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Comparative assessment of curve numbers based on land cover land use changes and rainfall-runoff data in remote sensing and GIS environment

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ABSTRACT

The curve number (CN) may be a key factor in calculation of runoff in the SCS-CN (Soil Conservation Service) based hydrologic methodology. The calculation of curve number is incredibly tiresome and time consuming in hydrologic modelling. In present study, the curve numbers based on land cover land use changes (CN_{LU}) and rainfall-runoff data (CN_{PQ}) were calculated to analyse the impact on runoff generation. The spatial and temporal changes in land use and land cover significantly affected the surface runoff potential from a watershed. The CN_{LU} distribution maps depicted gradual increase in CN values from 2006 to 2008 and from 2008 to 2011. Notably, the gradual variation in CN values in numerous polygon was due to change in LCLU considering the rainfall availability within the catchment. Three paired data sets of CN_{LU} and CN_{PQ} values for the year 2006, 2008 and 2011 were validated though their closeness with the line of perfect fit. CN_{LU} values had close association with the observed CN_{PQ}. Additionally, the comparison of computed CN_{LU} and observed CN_{PQ} also validated the derived land use land cover classification from satellite imageries for the year 2006, 2008 and 2011. It had been observed that paired data sets of observed and computed by distributed values had closeness with line of perfect fit. It's concluded that the SCS model under distributed dynamic annual CN_{LU} will be used to predict direct runoff potential in ungagged watersheds. The Nash coefficient of efficiency (CE) in percentage calculated for the developed distributed model with respect to yearly runoff yielded 89.46 per cent within the range of 80-90% and hence it had been found a reasonably good model.

1. Introduction

Runoff is one among the foremost important hydrological variables utilized in most of the water resources applications. The Soil Conservation Service Curve Number (SCS-CN) method (SCS, 1956, 1964, 1971, 1993, USDA, 1986), now renamed as Natural Resource Conservation Service (NRCS)-CN method, which is widely accepted and popular in literature (Schulze *et al.* 1992; Ponce and Hawkins, 1996; Mishra and Singh, 2003; and Mishra *et al.*, 2005, 2008), owing to its simplicity, accessibility of use and competency of incorporating several major runoff producing watershed characteristics like, soil type, land use, land treatment, surface condition, and antecedent moisture condition (AMC). The CN is an index based on physical parameters of the watershed. It is often applied to gauge as well as ungauged watersheds. This method is capable to reflect the effect of changes in land use on runoff. The CN is derived from a combination of land use and soil runoff potential (hydrologic soil group). The CN values range between zero and 100. A value of 100 indicates that entire rainfall is transformed into runoff (no abstractions), while for CN equal to zero, no direct runoff is generated. Rainfall generated runoff in a watershed is a crucial input in

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design of hydraulic structures and erosion control measures. On long run basis, change in runoff volume with respect to time, indicates dynamic changes occurring in a watershed. Improper land use planning and poor land management practices adversely affect surface runoff in terms of quantities and quality through the reduction of land use and land cover (LULC) and intensification in imperviousness of surface areas. Urbanization, deforestation, changes in agricultural practices, open grazing, etc. are a part of LULC change. Thus, a hydrologic model that uses LULC as input is beneficial to quantify the effect of LULC changes on runoff. Thus in this study, curve number(CN) and the runoff potential in SCS-CN based hydrologic modelling were calculated by considering the dynamic changes in LULC and available rainfall-runoff observations of the Panam catchment to judge the effects of LULC changes on the rate of runoff generation, estimation and modelling.

2. Description Of Study Area

The area selected for present study was Panam reservoir catchment, the sub basin of Mahi Lower basin. The Panam is left bank tributary of Mahi river. Panam river rises near Bhadra on the northern slopes of Vindhyas near Jhabua district of Madhya Pradesh at an elevation of about 300 m above M.S.L. The study area (Panam catchment) is situated between 73.3^0 E to 74.3^0 E and 22.3^0 N to 23.3^0 N in North East part of Gujarat state adjoining to Madhya Pradesh and Rajasthan states. It flows in the north-west direction and joins the main river on its left bank in the Panch Mahals district of Gujarat. It has a total length of about 136 km and drainage area of about 2349.04 Sq km. having an average annual rainfall is 940 mm. The Panam catchment is part of Mahi Lower sub basin as shown in Fig.1.

3. Materials And Methods

3.1 SCS-CN method

Natural Resources Conservation Service (NRCS), USDA developed a unique method referred as Soil Conservation Service Curve Number (SCS-CN) method for assessing direct runoff from storm rainfall in the year 1954. This SCS-CN method calculates the quantity of surface runoff for a given rainfall event from small agricultural, forest, and urban watersheds (SCS, USDA, 1986). The method is easy to use and requires basic inputs for estimation of direct runoff volume (Bonta, 1997).

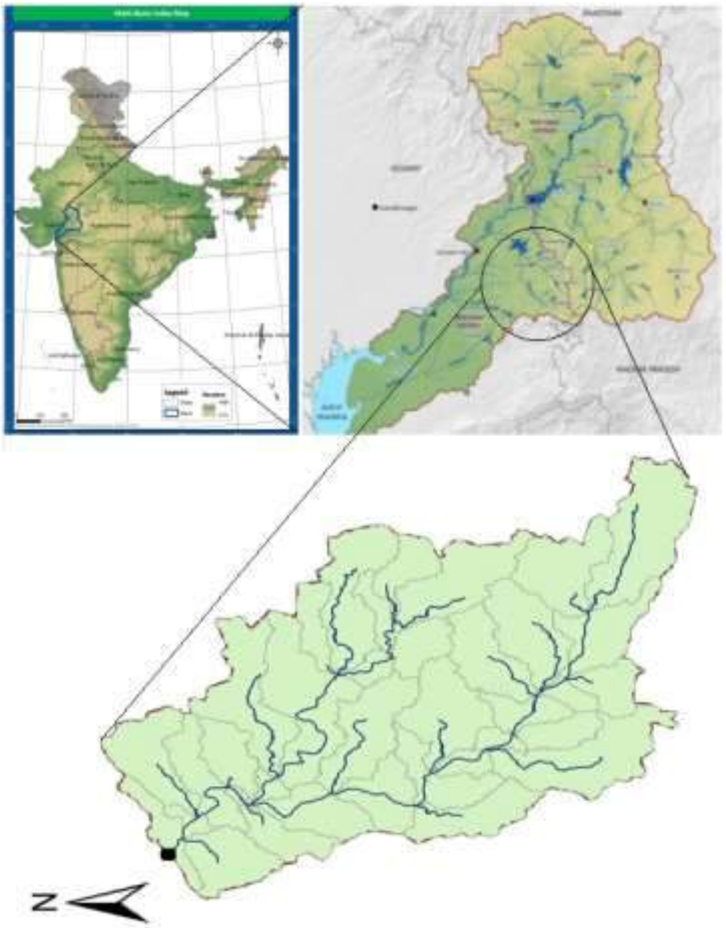

Figure 1. Location map of study area (Panam catchment)

Basically, the SCS-CN method is water balance equation with two fundamental hypotheses. The primary hypothesis equates the ratio of actual amount of direct surface runoff (Q) to the entire rainfall (P) or maximum potential surface runoff to the ratio of actual infiltration (F) to the quantity of the potential maximum retention (S). The second hypothesis relates the initial abstraction (Ia) to S and also described as potential post initial abstraction retention (Mc Cuen, 2002). The second hypothesis is a linear relationship between initial abstraction Ia and potential maximum retention S. In SCS-CN methodology, the expression for Q are often written as

$$Q=\frac{(P-I_a)^2}{P-I_a+S}$$

(Eq. 1)

Eq. (1) is the general form of the popular SCS-CN method and is valid for P ≥ Ia; Q = 0 otherwise. Where, P is total rainfall; Ia is initial abstraction; F is cumulative infiltration excluding Ia; Q is direct runoff; and S is potential maximum retention. In general I is taken as 0.2; the Eq. (1) reduces to;

