ESTIMATION OF RUNOFF USING NATURAL RESOURCES CONSERVATION SERVICE – CURVE NUMBER MODEL IN GIS FOR KUMARI RIVER BASIN IN PURULIA DISTRICT OF WEST BENGAL

[1]MADHURIMA DAS, [2]GUPINATH BHANDARI

[1]Research Fellow, Department of Civil Engineering, Jadavpur University, Kolkata 700032, INDIA;
[2]Associate Professor, Department of Civil Engineering, Jadavpur University, Kolkata 700032, INDIA;
E-mail: [1]jumadhurima@gmail.com, [2]g.bhandari.ju@gmail.com

Abstract - Runoff Estimation is a decisive step in water resource management. The crop production of the arid region is affected by the poor water resource. Therefore proper management of available water is essential to prevent crop failure. In the present work Kumari River Basin in Purulia District of West Bengal, has been considered as the study area. The agricultural system of the study area is basically rain-fed in nature hence the runoff information is essential for implementation of suitable water resource management strategies. Hence, the present study has been carried out to estimate the runoff from daily rainfall data, based on the method developed by United States Department of Agriculture (USDA). The same is called as Natural Resources Conservation Service – Curve Number (NRCS-CN) method. This method can be carried out in Geographical Information System (GIS) for the study area. Landuse and Hydrologic soil group data of the study area has beenanalyzed to derive the Curve Number values, based on the above said method. Finally, the daily runoff from weighted curve number could be obtained, for an average condition of the study area.

Keywords: Daily Runoff Estimation, Geographical Information System (GIS), Natural Resources Conservation Service – Curve Number (NRCS-CN), Remote Sensing

I. INTRODUCTION

The information of runoff is essential for implementation of water resource projects. One of the foremost problems of concerning matter may be the scarcity of obtaining accurate information of runoff of an area. Runoff information obtained by the aid of conventional techniques is accurate but the measurement process is very difficult and expensive. The associated work with this information is extremely affected by the unavailability of this information in necessary time. Therefore the problem creates a scope to work on runoff estimation for getting reliable runoff information of an area by using an appropriate runoff model. So, the study envisaged, has been aimed to add to possible solution to the following interlinked problems.

The present study has been carried out for water resource management for agriculture of Kumari River Basin in Purulia district, using the Natural Resources Conservation Service – Curve Number (NRCS-CN) model developed by USDA. Simplicity and predictability are two merits of this model. The present study has been conducted using the tools, Remote Sensing and GIS, using the advantages in computation power and managing large amount of spatial and non spatial data.

II. STUDY AREA AND RELEVANT DATA

2.1 Description of the Study Area

Kumari River Basin is located in the South- East Part of the Purulia District. It is surrounded by Kasai and Subarnarekha River Basin. The area occupied by this River Basin is 1110.379 Sq.km. The latitudinal extension of the study area is 22°51'49" N to 23°14'12"N and longitudinal extension is 86°9'34" E to 86°43'50"E . Location map of the study area has been shown in (Fig1).

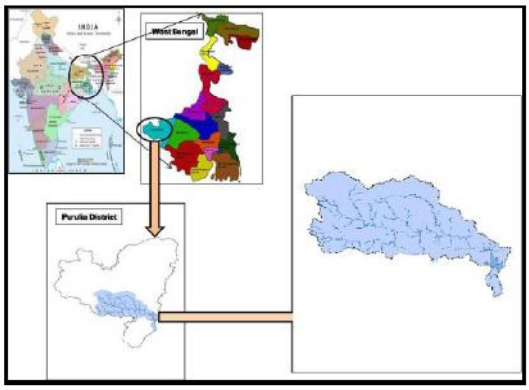

Fig1. Study area

2.2 Relevant Data

In this study, Remote Sensing and Ancillary data such as IRS-P6, LISS III, SRTM DEM data, Toposheet, District Planning Map, Soil Map have been used to prepare necessary maps which are associated with this study. Daily Rainfall data of Purulia District for 2015 has been obtained from the official website of Agricultural Meteorology Division, Indian Meteorological Department. The work has been carried out by the help of RS and GIS software.

