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# Runoff estimation by composite and distributed curve number methods using remote sensing data

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**ABSTRACT**

The comparison between composite and distributed curve number methods for runoff estimation was carried out in a study undertaken in the Kathajodi-Surua Inter-basin in the Odisha state of Eastern India. Indian Remote Sensing IRS P6 MX images were analyzed for classifying the land use/land cover of the study basin. The land use/land cover map of the basin were superimposed with the corresponding soil map to come out with the hydrologic soil cover complex or curve number distribution in the basin. The composite curve number of the entire area was computed by weighted average of the curve number of each polygon in the hydrologic soil cover complex map with respect to their area. Using distributed curve number technique, runoff was simulated at each grid and averaged at the outlet of the basin and finally compared with the values obtained from compositing technique. The study revealed that there is definite increase in runoff value estimated by distributed curve number method over the traditional composite curve number method. The higher estimated runoff in distributed curve number method has been explained by a hypothetical example.

## 1. INTRODUCTION

An accurate understanding of surface hydrology is a critical element in the design of different hydraulic structures. The ability to predict and design for future rainfall and surface runoff volumes is not only helpful in ensuring adequate drainage capacity of these structures, but also economically important. Runoff is also the most important hydrologic parameter of the water balance equation which can help in estimation of other parameters. One of the most widely used techniques for estimating direct surface runoff from rainfall is the USDA Soil Conservation Service (SCS) [now Natural Resources Conservation Service (NRCS)] Curve Number (CN) method (USDA SCS, 1985; Ponce and Hawkins, 1996; Mishra *et al.,* 2004; Jain *et al.,* 2006; Jadhao *et al.,* 2010). Using Remote Sensing (RS) data, French *et al.* (2006) estimated initial abstraction (Ia) of rainfall, infiltration, and direct surface runoff and suggested to use a SCS-CN approach with refinement to predict the flow of water to Playa Lake and, in turn, the duration of inundation. The Remote Sensing (RS) and Geographic Information System (GIS) approach has been widely used for estimation of CN in the recent past (Sharma *et al.,* 2001; French *et al.,* 2006; Ramakrishnan *et al.,* 2009; Jadhao *et al.,* 2010; Jena *et al.,* 2012). For runoff estimation, the composite CN technique of SCS-CN methodology is frequently and traditionally used. This averaging technique was more popular for reasons of easy manual calculations in its early stage of development. Despite availability of high-speed personal computers, runoff is still computed using the traditional composite technique. Of late, easy availability of spatially distributed digital database and use of GIS have accelerated the use of distributed curve numbers for runoff estimation (Jena *et al.,* 2012). In the current study, composite and distributed curve number methods have been compared for estimation of runoff using remote sensing data.

## 2. MATERIALS AND METHODS

### Study Area

The study was undertaken in the Kathajodi-Surua Inter-basin located in the Odisha state of Eastern India (Fig. 1). The basin which is locally known as 'Bayalish Mouza' is a typical river island surrounded by Kathajodi River and its branch Surua. It is located between 85°54'21" to 86°00'41" E longitudes and 20°21'48" to 20°26'00" N latitudes. The total area of the river island is 35 km$^2$. The study area has a tropical humid climate with an average annual rainfall of 1650 mm, of which 80% occurs during June to October months. The normal mean monthly maximum and minimum temperatures of the region are 38.8°C and 15.5°C in May and December, respectively. The mean monthly maximum and minimum evapotranspiration rates are 202.9 and 80.7 mm in May and December, respectively. Agriculture is the major occupation of the inhabitants and groundwater is the major source of irrigation. Embankments have been provided on the banks of the rivers to prevent the entry of river water into the inhabited area during flood events. Therefore, entire rainwater of the region is drained through the main drain and discharged at a single outlet into the river.