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

(Eq. 2)

The Eq. 2 is well recognized as popular form of the prevailing SCS-CN method. Thus, the prevailing SCS-CN method with $\lambda = 0.2$ is a one-parameter model for computing surface runoff from daily storm rainfall, having versatile importance, utility and vast in tapped potential. The parameter S of the SCS-CN method depends on soil type, land use, hydrologic condition and antecedent moisture condition (AMC). Analytically, parameter S is obtained from Eq. (2) as (Hawkins, 1993):

$$S = 5(P + 2Q - (4Q^2 + 5PQ)^{0.5}$$

(Eq. 3)

Similarly, the initial abstraction coefficient λ is usually recognized as a regional parameter counting on geologic and climatic factors (Boszany, 1989; Ramasastri and Seth, 1985). The prevailing SCS-CN method assumes λ to be equal to 0.2 for practical applications in Indian conditions. Since the parameter S can vary in the range of $0 \leq S \leq \infty$, it's mapped onto a dimensionless curve number CN, varying in a more appealing range $0 \leq CN \leq 100$, as:

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

(Eq. 4)

Where, S is in the units of mm. a value of CN = 100 represents the condition of zero potential maximum retention (S = 0), that is, an impermeable watershed. Conversely, CN = 0 depicts a potential maximum retention ($S = \infty$), that is an infinitely abstracting watershed. The CN has no intrinsic meaning; it's only a convenient transformation of S to determine a 0-100 scale (Hawkins, 1978).

The daily rainfall database from 1994 to 2013 of the watershed were collected and therefore the curve numbers like different land use and hydrological soil cover complex got as inputs and daily runoff results are obtained. The cumulative runoff from basin outlet was computed. The flow chart utilized in this analysis has shown in Fig. 2.

3.2 Estimation of CN from observed rainfall (P)-runoff (Q) data (CN_{PQ})

The observed daily rainfall data for a period of 20 years and corresponding observed daily runoff data were utilized in this analysis. The quantity of events selected in a year depends upon the amount of rainfall and its daily distribution in watershed. An easy line method is adopted for base flow separation. Procedure adopted for CN_{PQ} estimation for P–Q event is outlined here as: (i) estimate base flow using straight line method (ii) estimate direct runoff depth by deducting base flow from total runoff depth (iii) for the selected event, use of direct runoff depth and corresponding rainfall value is calculated by Hawkins formula $S = [P + 2Q-(4Q^2 + 5PQ)^{1/2}]$ to estimate S and (iv) estimate CN_{PQ} for selected event. Same procedure was followed for remainder of the observed P–Q events in each year to estimate event based CN_{PQ}. Finally, for AMCII condition, the median criterion given by Bonta (1997) and Mishra et al., (2005) was applied to get the annual CN_{PQ} values.

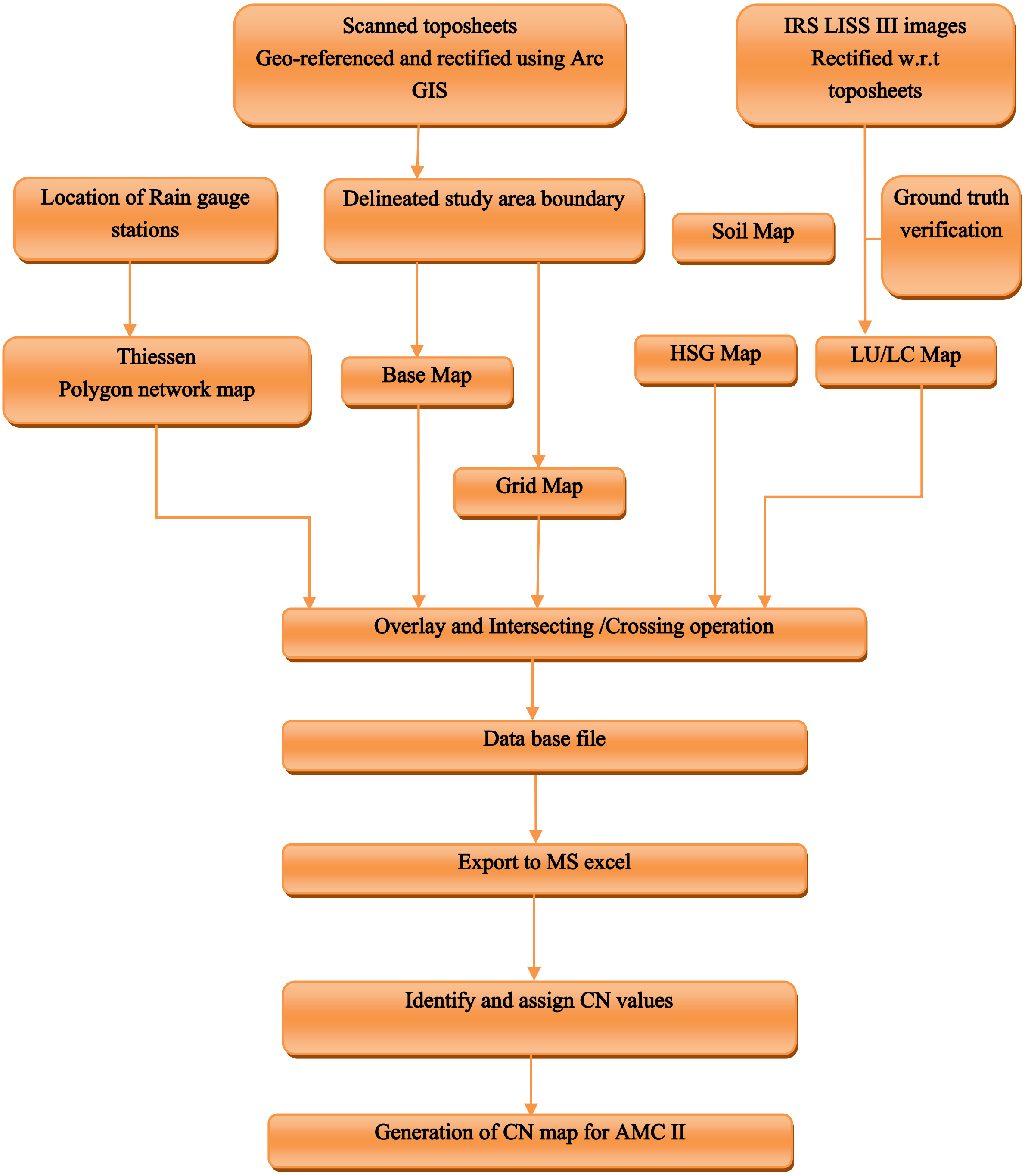

Figure 2. Flow chart showing the methodology for determination of CN map from land use land cover database in AMC II condition

3.3 CN from land use and land cover (LULC) and soil cover

The CN is a dimensionless runoff index based on hydrologic soil group (HSG), land use, land treatment, hydrologic conditions and antecedent moisture condition (AMC) which counts on previous 5 days rainfall total. In present study, land use land cover map of the years has been derived from satellite image by visual interpretation. The classified land use maps showing five major classes like agriculture, forest, waster/barren land, built-up/ settlement and water bodies/river are discussed as given below.

- Agriculture: It included distributed patches of standing crop as well as fallow agriculture land which is brought under cultivation immediately.
- Forest land: It mainly considers fairly dense to dense forest of evergreen and moist deciduous type and it mainly contains teak.
- Waste land /Barren land: Barren land in the study area

mainly defined as land of exposed area which contain small scrubs and very thin tree cover less 1/3 of total area. The very thin covered deforested area also included in this type.

- Built-up /Settlement: The settlement mainly covers large village to urban areas.
- River/Water body: It main includes manmade small water storage structure filled with water.