III. METHODOLOGY

3.1 Runoff Estimation Model:

Natural Resources Conservation Service – Curve Number (NRCS-CN) Model

In this study, Natural Resources Conservation Service – Curve Number (NRCS-CN) Model has been used to estimate Runoff from daily Rainfall data for one year which is explained in this study based on Handbook of hydrology, 1972.

NRCS-CN Model is developed by United States Department of Agriculture (USDA) for estimating runoff from rainfall. The NRCS runoff equation was developed to estimate total storm runoff from total storm rainfall (Handbook of hydrology, 1972). The NRSC-CN method is based on the following relationship between Rainfall and Runoff.

The curve number runoff equation is: (Source: Handbook of hydrology, 1972)

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad P > I_a \ \ldots\ldots\ldots \mathbf{Equ(i)}$$

$$Q = 0 \qquad P \leq I_a$$

Where:

Q = Depth of Runoff, in inches; P = Depth of Rainfall, in inches; I_a = Initial Abstraction, in inches; S = Maximum Potential Retention, in inches.

Two considerations weretaken for measurement of the runoff depth in this model in the experimental stage.

First, Consideration is initial abstraction (I_a) is zero. The initial abstraction consists mainly of interception, infiltration during early parts of the storm, and surface depression storage (Handbook of hydrology, 1972). The rainfall- runoff relationship, in this consideration is expressed by the following equation.

$$Q = \frac{P^2}{P + S} \ldots\ldots\ldots\ldots \mathbf{Equ(ii)}$$

[Where, Q= Actual Runoff, in inches; P=Actual Rainfall, in inches. S= Maximum Potential Retention after Runoff Begins, inches;]

In case of second consideration, the relationship of rainfall- runoff is expressed by following equation, where, the amount of rainfall available for runoff is ($P-I_a$) instead of P.

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

[Where, Q= Actual Runoff, in inches; ($P-I_a$)= Amount of Rainfall available for Runoff, in inches. S= Potential maximum retention after runoff begins, inches;]

Initial abstraction I_a has been assumed as a function of the Maximum Potential Retention, S. The Relationship between I_a and S was expressed as

$I_a = 0.2S$

Finally solving several equations, the rainfall-runoff relationship was obtained by the following equation.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad P > I_a \ \ldots\ldots\ldots \mathbf{Equ(iv)}$$

[Where, Q= Actual Runoff, in inches; P=Actual Rainfall, in inches. S= Maximum Potential Retention after runoff begins, inches;]

In this study, finally the runoff has been estimated using the above mentioned formula.

The maximum potential retention, S, is dependent on the soil-cover complex. Curve number (CN) is a function of Landcover and hydrologic soil groups. The Curve number (CN) indicates the runoff potential of a complex during periods when the soil is not frozen (Handbook of hydrology, 1972). The range of CN value is 0 to 100. A higher CN indicates a higher runoff potential.

The variability in the CN results from different parameters, such as, rainfall intensity and duration, total rainfall, soil moisture conditions, cover density, stage of growth, and temperature. The impact of variability is collectively called the Antecedent Runoff Condition (ARC) (Handbook of hydrology, 1972). In some documents ARC has presented as Antecedent Moisture Condition (AMC). ARC refers to the water content present in the soil at a given time. ARC is divided into three classes: ARC, II for average condition, ARC, I for dry condition, and ARC III for wetter condition.

Runoff has been estimated using derived value of Weighted Curve Number, Maximum Potential Retention and daily rainfall data. The equation is Weighted Curve Number (CN_w) for Antecedent Runoff Condition (ARC) II.

$$\mathbf{CN_w} = \frac{\sum(\mathbf{CN_i} \times \mathbf{A_i})}{\mathbf{A}} \ldots\ldots\ldots\ldots \mathbf{Equ(v)}$$

Where CN_w= the weighted curve number; CN_i=the curve number from 1 to any number N; A_i=the area with curve numberCN_i; A = the total area of the watershed.

Maximum potential retention, S, has been obtained using Weighted Curve Number value.