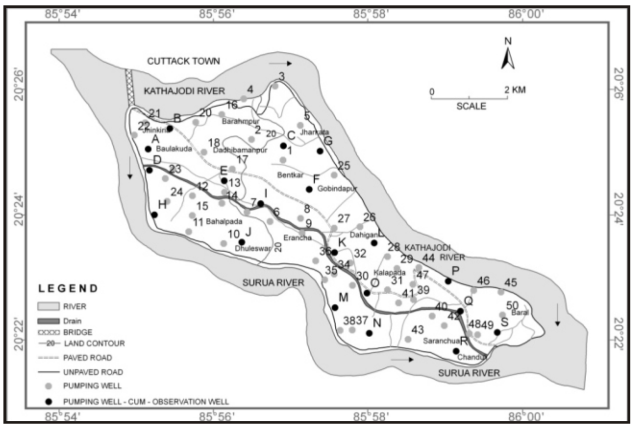


**Fig. 1. Location of the study area**

## Generation of Land Use Map

Land use/land cover map of the study area for the rainy (Kharif) season was generated using remote sensing imagery. One IRS P6 satellite image (path-102, row-073, LISS-4 MX sensor, and date of pass: 20.11.2004) of the study area was procured from National Remote Sensing Centre (NRSC), Hyderabad, Andhra Pradesh. The image was rectified and geometrically corrected with respect to the Survey of India toposheets of the study area namely 73 h/15 and 73 l/3 using ERDAS IMAGINE 8.7 software. This process of rectification was done by transferring coordinates of permanent features like road and rail crossings on rivers, road-canal or rail-canal crossings present on already rectified toposheets to remote sensing images. The three basic colours of red, blue and green were assigned to different bands of remote sensing image, which produced false color composite (FCC) map of the image. Then the Kathajodi-Surua Inter-basin portion was subset from the full image which gave the FCC map of the study area.

The classification of the FCC map of the study area was accomplished by supervised classification method. Supervised classification is an interactive approach in which classification of an area or a group of pixels belonging to one or more categories of specific land use/land cover (LU/LC) is done (Lilisand and Keiffer, 1994). The Land use/land cover classifications were performed with the help of ERDAS IMAGINE software using Maximum Likelihood Classifier (MLC). A number of ground truthing were done to verify the accuracy of land use classifications obtained from satellite imagery. Global Positioning System (GPS) was also used during the field verification. The classified images in raster format were changed to vector format (polygons) using ERDAS IMAGINE software and map composition was done using ArcGIS software.

## Soil Map

The soil map of the study area was prepared in GIS environment with reference to the soil map of the region prepared by Orissa Space Application Centre (ORSAC), Bhubaneswar, India. The soil map was rectified and geometrically corrected as explained above in case of land use/land cover map. The different soil polygons representing different soil taxonomy were delineated using ArcGIS software. The soil map along with the land use/land cover map was used for runoff estimation by composite curve number method.

## Estimation of Runoff

The curve number technique (USDA SCS, 1985) was used for runoff estimation in the study area. According to characteristics of the soil types in the study area, soils were classified into different hydrologic soil groups. The land use/land cover coverage of the rainy season and the soil coverage were merged using ArcGIS software to delineate the curve number coverage of the study area (Subramanya, 2008). All the polygons having a particular land use and a hydrologic soil group were selected and then curve numbers for Antecedent Moisture Condition (AMC) II were assigned to these polygons with the help of standard table (USDA SCS, 1985). AMC conditions were determined based on the cumulative previous 5 days rainfall for a particular rainfall event and using standard guidelines. Based on the AMC conditions, *i.e.,* AMC I, AMC II or AMC III, curve numbers were assigned to the polygons using the AMC conversion table (Subramanya, 2008). Thereafter, the weighted curve number for the study area was found out by using the following formula:

$$CN_w = \frac{CN_1 \text{ x } A_1 + CN_2 \text{ x } A_2 + ........... + CN_n \text{ x } A_n}{A} \quad \dots (1)$$

Where, $CN_w$ = composite curve number of the study area; $A_1$, $A_2$, ……, $A_n$ = areas of the polygons having CN values $CN_1$, $CN_2$, ……, $CN_n$, respectively; and $A$ = total area of the study area ($A_1 + A_2 + \dots + A_n$).