To identify the soil type and hydrologic soil group (HSG) within the study area, the soil map was prepared using available soil type and location maps obtained from the National Bureau of Soil Survey and Land Use, Nagpur, as shown in Fig. 3. It was observed that about 40 percent study area dominated by Loamy, Mixed type soil and about 50 per cent study area was dominated by fine to fine loamy type soils loamy in texture and blended with the clay content. The depth of the soil is extremely shallow and stony with loam texture on the steep sloping hills and soil is shallow to medium deep clay on medium and gently sloping plateau. Based on the textural and hydraulic properties, the soil was classified into hydrological soil groups as shown in Fig. 4.

4. Results and Discussion

4.1. Land cover and land use analysis in Panam catchment

The thematic map of land use / land cover has been prepared using ERDAS Imagine 9.1. The land use / land cover classes were estimated using Normalized Difference Vegetation Index (NDVI) approach. Satellite imageries pertain to the dates 28-10-2006, 13-10-2008 and 03-11-2011 of *kharif* season were acquired from Bhashkaracharya Institute of Space Application and Geo-informatics (BISAG), Gandhinagar. The land cover and land use has been classified into five classes *viz.,* water bodies, agriculture land, waste land/ barren land, forest and built-up area and presented in Fig.5, Fig.6 and Fig.7. The areal extent under each class has been calculated from the attribute data and land cover and land use classification was prepared year wise for each Thiessen polygon (Fig. 8) as listed in Table 1 to Table 3.

