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Measuring the spatial pattern of surface runoff using SCS-CN method of Hinglo River Basin: RS-GIS approach

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Abstract

The study intents to determine the surface runoff using Soil Conservation Service-Curve Number(SCS-CN) method. For the watershed management and understanding hydrological characteristics, the SCS-CN method is extensively used. The effective indicators like land use/land cover, soil texture, rainfall has been selected for the present study. The CN method is an index that help to estimate the runoff depth at different hydrological soil groups combining LULC and soil texture. To estimate the surface runoff, the selected parameters have been integrated with the help of ArcGIS software. The results show that the value of annual surface runoff varies from 677.07mm to 1348.12 mm within this river basin. It has found that in the middle catchment area amount of runoff is lower than the upper and lower catchment in pre-monsoon season and reverse condition is found in post-monsoon. The average annual runoff of this basin is relatively higher than the other parts due to having the high slope and elevation.

Keywords: SCS-CN method, Runoff, Hydrological Soil Group, Curve Number, Antecedent Moisture Condition, GIS.

Introduction

Surface runoff is not only controlling the hydrological cycle but also soil erosion. The watershed management policy specifies the managing procedure to prevent the soil loss of the catchment area[1,2]. Precipitation generates surface runoff on land surface which creates the drainage network of a watershedarea[3]. Runoff is the important hydrological process which determines economic and social development of watershed region[4]. Soil Conservation Service-Curve Number (SCS-CN) method is simple, reliable and conceptual technique which helps to determine the surface runoff of a watershed region to analysis the hydrological behaviour and helps the planners to take suitable watershed management plans[5]. Curve Number(CN) has been calculated from the hydrological soil groups which is composed of LULC and soil textural class. The value of weighted curve numbers indicates the runoff condition, like maximum value of curve number represents the high runoff flow and low infiltration rate and low curve number signifies the low runoff and very high infiltration rate[6],[7].

In the present article Remote Sensing (RS) and Geographical Information System (GIS) has been used for the analysing, manipulating, restoring of the spatial and non-spatial data for this study[8,9]. To compute the curve number, the traditional method is very tedious and takes up the calculation time. Through the SCS-CN method using Remote Sensing and Geographical Information System one can easily determines the surface runoff to predict the hydrological condition[10]. This model helps to analysis the flood and peak discharges of watershed. Some of the research scholars have been applied the SCS-CN method to estimate surface runoff in a watershed region[11-17].

This work attempts to determine the surface runoff using SCS-CN method with the help of Remote Sensing and Geographical Information System in the Hinglo river basin.

Description of the study area: Hinglo River is the one of the most important tributary of Ajay River. It originates from a spring which is located in Fatapur block of Jamtra district, Jharkhand and merged with Ajay River near Palasdanga village of Birbhum district, West Bengal. Geographically, the basin area extent from 23°42′7.09′′ to 24°0′56.78 ′′N latitudes and 86°59′32.68 ′′ to 87°23′31.91′′ E longitudes and cover an area about 391.75 sqs.km. It flows from source to mouth through the Chotonagpur plateau and Rarh regions. This river system has created distinctive landforms in this watershed[18,19]. This region is consisting of different geological unit such as granite gneiss, barker formation, ironstone shale, quartzite and newer alluvium over the watershed[20].

The ground waters depth is not same at different places of this region and it varies from 5 to 10 m.bgl[21]. Pedologically this region is composed of different type of soil textural class such as sandy, clay, clay loam, sandy loam, loam, fine loamy mixed type of hyperthermic haplustepts and fine loamy mixed type of plustepts[22]. Physical and chemical weathering, mass wasting, laterizition and fluvial process are the major morphogenetic process of this watershed. The relief height ranges from 60metresto 289 metres. The north-middle parts and western parts of this watershed region is of high slope[23].