## Composite curve number method

In composited method, each grid in the hydrologic soil cover complex map was assigned a curve number and the weighted average was calculated to determine the composite curve number for the basin as described in Eqn. (1). Daily runoff of the entire basin was calculated considering the weighted curve number of the whole area.

**Distributed curve number method**

In the distributed approach, runoff depth was estimated for each individual grid cell or polygon in the watershed, based on the hydrologic soil cover complex map. There was no averaging of curve numbers, rather separate curve number values were assigned for each cell or polygon and separate runoff values were calculated for each of them. These runoff values were then averaged to find out the total runoff depth for the whole basin.

The event-based daily runoffs were computed for the monsoon months (June to October) of 20 years (1990-2009) period with the help of Microsoft-Excel software using the following equations:

$$S = \frac{25400}{CN_w} - 254 \qquad \dots (2)$$

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \; (Q = 0 \text{ for } P \leq 0.2S) \qquad \dots (3)$$

Where, $S$ = potential maximum retention or infiltration (mm), $Q$ = direct runoff (mm), and $P$ = total precipitation (mm).

The annual runoffs of the monsoon period for individual years were computed by adding the corresponding daily runoff values. Comparison was made between the runoff values obtained from the composite curve number method and distributed curve number method. These annual runoffs were analyzed to explore temporal variation.

## 3. RESULTS AND DISCUSSION

**Land Use/Land Cover Variation**

Based on the remote sensing image analysis of the study area, land use in rainy season was classified into 6 categories, namely settlement, orchard/plantations, water body, wetland, fallow land and paddy area. The land use/ land cover map of the study area is shown in Fig. 2. The areas and percentages of areas under different land uses/land covers are summarized in Table 1. Paddy is the most dominant crop in the rainy season covering an area of 1140.57 ha which accounts for 32.6% of the total area. It is followed by fallow land (945.25 ha) and built-up land (816.42 ha) accounting for 27 and 23.3% of the total area, respectively. The water bodies, wet lands and orchard/ plantation crops account for 0.6, 7.4 and 9.1% land of the total study area, respectively.

**Soil Map**

The study area comprised three major soil types, namely (i) Fine loamy, Udic Ustochrepts, (ii) Coarse loamy, Typic Udipsamments, and (iii) Fine, Typic Endoaquepts with a majority of the area belonging to type 1 category. The area under different soil types and their percentage of total land area is presented in Table 2. Maximum area (3032.6 ha) is covered under the soil type 'Fine loamy, Udic Ustochrepts' whereas minimum area (67.17 ha) is covered under the soil type 'Fine, Typic Endoaquepts'. Based on the characteristics of the soil types present in the study area, the soil types Fine loamy, Udic Ustochrepts and Fine, Typic Endoaquepts were grouped under hydrologic soil group C (moderately high runoff potential) and the soil type Coarse loamy, Typic Udipsamments was grouped under hydrologic soil group B (moderately low runoff potential) according to the guidelines of USDA Soil Conservation Service (USDA SCS, 1985).