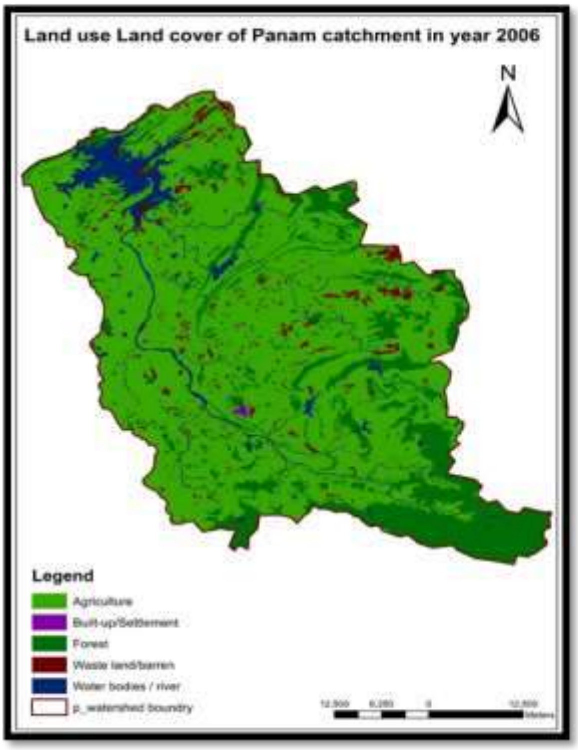

Figure 5. Land cover and land use of Panam catchment in the year 2006

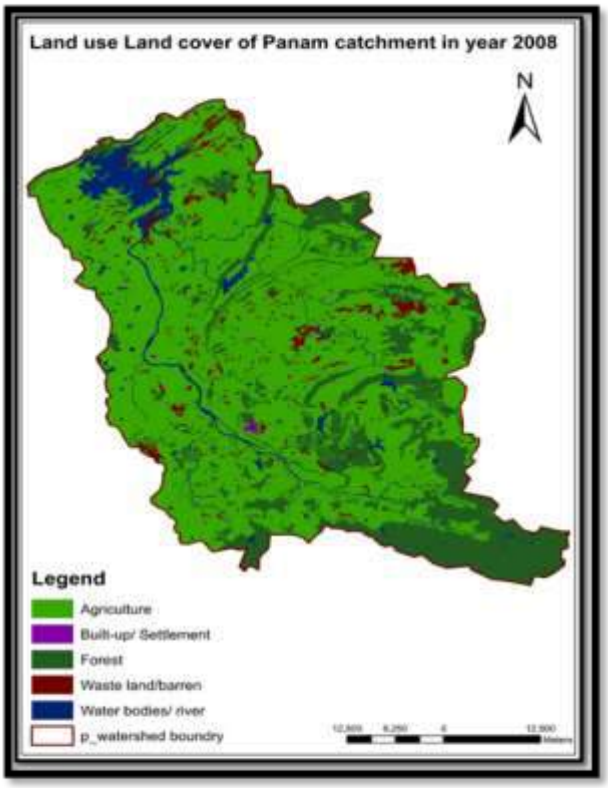

Figure 6. Land cover and land use of Panam catchment in the year 2008

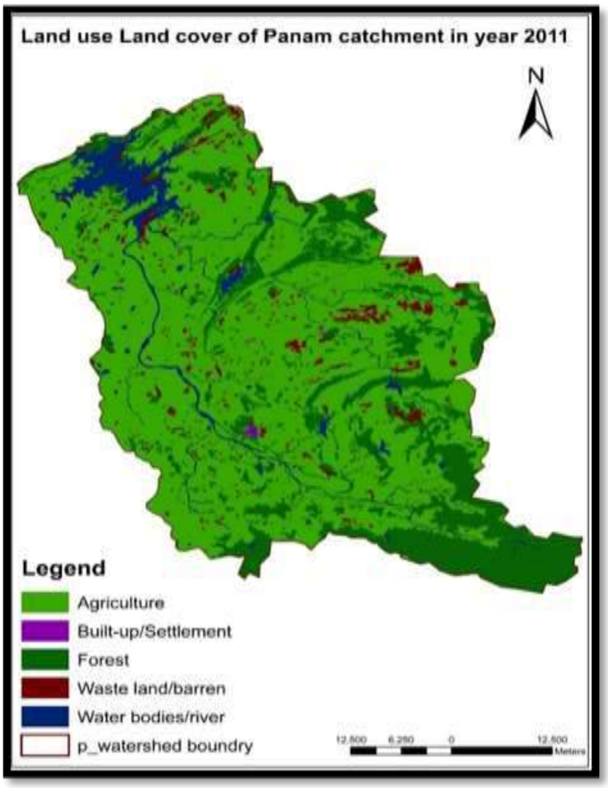

Figure 7. Land cover and land use of Panam catchment for the year 2011

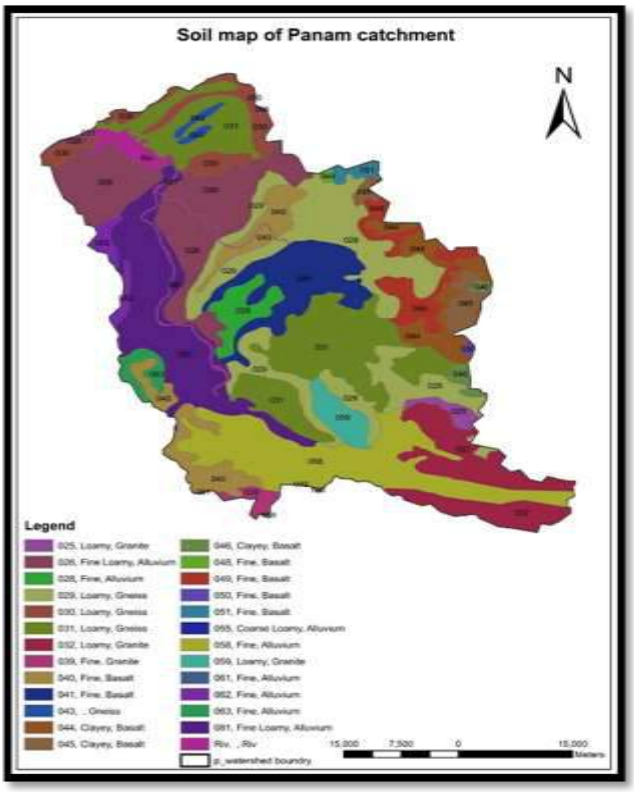

Figure 3. Soil map of Panam catchment

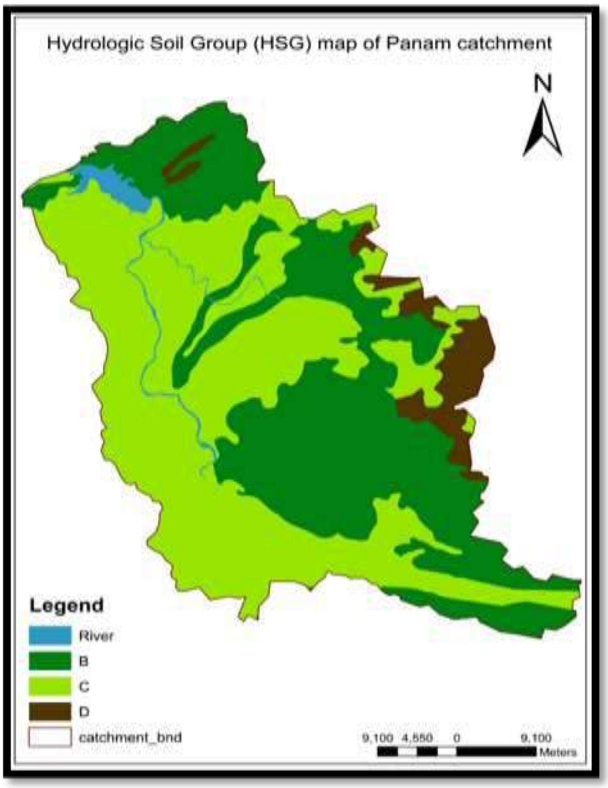

Figure 4. Hydrologic Soil Group (HSG) map of the Panam catchment

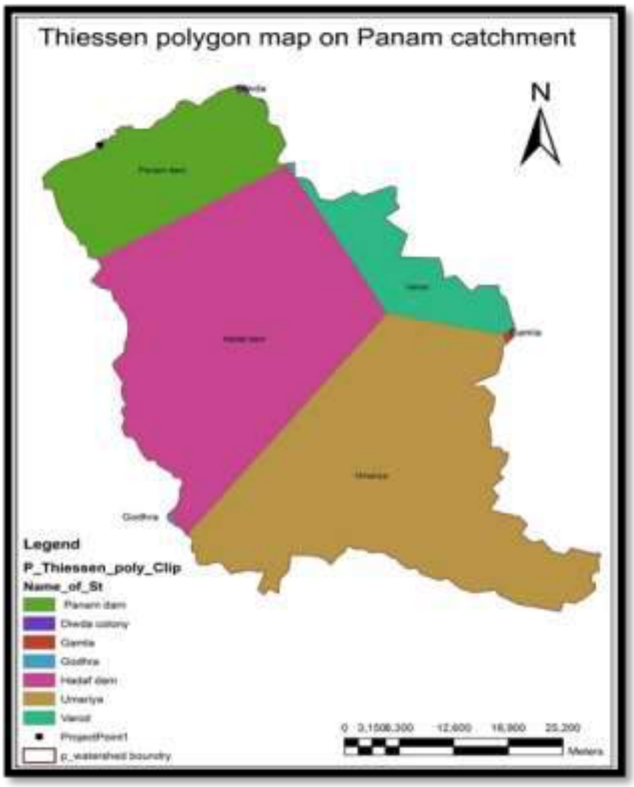

Figure 8. Thiessen polygon map of Panam catchment

Table 1. Land Use / Land Cover details of the Study Area (km^2) Date of pass: 28-10-2006

LU/LC category	Panam dam	Gamla	Varod	Diwda	Hadaf	Umariya	Godhra	Total
Water bodies	72.715	0.000	1.727	0.000	38.128	23.905	0.000	136.475
Agriculture	207.695	0.381	115.392	1.061	762.116	571.225	0.537	1658.407
Waste land/ barren	20.803	0.000	11.376	0.087	26.725	15.572	0.000	74.563
Forest	36.096	0.982	52.720	0.000	60.156	328.928	0.000	478.882
Built-up	0.306	0.000	0.049	0.000	2.581	0.862	0.000	3.798

Table 2. Land Use / Land Cover details of the Study Area (km^2) Date of pass: 13-10-2008

LU/LC category	Panam dam	Gamla	Varod	Diwda	Hadaf	Umariya	Godhra	Total
Water bodies	67.7710	0.0000	1.7260	0.0000	37.7690	23.9120	0.0000	131.1780
Agriculture	211.1070	0.3810	105.1890	1.0570	750.9520	537.7640	0.5410	1606.9910
Waste land/ barren	20.8630	0.0000	12.6720	0.0860	33.0380	16.0250	0.0000	82.6840
Forest	37.8400	0.9820	61.6270	0.0000	65.3600	362.2800	0.0000	528.0890
Built-up	0.3060	0.0000	0.0490	0.0000	2.5810	0.8660	0.0000	3.8020

Table 3. Land Use / Land Cover details of the Study Area (km^2) Date of pass: 03-11-2011

LU/LC category	Panam dam	Gamla	Varod	Diwda	Hadaf	Umariya	Godhra	Total
Water bodies	74.138	0.000	1.711	0.000	38.374	24.165	0.000	138.388
Agriculture	200.564	0.376	106.846	1.057	741.507	556.995	0.528	1607.873
Waste land/ barren	18.342	0.000	11.369	0.086	29.806	20.862	0.000	80.465
Forest	44.289	0.979	61.266	0.000	77.433	337.769	0.000	521.736
Built-up	0.306	0.000	0.050	0.000	2.582	0.866	0.000	3.804

4.2. CN from land use and land cover (LULC) and soil cover (CN_{LU})

It is termed as 'CN_{LU}'. Based on the CN_{LU} values derived from Land Use, Land Cover, Soil type and hydrologic soil group, grid wise spatially distributed CN_{LU} maps were prepared in GIS environment (Arc GIS 9.1.) as per the procedure given in Fig. 2. The collective layers with their assigned CN values were used to generate distributed CN map of three different years 2006, 2008 and 2011 as shown in Fig. 5, Fig. 6 and Fig.7. The weighted CN values for all Thiessen polygons were determined using the formula given as under.

$$CN_{LU} = \frac{\sum (CN_i X A_i)}{A} \qquad \text{(Eq.5)}$$

Where, CN_{LU} is weighted curve number; CN_i is curve number of area i assigned on the basis of land use and land cover and hydrologic soil group conditions; varies from 0 to 100, A_i is area having CN_i and A is total area of watershed. The CN_{LU} values obtained from land use, land cover, soil type and hydrologic soil group, the grid wise spatially distributed CN_{LU} for each Thiessen polygon of different three years 2006, 2008 and 2011 were presented in Table 4.

4.3. Development of CN estimation model for prediction of runoff potential based on LULC change

The conventional methods of runoff measurements aren't easy for inaccessible terrains and not economical for a large number of small watersheds and at a similar time, for ungauged watersheds accurate prediction of runoff requires much efforts and time. Hence, remote sensing and GIS techniques may be utilized successfully to facilitate estimation of watershed parameters like Curve Number to estimate runoff potential using SCS-CN method so as to assess effects of changes in LULC.