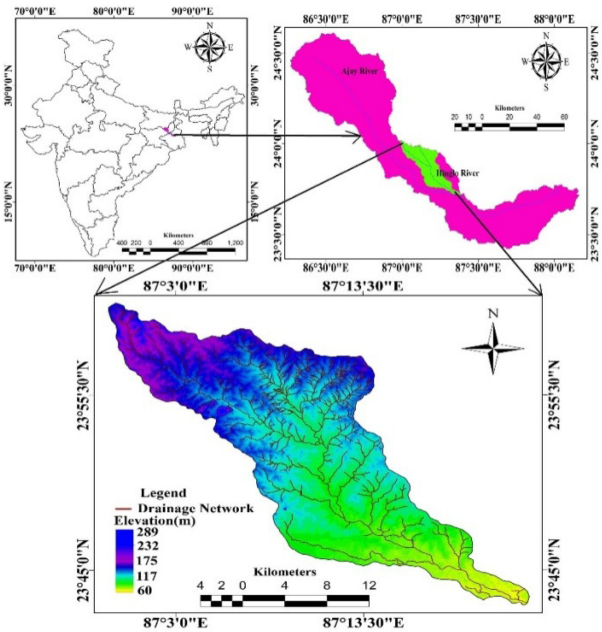

Figure-1: Location map of Hinglo River Basin.

Materials and methods

Data source: Topographic sheets such as map. no.73 I/13, 72 L/16, 73M/1, 73 M/5, 73 M/6 and 73P/4 at the scale of 1:50000 have been selected for the identifying the watershed region. The soil map has been collected from National Bureau of Soil Survey and Land Use Planning (NBSS & LUP). Rainfall data has been collected from Indian metrological department. The Lands at 8TM/TIRS and ASTER DEM has been downloaded from earth explore usgs website. LULC map has been generated in remote sensing and GIS environment through Maximum likelihood classification method using Lands at images.

Hydrological soil group: For the Present study, USDA department has been developed National Engineering Handbook (NEH) and NEH has been classified the soil into four hydrological soil categories like A, B, C and D groups[24]. The characteristics of hydrological soil groups have been analysed in following Table-1 and Table-2.

Table-1: Hydrological Soil Group and their Characteristics[24].

Soil Hydrologic Group	Characteristics
A	Having low runoff potential and high infiltration rate. Examples: sands or gravels.
B	Having low runoff potential and moderate infiltration rate. Examples: fine to moderate coarse textures.
C	Having high runoff potential and low infiltration rate. Examples: fine texture.
D	Having high runoff potential and very low infiltration rate. Examples: clay soils

Table-2: LULC and Hydrological Soil Group[24].

Land use/ Land cover unit	Hydrological Soil Group			
	A	B	C	D
Agriculture land	76	86	90	93
Build-up Area	49	69	79	84
Tree cover	41	55	69	73
Forest area	26	40	58	61
Barren land	71	80	85	88
Water bodies	97	97	97	97

Antecedent moisture condition (AMC): Antecedent Moisture Condition (AMC) helps to calculate surface runoff of a watershed region. To estimate the runoff, the antecedent moisture condition has been classified into three categories like AMC-1, AMC-II and AMC-III. Table-(2) gives the brief description of seasonal rainfall condition on the basis of antecedent moisture conditions[25].

Table-2: Antecedent Moisture Condition (AMC) and characteristics[25].

Soil Moisture Group	Characteristics	Initial abstraction	Total 5 days Antecedent Rainfall in mm.		
			Dormant season	Growing season	Average
AMGI	The soils in the drainage basin are practically dry (i.e. the soil moisture content is at wilting point).	(Ia = 0.2S)	<13	<35	<23
AMGII	Average condition	(Ia= 0.1S)	13-28	35 – 52.5	23-40
AMG III	The soils in the drainage basins are practically saturated with antecedent rainfalls.	Heavy rainfall. (Ia=0.1S). All other regions (Ia=0.3S) (i.e. polar region)	>28	>52.5	>40

Estimated curve number (CN): To generate the curve number, the soil map and LULC map have been used. The hydrological soil group map and LULC map has been intersected and assigned the CN value with the help of software. The curve number has been estimated using the following equation -

$$CN = \sum (CNi \times Ai) / A$$

Where: CN = weighted curve number, CNi= curves number from 1 to any no. N. Ai = area with curve numbers CNi, A = the total area of the watershed.