The potential maximum retention (in mm) is obtained by following equation.

$$\mathbf{S} = \frac{\mathbf{25400}}{\mathbf{CN}} - \mathbf{254} \ldots\ldots\ldots\ldots \mathbf{Equ(vi)}$$

3.2 Calculation of Runoff using GIS and Remote Sensing

Curve number (CN) is a function of Landcover and hydrologic soil groups. IRS-LISS III Satellite Imagery has been analyzed for preparing Landuse Classification map of the study area. Soil Texture information of the study area has been obtained from (NBSS &LUP). Soil classification for NRSC- CN number method has standardization. Soil classified into Hydrological soil groups (HSG's) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting (Handbook of hydrology,

1972). In this study soil textured map of the study area has been converted into Hydrological soil groups map by follow the standardization and instruction provided in Soil Conservation Service, (USDA) study guide.

Calculation of Curve Number and preparation of Runoff Potentiality map

In this study, Landuse and Hydrological Soil group maps are two elementary databases for calculating Curve Number for runoff estimation based on NRSC –CN method, USDA . Curve number values have been assigned in every Soil-Cover Complex based on Specification provided by USDA. Then weighted curve number and Maximum Potential Retention (S) have been calculated for whole Runoff Estimation using Equ. (v) & (vi)

Calculation of Runoff using NRSC-CN method

Finally, Runoff has been estimated using daily rainfall data which obtained from Agricultural Meteorological Division of Indian Meteorological Division follow by the (Equ. iv)

RESULT AND DISCUSSION

Kumari River Basin is an important River Basin among several delineated River Basin in Purulia district. The Curve number value is a function of Landuse and Hydrologic Soil Groups. The study area has been classified into six dominant Landuse categories based on the instruction provided in NRCS-CN method. The maximum area is occupied by agricultural land.

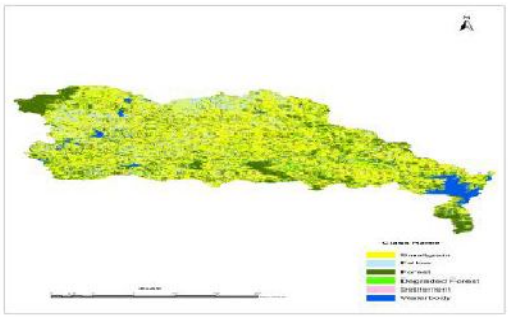

Fig.2 Landuse Map of Kumari River Basin

Landuse Classes	Area (in Hectares)
Smallgrain	57622.2336
Fallow	17190.5472
Forest	23904.8064
Degraded Forest	4685.4144
Settlement	49.8240
Waterbody	7803.2448

Table.1 Area Statistics for Landuse distribution of Kumari River Basin in Purulia District

Soil Texture map has been prepared for deriving Hydrological Soil Groups map of the study area. There are several kinds of soil textures shown in the The Soil texture map has been converted into Hydrological Soil Groups.

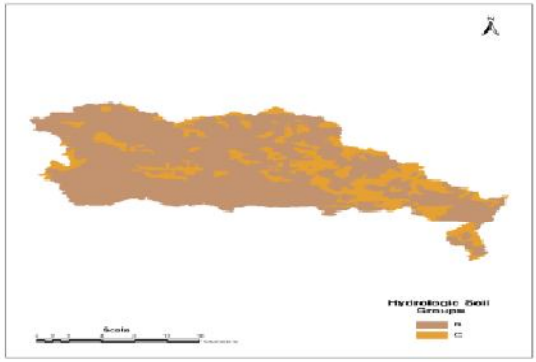

Fig.3 Hydrologic Soil Groups Map of Kumari Basin

The study area is occupied by only B and C Hydrological soil groups. Maximum area is covered by B hydrological soil group.

Hydrologic Soil Groups	Area (in Hectares)
B	84814.9638
C	25702.5069

Table.2 Area distribution of Hydrologic Soil Groups of Kumari River Basin in Purulia District

The curve number is a function of Landuse and Hydrological soil group. Therefore combination of Landuse and Hydrological soil group map has been done for acquiring CN value.Curve Numbers Value for Hydrologic Soil-Cover Complexes for Antecedent Moisture Condition (AMC) I, II and III of Kumari River Basin in Purulia District have been calculated.