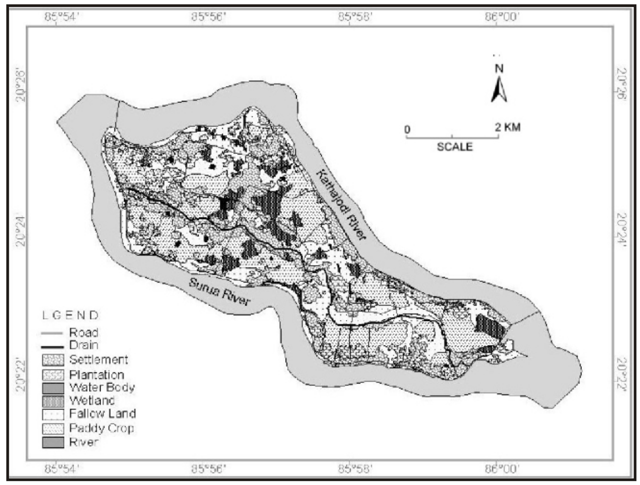


**Fig. 2. Land use/land cover map of Kathajodi-Surua Inter-basin in the rainy season**

**Table: 1**
**Land use/land cover in the study area during rainy season**

| S. No. | Land use | Area (ha) | Percentage of total area (%) |
|---|---|---|---|
| 1 | Built-up Land | 816.42 | 23.3 |
| 2 | Orchard/Plantations | 318.33 | 9.1 |
| 3 | Water Body | 21.09 | 0.6 |
| 4 | Wetland | 260.48 | 7.4 |
| 5 | Fallow Land | 945.25 | 27.0 |
| 6 | Paddy Cultivated Land | 1140.57 | 32.6 |
| | Total | 3502.14 | 100 |

**Table: 2**
**Soil types in the study area**

| S.No. | Soil type | Area (ha) | Percentage of total area (%) |
|---|---|---|---|
| 1 | Fine loamy, Udic Ustochrepts | 3032.36 | 86.6 |
| 2 | Coarse loamy, Typic Udipsamments | 402.68 | 11.5 |
| 3 | Fine, Typic Endoaquepts | 67.17 | 1.9 |
| | Total | 3502.21 | 100 |

**Runoff Estimation by Composite and Distributed CN Methods**

The curve number (AMC II) map obtained by overlaying the land use map of the rainy season and the soil map of the study area in GIS environment is shown in Fig. 3. The areas under different curve numbers are shown in Table 3. It is evident from this table that a majority of the study area (1081.20 ha) falls under paddy on hydrologic soil group C, *i.e.,* curve number = 82, while only 41.72 ha falls under orchard/plantation crops in hydrologic soil group B, *i.e.,* curve number = 55. The estimated runoff along with their percentage of total monsoon rainfall obtained by composite curve number method and distributed curve number method for the 1990-2009 period is shown in Table. 4. The estimated runoffs by composite curve number method for the twenty years period (1990-2009) vary from a minimum of 76.15 mm in the year 1996 to a maximum of 935.29 mm in the year 2003. Further, the runoff as percentage of total monsoon rainfall varies from a minimum of 10.19% in the year 1995 to a maximum of 43.3% in the year 2003. The estimated runoff by distributed curve number method for the same period varies from a minimum of 154 mm in the year 1996 to a maximum of 977.6 mm in the year 2003. The runoff as