Table 4Thiessen polygon wise CN_{LU} for AMC II condition for Panam catchment

Name of Thiessen Polygon	Area in Sq km	CN_{LU} for following years		
		2006	2008	2011
Panam dam	337.19	77.20	77.89	77.81
Gamla	1.36	86.83	86.84	86.84
Varod	181.01	80.79	80.41	80.57
Diwda	1.14	76.32	76.33	76.33
Hadaf	888.70	82.40	82.32	82.29
Umariya	939.10	79.40	79.22	79.24
Godhra	0.54	85.00	85.00	85.00

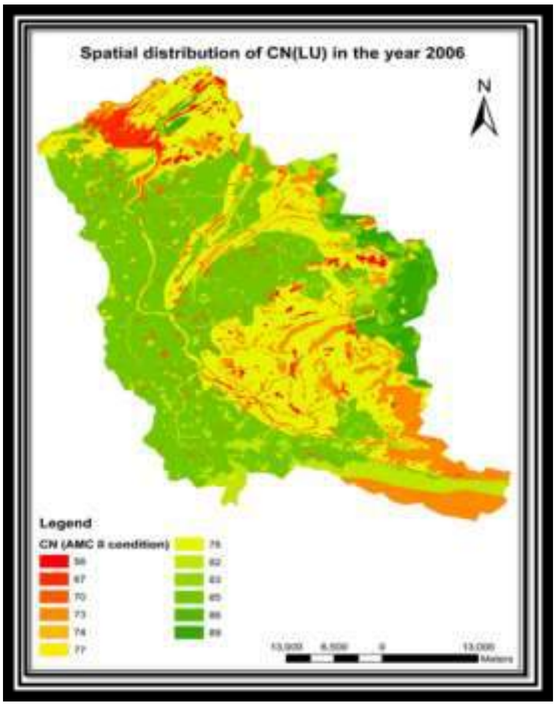

Fig. 9 Spatial distribution of CN_{LU} (runoff potential) in the year 2006

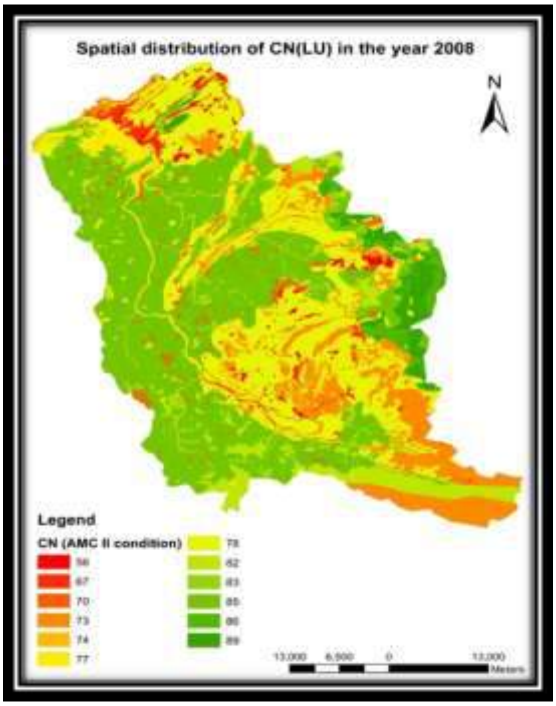

Fig. 10 Spatial distribution of CN_{LU} (runoff potential) in the year 2008

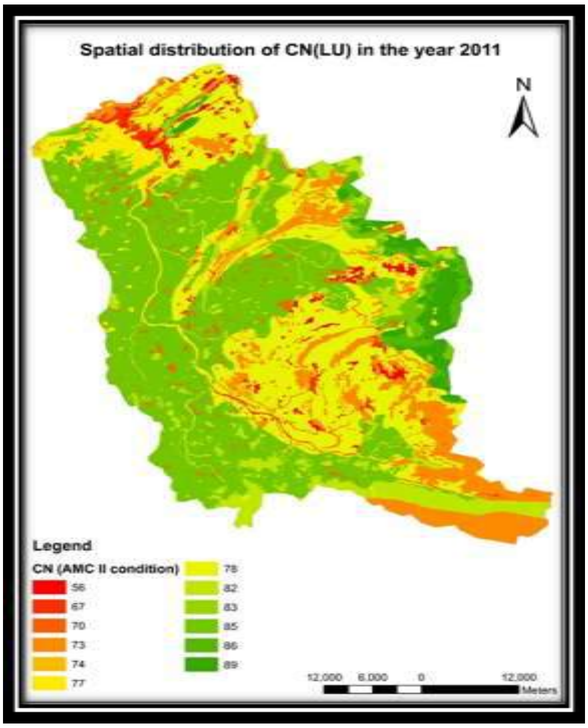

Fig. 11. Spatial distribution of CN_{LU} (runoff potential) in the year 2011

Hence, the computed CN_{LU} values based on LULC and hydrologic soil group were regressed with respect to time 't' (numeric value of years in present case) to develop a simple and unique but versatile model for the different Thiessen polygons of the study area Panam catchment.

For Hadaf Thiessen polygon $CN_{LU} = -0.055(t) + 82.447$, $R^2 = 0.9356$ (Eq.6)
For Diwda Thiessen polygon $CN_{LU} = 0.005(t) + 76.317$, $R^2 = 0.75$ (Eq.7)
For Gamla Thiessen polygon $CN_{LU} = 0.005(t) + 86.827$, $R^2 = 0.75$ (Eq.8)
For PanamThiessen polygon $CN_{LU} = 0.305(t) + 77.023$, $R^2 = 0.65$ (Eq.9)
For UmariyaThiessen polygon $CN_{LU} = -0.08(t) + 79.447$, $R^2 = 0.66$ (Eq.10)
For VarodThiessen polygon $CN_{LU} = -0.11(t) + 80.81$, $R^2 = 0.38$ (Eq.11)
For GodhraThiessen polygon $CN_{LU} = 85$, R^2 = #N/A (Eq.12)

Eq. 6 to Eq. 12 were used to predict CN_{LU} (runoff potential) values for desired span of time to plan effective watershed planning & management approach as illustrated in Fig. 9, Fig. 10and Fig. 11. (CN_{LU} distribution maps) for three different years. These figures depicted gradual changes in CN values from the year 2006 to 2008 and from the year 2008 to 2011.Notably, the gradual variation in CN values in different polygon was because of change in LCLU considering the rainfall availability in the catchment. The changes in CN_{LU} all Thiessen polygons were not remarkable as assessment period from 2006 to 2011 is short up to some extent for agriculturally dominated undisturbed watershed in tribal belt of eastern part of the Gujarat state. Deforestation has led to emergence of barren land along the boundaries of forest and agriculture land and which resulted the increase in CN values. Among seven Thiessen polygons, Gamla Thiessen polygon showed highest CN_{LU} value for AMC II condition, while Diwda Thiessen polygon showed the lowest CN_{LU} for selected years. Consequently, Gamla Thiessen polygon had highest runoff potential under the same magnitude of received rainfall in comparison to other polygons. Further, it can be observed that CN_{LU} values not shown significant variation despite the spatial changes in LULC with time of five years. The agriculture area in all Thiessen polygons had almost became stabilized and further increase is not expected in short span of time as agriculture area has almost replaced previous existed land classes such as bad land area and forest cover area. On the other hand, upper most part of catchment is hilly and terrain, hence, conversion of forest area to agriculture area was at very slow rate. This could be mainly due to inadequate water availability for agriculture. Here, Godhra Thiessen polygon had not exhibited change in LULC as very small area (0.54 sq.km) of catchment was covered under polygon, which belongs to agriculture use.

4.4 Future prediction of CN_{LU} for study watersheds

The developed relationships of CN_{LU} with past years of 2006, 2008 and 2011 (Eq. 6 to Eq. 12) can be used for prediction of CN_{LU} in future, if, the on-going rate of changes in LULC persists in the watersheds. CN_{LU} values for each watershed have been predicted for time period up to 2080 as shown in Table 5.

It is observed from Table 5 that the predicted CN_{LU} values for Hadaf, Umariya and Varod Thiessen polygon has decreased in CN values. This would be due to conversion of agricultural and forest land to barren or waste land. Diwda and Gamla Thiessen polygon has much lower CN increments due to slow rate of agriculture expansion. Panam Thiessen polygon have the adequate scope for further increase in agricultural area by replacing barren land in future which is possible by introducing surface water storage structures and by improving irrigation schemes. Therefore, CN_{LU} prediction for Panam Thiessen polygon may follow the current trend of CN_{LU} values in future year as shown in Table 5. If the predicted trend of CN_{LU} continues, CN_{LU} for Panam will attain the theoretically ultimate values of 100 in future. The value of CN_{LU} = 100 represents completely impermeable state of watershed which is practically not possible. Therefore, possible upper limit of CN_{LU} is 90 to93 which is representative of CN_{LU} of agriculture for hydrological soil group of C and D, respectively. This situation expected to be reached between around year 2060 to 2080.