Weighted Curve Number, Maximum Potential Retention (S) and Initial Abstraction (Ia) for Antecedent Moisture Condition (AMC) II of Kumari River Basin in Purulia District have been calculated for estimate the Runoff of Kumari River Basin. **(Table.3)**

Weighted Curve Number (CN)	Maximum Potential Retention (S)		Initial Abstraction (Ia)	
	In Inches	In Millimeters	In Inches	In Millimeters
73.983	3.517	89.322	.703	17.864

Finally estimated runoff from daily rainfall data of the monsoon season of 2015 has been shown graphically. On examine the graph, it has been found that maximum rainfall happened in 28th July 2015 is 120 mm, derived runoff of that date is 60 mm.

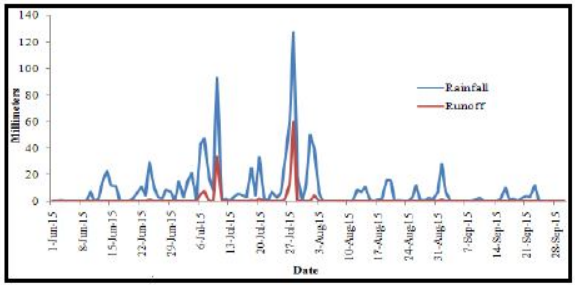

Fig4. Estimated Runoff with Daily Rainfall for Monsoon Season of 2015 of Kumari River Basin in Purulia District

ACKNOWLEDGEMENT

The authors would like to extend the heartiest thanks to the University Grant Commission (UGC), Government of India, for funding the research work; also extending the heartiest thanks to Department of Civil Engineering, Jadavpur University, for providing the golden opportunity to work on this problem. The authors are also thankful to National Bureau of Soil Survey & Land use Planning (NBSS & LUP), Indian Meteorological Division (IMD), National Remote Sensing Centre (NRSC), Government of India, National Aeronautics & Space Administration (NASA), United States Federal Government, for providing the data to carry out the Research Work. The authors would like to extent the thanks to 'UGC-BSR Research Fellowship in Science for Meritorious Students', 2012-2013 for funding.

CONCLUSION

The study has been conducted to assess the available runoff of Kumari River Basin in Purulia district, in order to do the Water Resource Management. The present study also showed the Runoff potentially map of the study area in AMC I, AMC II and AMC III conditions. The resulted value showed maximum Runoff occurs in the middle part of monsoon season. The present study also revealed the advantage of using GIS tool to estimate runoff from daily rainfall data based on NRCS-CN number model.

REFERENCES

[1] United States Department of Agriculture (USDA), Handbook of hydrology, 1972.
[2] Pradhan, R., Pradhan., M.P., Ghose, M. K., Agarwal, V. S., Agarwal, S., (2010). Estimation of RainfallRunoff using Remote Sensing and GIS in and around Singtam, East Sikkim. International Journal of Geomatics and Geoscience, 1(3).
[3] Nahayo,A., Ntandayera,C., Mukashema,A., (2012). Application of Geographic Information System (GIS) and Remote Sensing (RS) to estimate the available rainwater harvested for crop production in Kinoni watershed, Kirehe District, Rwanda, Nature and Science,10(11), 38-52.
[4] Khaddor.,I., Alaoui.,A.H, (2014). Production of a Curve Number map for Hydrological simulation - Case study: Kalaya Watershed located in Northern Morocco, International Journal of Innovation and Applied Studies, 9 (4), 1691-1699.
[5] Yamini, S.J (2014). Runoff Map Preparation for Khadakwasla using Arc-CN Runoff Tool. The International Journal of Science & Technoledge, 2(11), 131-135.
[6] Ahmad, I., Verma, V., Verma, M.K., (2015). Application of Curve Number Method for Estimation of Runoff Potential in GIS Environment. International Conference on Geological and Civil Engineering, 80 (4).

★★★