and Observed Runoff **A.** 9-17 April 2004 **B.** 24 June-14 July 2003 **C.** 4-17 June 2006 and **D.** 6-12 October 2004

III. CONCLUSION

In the specific high humid conditions of landforms in the foot-hills of Arunachal Himalayas, where temperature varies from 10^0-35^0C during the hydrologic regime of monsoon climate, there are some general conclusions regarding the trend of daily RO. Daily RO is not so smooth in this region as it happens in the sub-tropical region of the world. Dry winters have one-third discharge conditions in the river catchments when rainfall was recorded very low. On the other hand, the amount of RO is concentrated during the monsoon season when more that 80% rain is precipitated. There are some specific findings inferred from the present analysis:

(i) Rainfall intensities play an important role to estimation of runoff through the SCS-CN method. There are cases of over estimation of runoff usually at higher rainfall intensities and vice-versa.

(ii) Due to fully saturation of soil, this method predicts more runoff when the rainfall intensity is high.

(iii) SCS-CN method is based on land use/land cover pattern and different hydrological soil group. Dense and open forests cover more than 70% area in the Dikrong river catchment which is located mostly in the upper parts of hilly topography. Because of land use/land cover pattern, the soils retain more water throughout the year and release runoff even when there is no infiltration.

(iv) The runoff prediction through the SCS-CN method is basically dependent on absorption of water in the soil (Se). Therefore, when rain is equal to 30% share of effective available soil storage (P-.3Se) =0, then Q=0. This method under estimate the runoff when rainfall intensity becomes low and over estimates when the intensity goes much high on rainfall scale for the Dikrong river basin in extreme condition of rainfall especially in the monsoon season.
(v) The predicted runoff depth was high during the monsoon events and very low in pre-monsoon period as only 7.34 mm/day in April 2004 (Fig.-6.600 and Table 6.100).
(vi) Performance of this method is satisfactory for pre-monsoon and monsoon period events. Al these performance tests given good performance of the CN method.

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