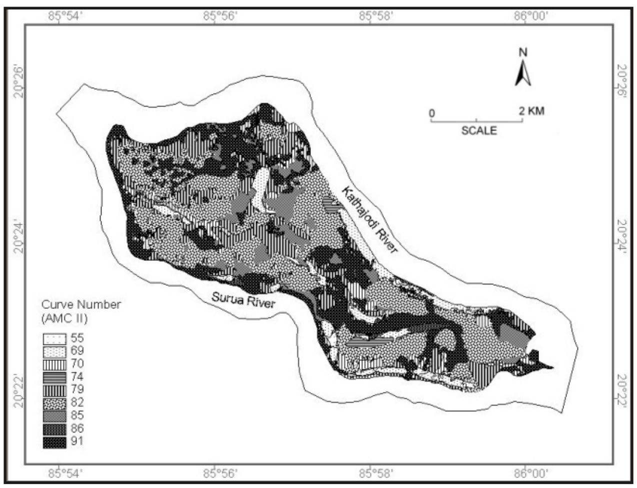


**Fig. 3. Spatial distribution of curve number over Kathajodi-Surua Inter-basin**

**Table: 3**
**Curve Number Distribution (AMC II) in the study area during Wet Season**

| Hydrologic Soil Cover Complex | Curve Number (AMC II) | Area (ha) | Area (%) |
|---|---|---|---|
| Settlement on Hydrologic Soil Group B | 69 | 235.82 | 6.73 |
| Settlement on Hydrologic Soil Group C | 79 | 580.64 | 16.58 |
| Orchard/Plantation on Hydrologic Soil Group B | 55 | 41.72 | 1.19 |
| Orchard/Plantation on Hydrologic Soil Group C | 70 | 276.66 | 7.90 |
| Paddy on Hydrologic Soil Group B | 74 | 59.39 | 1.70 |
| Paddy on Hydrologic Soil Group C | 82 | 1081.20 | 30.87 |
| Fallow Land on Hydrologic Soil Group B | 86 | 45.65 | 1.30 |
| Fallow Land on Hydrologic Soil Group C | 91 | 899.61 | 25.69 |
| Water Body/Wetland | 85 | 281.60 | 8.04 |
| Total | | 3502.29 | 100.00 |

percentage of total monsoon rainfall varies from a minimum of 19.37% in the year 1994 to a maximum of 45.26% in the year 2003. More runoff were generated in the years 1993, 1997, 1999, 2001, 2003, 2006 and 2007 as more high rainfall events occurred in the said years. The comparison of both the methods shows that distributed curve number method estimates a marginally higher runoff than the composite curve number method. This is in agreement with the findings of Jena *et al.* (2012).

**Table: 4**
**Total monsoon rainfall and estimated runoff during 1990-2009 period**

| Year | Total monsoon rainfall | Composite curve number method | | Distributed curve number method | |
|---|---|---|---|---|---|
| | | Total runoff (mm) | Runoff (%) | Total runoff (mm) | Runoff (%) |
| 1990 | 1257.5 | 271.2 | 21.57 | 301.0 | 23.94 |
| 1991 | 1327.7 | 309.7 | 23.33 | 342.2 | 25.77 |
| 1992 | 1214.3 | 331.6 | 27.31 | 362.9 | 29.88 |
| 1993 | 1564.8 | 559.1 | 35.73 | 587.0 | 37.51 |
| 1994 | 1231.2 | 206.6 | 16.78 | 238.5 | 19.37 |
| 1995 | 1132.6 | 115.4 | 10.19 | 319.6 | 28.22 |
| 1996 | 689.9 | 76.2 | 11.04 | 154.0 | 22.32 |
| 1997 | 1540.8 | 657.5 | 42.67 | 687.5 | 44.62 |
| 1998 | 1268.0 | 279.8 | 22.06 | 287.4 | 22.67 |
| 1999 | 1906.3 | 682.1 | 35.78 | 689.8 | 36.19 |
| 2000 | 995.5 | 215.0 | 21.60 | 235.4 | 23.65 |
| 2001 | 1629.2 | 455.7 | 27.97 | 497.6 | 30.54 |
| 2002 | 927.1 | 213.3 | 23.01 | 235.3 | 25.38 |
| 2003 | 2160.0 | 935.3 | 43.30 | 977.6 | 45.26 |
| 2004 | 1157.4 | 332.1 | 28.70 | 363.5 | 31.41 |
| 2005 | 1586.8 | 545.7 | 34.39 | 581.8 | 36.67 |
| 2006 | 1789.0 | 757.5 | 42.34 | 791.3 | 44.23 |
| 2007 | 1605.1 | 649.6 | 40.47 | 679.3 | 42.32 |
| 2008 | 1546.4 | 461.2 | 29.82 | 480.4 | 31.07 |
| 2009 | 1301.0 | 415.3 | 31.92 | 436.0 | 33.51 |

## Comparison of Composite and Distributed CN Methods using Hypothetical Example

In order to study the reason behind higher runoff estimation in distributed curve number method, a hypothetical runoff estimation was done considering 4 set of rainfall values, *i.e.* 50, 100, 150 and 200 mm; and 7 sets of curve number values, *i.e.,* 30, 40, 50, 60, 70, 80 and 90. The average runoff ($runoff_{av}$) for a particular curve number was estimated by taking average of the runoff amount for the current curve number, preceding curve number and succeeding curve number. For example, $runoff_{av}$ for curve number 60 was estimated by taking average of runoff amount for curve numbers 50, 60 and 70. In this case, 'runoff' and '$runoff_{av}$' can be considered as equivalent to runoff estimated by composite curve number method and distributed curve number method, respectively.