4.5 Estimation of CN from observed rainfall (P)-runoff (Q) data (CN_{PQ})

Procedure adopted for CN_{PQ} estimation for P–Q event occurring from 12th to 19th July, 2000 (Fig.12) is outlined here as: (i) estimate base flow using straight line method (=0.50 mm); (ii) estimate direct runoff depth by deducting base flow from total runoff depth. For the selected event, direct runoff depth = 97.3 mm and corresponding rainfall = 163.86 mm; (iii) use Hawkins formula to estimate S = 77.75 mm; and (iv) estimate CN_{PQ} for selected event; CN_{PQ} = 76.56. Same procedure was followed for rest of the observed P–Q events in each year to estimate event based CN_{PQ}. Finally, for AMCII condition, the median value criteria given by Bonta (1997) and Mishra *et al.* (2005) was applied to get the annual CN_{PQ} values as shown in Fig 13.

4.6 Relative performance of the proposed CN_{LU} and CN_{PQ} estimation models for runoff simulation

CN_{LU} values derived from LULC and hydrologic soil group were compared with observed CN_{PQ} for the study area Panam catchment. The agreement between CN_{LU} and CN_{PQ} is depicted in Fig. 14. From the Fig.14, it may be concluded that CN_{LU} values had close association with the observed CN_{PQ}. Additionally, the comparison of computed CN_{LU} and observed CN_{PQ} also validated the derived land use land

Table 5. Predicted CN_{LU} values using versatile CN regression models

Name of Thiessen Polygon	Predicted CN_{LU} for following selected future years			
	2020	2040	2060	2080
Panam	79.77	85.87	91.97	98.07
Gamla	86.87	86.97	87.07	87.17
Varod	79.82	77.62	75.42	73.22
Diwda	76.36	76.46	76.56	76.66
Hadaf	81.95	80.85	79.75	78.65
Umariya	78.73	77.13	75.53	73.93
Godhra	-	-	-	-