SCS model: The SCS model is also known as the Hydrologic Soil Cover Complex Model, is an adaptable and appropriate procedure which are used for runoff estimation[26]. The curve numbers (CN) value varies from 0 to 100 of an area. The following equation has been used for estimation of runoff depth.

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

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

Where: Q= actual surface runoff in mm, P= rainfall in mm, Ia =Initial abstraction (mm), S = Maximum recharges capacity of mm. CN = Curve Number.

The initial abstraction (s) has been calculated in the ArcGIS software with maintaining the formula.

Software used: For the present study, the thematic maps like LULC map, soil textural map, Rainfall map, hydrological soil group map, curve number map and runoff map has been generated and calculated with the help of ArcGIS 10.3.1 and ERDAS 9.2 Software.

Results and discussion

Land use/land cover (LULC): This region is composed of five categories land uses like water bodies, settlement, natural vegetation, fallow land and agricultural land (Figure-2). The natural vegetation and build up areas are main components which strongly determine the surface runoff. The fallow or barren land, agricultural land, gullies, and rivers accelerates the surface runoff. The water bodies, settlement, natural vegetation, fallow land and agricultural covers about 0.505%, 2.105%, 6.194%, 4.278% and 86.916% of the basin respectively.

Soil texture: Pedologically, this region is composed of seven soils textural classes like clay, clay loam, haplustepts, loam, plustepts, sandy and sandy loam (Figure-3). Surface Runoff depend on the soil textural class. The clay soil texture increases the runoff due to very low infiltration rate and sandy, sandy loam reduces the runoff due to very high infiltration rate.

Hydrological soil group: In the present basin all the hydrological soil groups which have been developed by National Engineering Handbook (NEH) of USDA have been found (Figure-4). The brief description of the hydrological soil group has been mentioned in Table-1. For the generation the curve number, the hydrological soil groups and LULC has been integrated. The Curve-Number (CN) has been calculated based on Table-2.

Curve Number (CN): The CN value has been determined with the help of antecedent moisture condition class III for Indian country. The value of the CN number of this region varies from 26 to 96 respectively (Figure-5). The CN value has been classified into four categories like 26-61, 61-74, 74-83, and 83-96. The low range CN value has been found in the natural vegetation cover area and high CN values found in the areas which are covered by the barren land, agricultural land, settlement and water bodies.

Table-3: Area distribution and Description of Soil Texture.

Texture class	Area (sq.km)	% of Area	Description
Clay	25.445	6.495	Heavily sticky, hard when dry.
Clay loam	6.801	1.736	Coarse, sticky, easily broken.
Haplustepts	231.063	58.982	Fine loamy mixed type, granite and gneiss formation, concrete, hard.
Loam	7.731	1.973	Not coarse and have sticky.
Plustepts	15.333	3.914	Fine loamy mixed type, hard and concrete, and granite gneiss formation.
Sandy	63.934	16.320	Very coarse, cannot form clods and no stickiness.
Sandy loam	41.439	10.578	Coarse, can easily collapse, some stickiness.

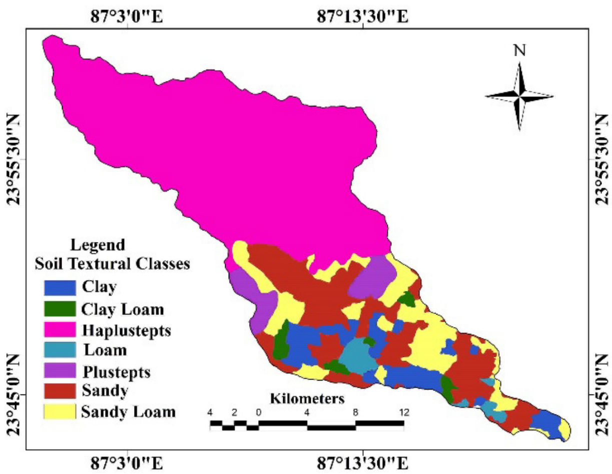

Figure-2: LULC Map.