Table 5 shows the estimated runoff, $runoff_{av}$ and percent change in runoff value due to averaging for different curve number and rainfall scenarios. It is evident from the table that '$runoff_{av}$' is invariably more than 'runoff' for all the conditions. It can be attributed to the fact that the difference in values of runoff for two consecutive curve numbers is higher for higher curve numbers. Therefore, the runoff value for a particular curve number is lower than the average of runoff values for three consecutive curve numbers centering the corresponding curve number. This explains why the runoff estimated by distributed curve number method is always higher than the composite curve number method. It is interesting to observe that for lower rainfall values, the increase in runoff values due to averaging is higher in higher curve numbers and it decreases with decrease in curve numbers. However, for higher rainfall values, the increase in runoff is lower at higher curve numbers and it increases with decrease in curve number.

**Table: 5**
**Estimated runoff with different rainfall and curve number values**

| Curve No. | Rainfall = 50 mm | | | Curve No. | Rainfall = 100 mm | | |
|---|---|---|---|---|---|---|---|
| | Runoff | $Runoff_{av}$ | Percent Change | | Runoff | $Runoff_{av}$ | Percent Change |
| 90 | 27.11 | | | 90 | 72.63 | | |
| 80 | 13.80 | 15.57 | +12.85 | 80 | 50.54 | 51.96 | +10.29 |
| 70 | 5.81 | 7.00 | +8.65 | 70 | 32.71 | 33.94 | +8.91 |
| 60 | 1.40 | 2.40 | +7.27 | 60 | 18.57 | 19.75 | +8.57 |
| 50 | 0.00 | 0.47 | +3.38 | 50 | 7.98 | 9.32 | +9.69 |
| 40 | 0.00 | 0.00 | 0.00 | 40 | 1.40 | 3.13 | +12.51 |
| 30 | 0.00 | | | 30 | 0.00 | | |
| **Curve No.** | **Rainfall = 150 mm** | | | **Curve No.** | **Rainfall = 200 mm** | | |
| | Runoff | $Runoff_{av}$ | Percent Increase | | Runoff | $Runoff_{av}$ | Percent Increase |
| 90 | 120.75 | | | 90 | 169.72 | | |
| 80 | 93.88 | 94.66 | +5.65 | 80 | 139.88 | 140.08 | +1.47 |
| 70 | 69.35 | 70.16 | +5.87 | 70 | 110.65 | 110.93 | +2.05 |
| 60 | 47.25 | 48.15 | +6.55 | 60 | 82.27 | 82.71 | +3.19 |
| 50 | 27.86 | 29.03 | +8.48 | 50 | 55.21 | 55.95 | +5.34 |
| 40 | 11.98 | 13.81 | +13.26 | 40 | 30.36 | 31.80 | +10.46 |
| 30 | 1.59 | | | 30 | 9.84 | | |

## 4. CONCLUSIONS

The land use/land cover map of the Kathajodi-Surua Inter-basin for the rainy season prepared by analyzing the IRS P6 MX image of the study area showed that paddy is the most dominant crop of the basin in the said season covering about 32.6% of the total area. The hydrologic soil cover complex map of the basin prepared by overlaying the land use/ land cover map and the soil map of the basin was used for runoff estimation. The runoff values were generally higher in the years in which there were more of peak rainfall events. The distributed curve number method gave slightly higher values of runoff in comparison to composite curve number method. In the hypothetical example involving different rainfall and curve number values, it was observed that runoff value for a particular curve number is lower than the average of runoff values for three consecutive curve numbers centering the corresponding curve number. This explains the higher runoff estimation by the distributed curve number method.

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