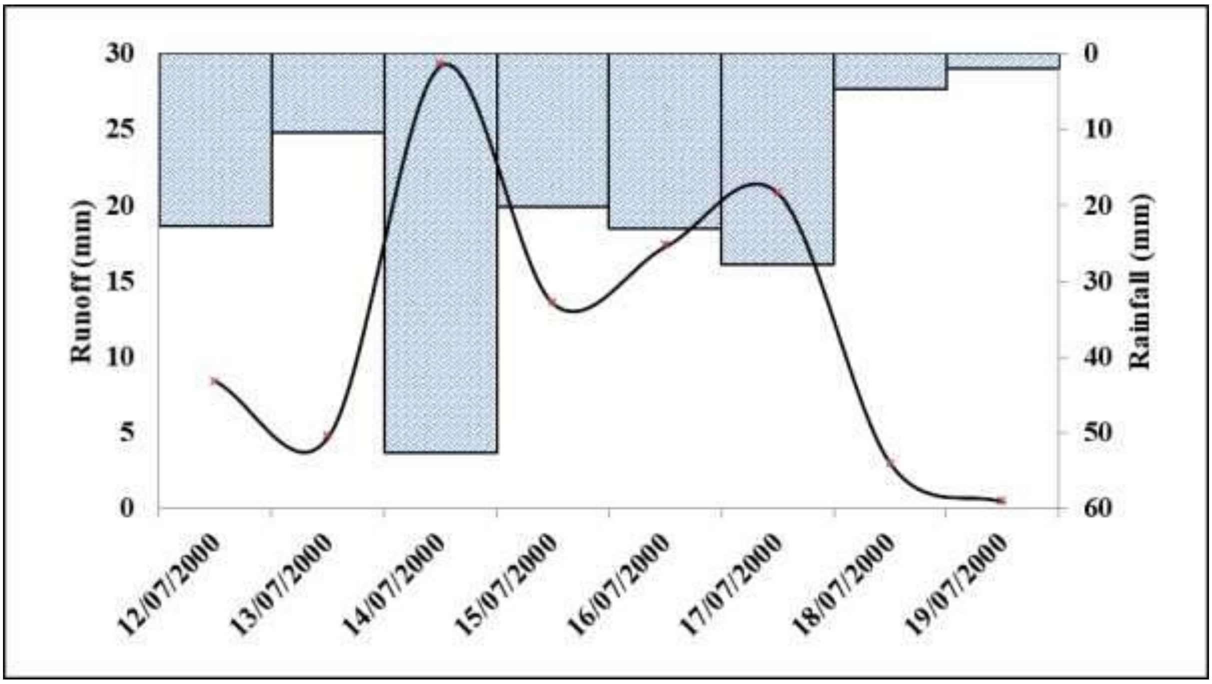

Fig 12. Base flow separation procedure for the P-Q event, year 2000

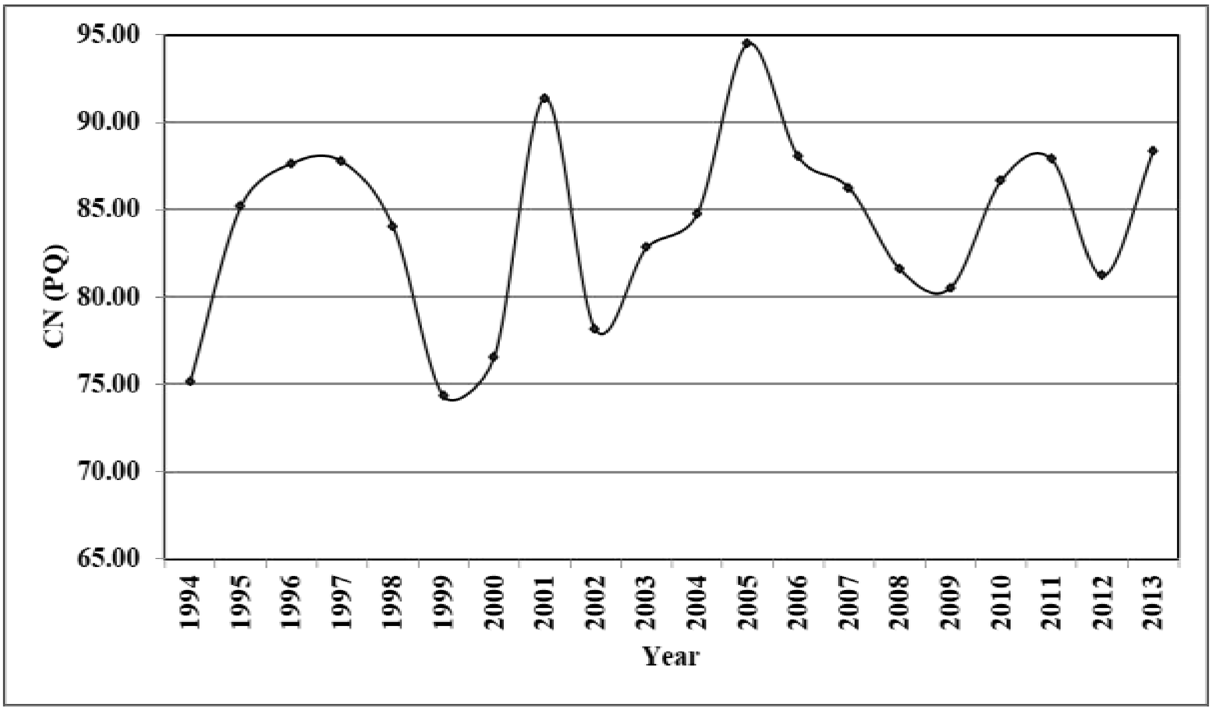

Fig 13. Annual CN_{PQ} values of AMC II condition for the Panam catchment

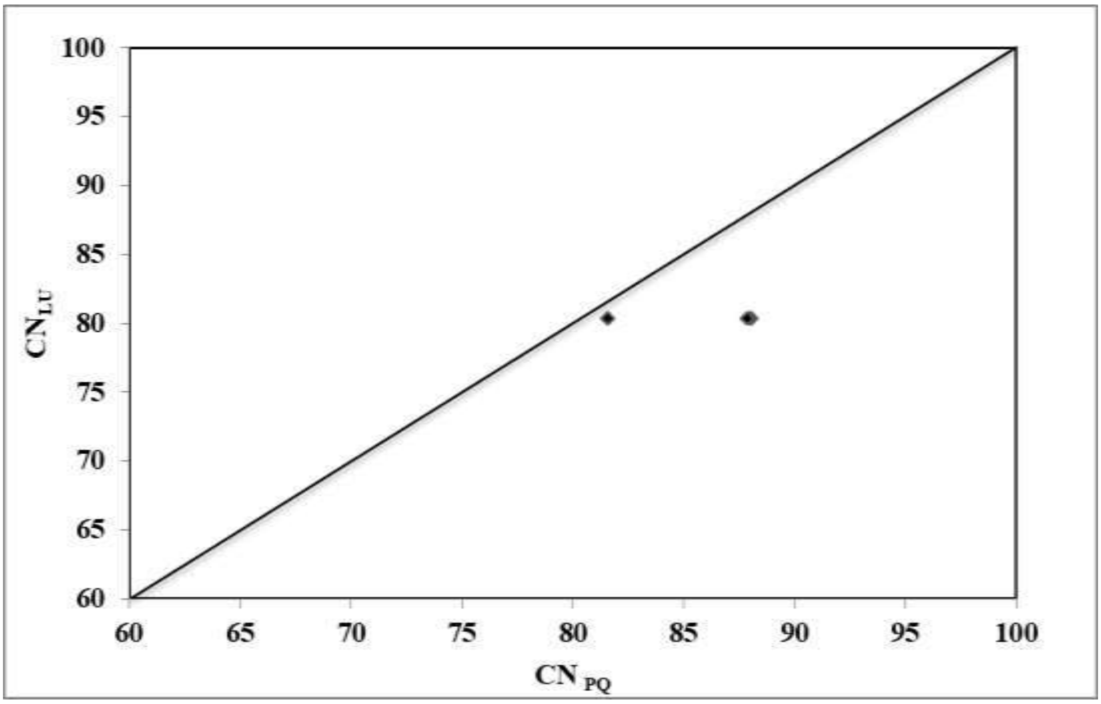

Fig 14. Comparison of CN_{LU} and CN_{PQ} for the Panam catchment

cover classification from satellite imageries for the year 2006, 2008 and 2011.

The CN_{LU} estimated for the Panam catchment from the proposed Versatile CN Regression model were used for the computation of runoff using existing SCS-CN method. The agreement between computed and observed runoff values for Panam catchment is shown in Fig. 15.It was observed that paired data sets of observed and computed values have closeness with line of perfect fit.

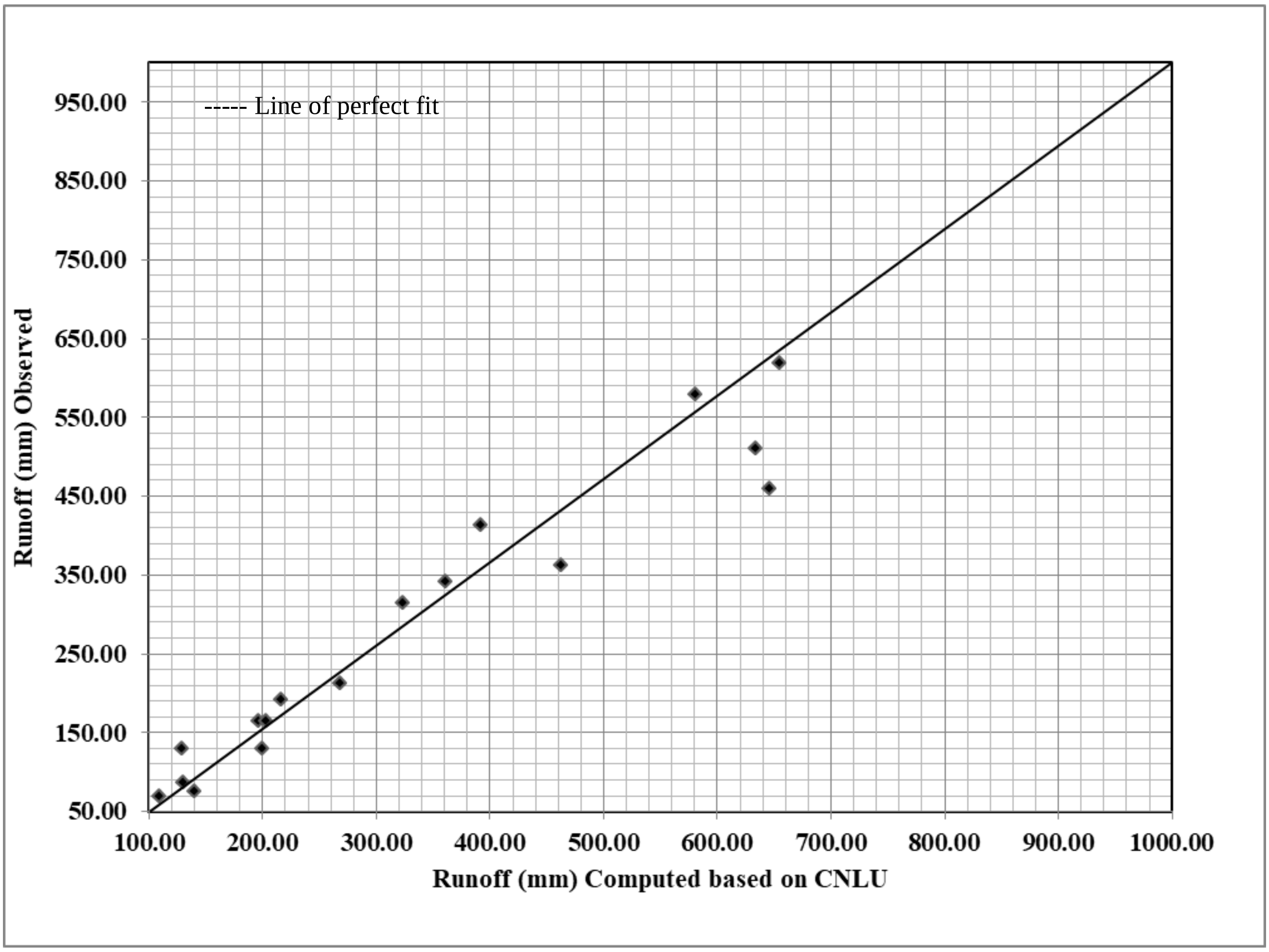

Fig 15. Comparison of observed and computed runoff based on CN_{LU} for the Panam catchment

5. Conclusion

1. The temporal and spatial variation in land use and land cover significantly affects the surface runoff potential from a watershed. Such changes in runoff potential will have influence on sustainable utilization of water resource for the watershed development and management.
2. The developed relationship of CN_{LU} with historical year can be used for prediction of CN_{LU} in future if the on-going changes persist in the watersheds.
3. The CN_{LU} distribution maps depicted gradual changes in CN values from the year 2006 to 2008 and from the year 2008 to 2011. Notably, the gradual variation in CN values in different polygon was because of changes in LCLU considering the rainfall availability in the catchment.
4. Deforestation has led to emergence of barren land along the boundaries of forest and agriculture land which resulted the increases in CN values in some part of the Panam catchment.
5. Among seven Thiessen polygons, Gamla Thiessen polygon showed highest CN_{LU} value for AMC II
6. condition, while Diwda Thiessen polygon showed the lowest CN_{LU} for selected years. Consequently, Gamla Thiessen polygon had highest runoff potential under the same magnitude of received rainfall in comparison to other polygons.
7. Three paired data sets of CN_{LU} and CN_{PQ} values for the year 2006, 2008 and 2011 were validated though their closeness with the line of perfect fit. The CN_{LU} values had close association with the observed CN_{PQ}. In addition, the comparison of computed CN_{LU} and observed CN_{PQ} also validated the derived land use land cover classification from satellite imageries for the year 2006, 2008 and 2011.
8. Model performance was again checked by plotting computed and observed direct runoff values with the line of perfect fit. It is observed that paired data sets of observed and computed by distributed values have closeness with line of perfect fit. It is concluded that the SCS model under distributed dynamic annual CN_{LU} can be used to predict direct runoff potential in ungauged watersheds.