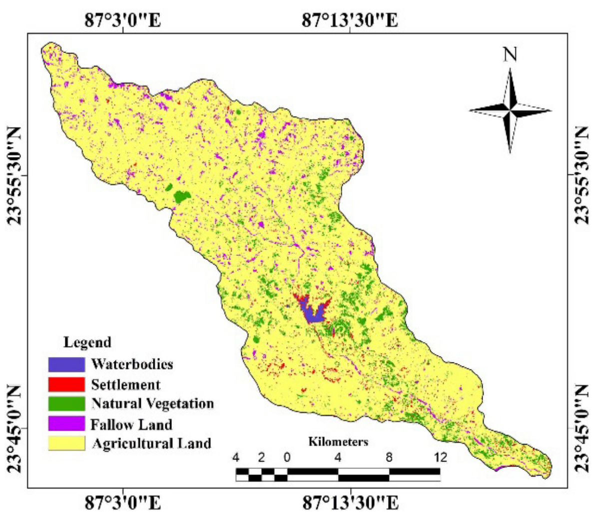

Figure 3: Soil Texture Map.

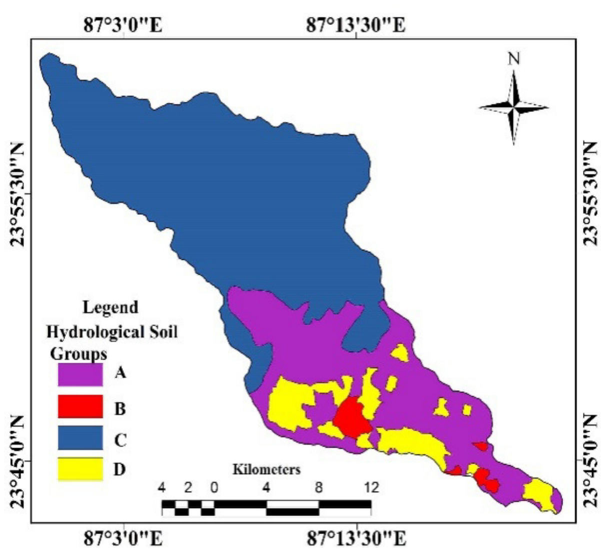

Figure-4: Hydrological Soil Group Map.

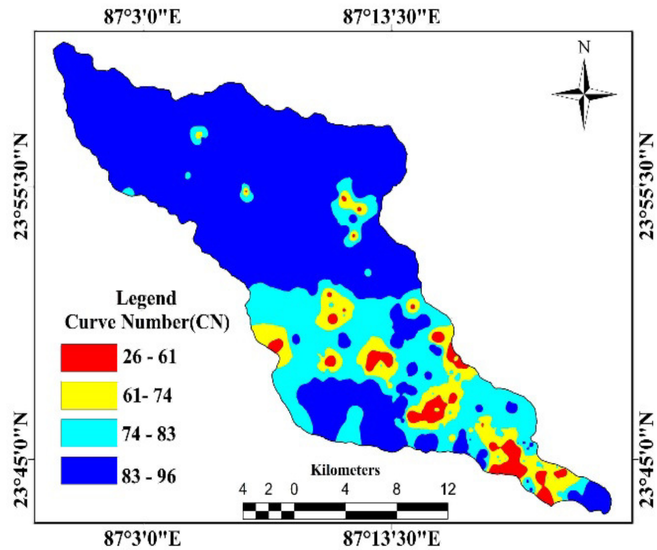

Figure-5: Curve Number(CN) Map.

Rainfall: Rainfall is the important component to estimate the surface runoff of this region. The rainfall data has been collected from Indian metrological department in last 5 years (2011-2016) and the thematic map has been generated by IDW process with the help of ArcGIS software. The annual average rainfall of this region ranges from 1316 mm to 1360 mm respectively (Figure-6). Rainfall controls the runoff condition on the land surface and helps to maintain the balance of hydrological cycle.

Heavy rainfall accelerates runoff flow and paucity of rainfall region signifies the nil runoff. So, rainfall plays an important role for the generation of surface runoff. Surface retention capacity(S) has been calculated with the help of Curve number. The value of surface retention(S) varies from 7mm to 722 mm respectively (Figure-7) of this watershed.