6. References

ArcGIS, (2004). “GIS software, version 9.0” Environmental Systems Research Institute (ESRI), New York.

Arnold, J. G., Williams, J. R., Srinivasan, R., and King, K. W. (1996). *SWAT: Soil and Water Assessment Tool.* Temple: Grassland, Soil & Water Research Laboratory, U. S. Department of Agriculture.

Beighley, R.E. and Moglen, G.E., 2002. Trend assessment in rainfall-runoff behavior in urbanizing watersheds. *Journal of Hydrologic Engineering*, *7*(1), pp.27-34.

Bonta, J. V.,(1997). Determination of watershed curve number using derived distributions. *Journal of Irrigation and Drainage Engineering*, 123(1):28-36. *[doi:10.1061/(ASCE)0733-9437(1997)123:1(28)].*

Boszany, M.,(1989). Generalization of SCS curve number method. *Journal of Irrigation and Drainage Division*, ASCE, Vol. 115(1):139-144.

Chow, V. T., Maidment, D. R. and Mays, L. W.(1988). *Applied Hydrology*, New York: McGraw-Hill.

Garbrecht, J., Ogden, F. L., DeBarry, P. A. and Maidment, D. A.(2001). GIS and distributed watershed models. I: Data Coverages and Sources. *Journal of Hydrology*, 506–512.

Geetha, K., Mishra, S. K., Eldho, T. I., Rastogi, A. K., and Pandey, R. P.(2008). SCS-CN based continuous model for hydrologic simulation. *Water Resource Management*, 22:165–190.

Grove, M., Harbor, J. and Engel, B. (1998). Composite vs. distributed curve numbers: Effects on estimates of storm runoff depths. Journal of the American Water Resources Association, 34(5), 1015-1023. [doi:10.1111/j.1752-1688.1998.tb04150.x]

Harr, R.D., Harper, W.C., Krygier, J.T. and Hsieh, F.S., 1975. Changes in storm hydrographs after road building and clear‐cutting in the Oregon Coast Range. *Water Resources Research*, *11*(3), pp.436-444.

Hawkins, R. H. (1978). Runoff curve numbers with varying site moisture. *Journal of Irrigation and Drainage Engineering*, ASCE.104 (IR4):389–398.

Hawkins, R. H.(1979). Runoff curve number from partial area watersheds. Journal of the Irrigation and Drainage Division, ASCE, 105 (IR4): 375 -389.

Hawkins, R. H. (1993). Asymptotic determination of runoff curve numbers from data. Journal of Irrigation and Drainage Engineering, 119(2), 334-345. [doi:10.1061/(ASCE)0733-9437(1993)119:2(334)]

Hawkins, R. H. and Rietz, D. (2000). Effects of land use on runoff curve number. Watershed Management and Operations Management, 2000: 1-11.

Hjelmfelt, A. T. (1991). Investigation of curve number procedure. Journal of Hydraulic Engineering, 117(6), 725-737. [doi:10.1061/(ASCE)0733-9429(1991)117:6(725)]

Kachroo, R. K. (1986). HOMS Workshop on River Flow Forecasting, Nanjing, China, Unpublished Internal Report, Department of Engineering Hydrology, University College Galway, Ireland.

McCuen, R. H. (2002). Approach to confidence interval estimation for curve numbers. *Journal of Hydrology*, 7(1):43–48.

Mishra, S. K. and Singh, V. P. (2003). Soil Conservation Service Curve Number (SCS-CN) Methodology, Kluwer Academic Publishers, Dordrecht, The Netherlands, ISBN 1-4020-1132-6, 2003.

Mishra, S. K. and Singh, V. P. (2004). Long-term hydrologic simulation based on the Soil Conservation Service curve number. *Hydrological Processes*, 18:1291-1313.

Mishra, S. K., Sahu, R. K., Eldho, T. I. and Jain, M. K. (2008). An improved I_a-S relation incorporating antecedent moisture in SCS-CN methodology. *Water Resources Management*, 20(5):643-660. *[doi:10.1007/s11269-005-9000-4]*

Mishra, S. K., Singh, V. P., Sansalone, J. J. and Aravamuthan, V. (2003). A modified SCS-CN method: Characterization and testing. *Water Resources Management*, 17(1), 37-68. [doi:10.1023/A:1023099005 944].

Moglen, G. E. (2000). Effect of orientation of spatially distributed curve numbers in runoff calculations. *Journal of the American Water Resources Association*, 36(6), 1391-1400. [doi:10.1111/j.1752-1688.2000.tb 05734.x].

Nash, J. E. and Sutcliffe, J. V. (1970). River flow forecasting through conceptual models. Part I – A discussion of principles. *Journal of Hydrology,* 10:282–290.

Pandey, V. K., Panda, S. N. and Sudhakar, S. (2002). Curve Number Estimation for Watershed Using Digital Image of IRS-1D LISS-III. *Map Asia 2002. <http:// www.gisdevelopment.net/technology/ip/techip013pf.htm>.*

Ponce, V. M. and Hawkins, R. H. (1996). Runoff curve number, has it reached maturity?. *Journal of Hydrology*, 1(1):11–19.

Ramasastri, K. S. and Seth, S. M.(1985). Rainfall-runoff relationships, Report RN - 20, National Institute of Hydrology, Roorkee, UP, India.

Schulze, R. E., Schmidt, E. J. and Smithers, J. C. (1992). SCS-SA user manual PC based SCS design flood estimates for small catchments in southern Africa. Pietermaritzburg: Department of Agricultural Engineering, University of Natal.

SCS, 1956, 1964, 1971, 1972. (1993). Hydrology, National Engineering Handbook, Supplement A, Section 4, Chapter 10, Soil Conservation Service, USDA, Washington, DC.

Soil Conservation Service (SCS). (1972). Hydrology, National Engineering Handbook. Washington, D. C: Soil Conservation Service, USDA.

Soil Conservation Service, United States Department of Agriculture (SCS-USDA), (1986). Urban Hydrology for Small Watersheds. Washington, D. C.: U. S. Government Printing Office.

Tong, S.T. and Chen, W., 2002. Modeling the relationship between land use and surface water quality. *Journal of environmental management*, *66*(4), pp.377-393.

Williams, J. R.(1995). The EPIC model. Singh, V. P., ed., *Computer Models of Watershed Hydrology*. CO: Water Resources Publications.

Xu, A. L. (2006). A new curve number calculation approach using GIS technology. *ESRI 26th International User Conference on Water Resources*.

Young, R. A., Onstad, C. A., Bosch, D. D. and Anderson, W. P. (1987). *AGNPS, Agricultural Non-Point Source Pollution Model: A Watershed Analysis Tool*. Washington, D. C.: USDA-ARS.

Yu, B. (1998). Theoretical justification of SCS method for runoff estimation. *Journal of Irrigation and Drainage Engineering*, ASCE.124:306-309.