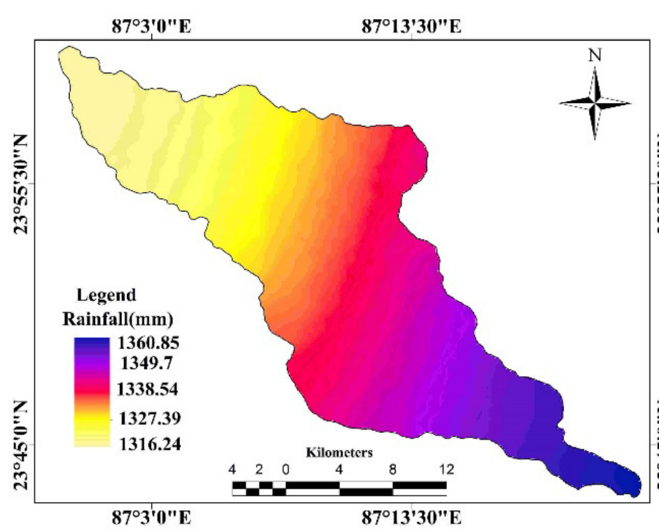

Figure-6: Rainfall Map.

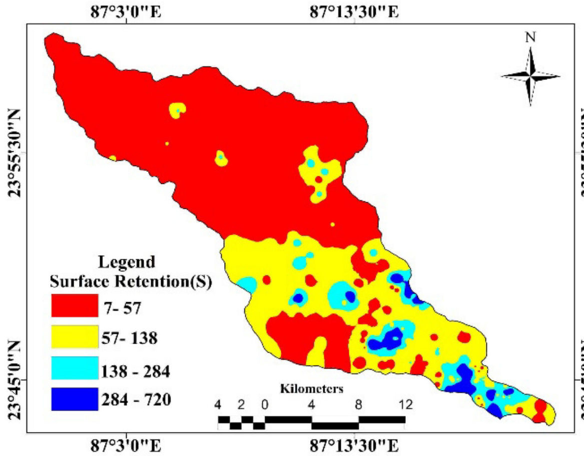

Figure-7: Surface Retention (S) Map.

Runoff: Using SCS-CN method, the surface runoff has been estimated in Hinglo River basin. Different parameters like the rainfall, LULC, soil texture, hydrological soil group, and curve number conditions have been used to calculated the surface runoff. The surface runoff of this region has been calculated for three seasons like pre-monsoon, monsoon, and post-monsoon. The surface runoff of the pre-monsoon, monsoon and post-monsoon seasons has been classified into four categories like very low, low, medium and high runoff potential respectively. The annual runoff map has also been classified into four categories like very low (696.44 to 1034.82mm), low (1034.82 to 1190.23mm), medium (1190.23 to 1265.43mm) and high runoff potentiality (1265.43 to 1335.61mm). The upper catchment is the high runoff potentiality area rather than lower catchment in pre-monsoon and monsoon season and its reverse condition is found in the post monsoon season. The average annual high potential runoff of this region has been found in the upper portion like western and north-middle part because geologically this portion covers with granite-gneiss formation and barakar formation. Granite-Gneiss and Barakar formation obstructs the infiltration and accelerates the surface runoff flow. The very low and low annual runoff has been found in the lower catchment area. Geologically this region covers with newer alluvium which is suitable for the high infiltration. The natural vegetation cover is main preventive component of environment and it decreases the torrent flow of the surface runoff (Figures 8-11).

Conclusion

Remote Sensing and Geographical Information System is a reliable technique which demonstrate the data planning, data processing, storing and manipulation of the spatial and non-spatial data of the Hinglo watershed region. The environmental parameters like land use land cover, soil texture map, rainfall and hydrological soil groups are the vital component for determination of the surface runoff using the SCS-CN method. With the help of the Remote Sensing and Geographical Information System, it is easily possible to compute the runoff and also helps in the watershed development and management planning. The study shows that the upper portion of this region are the high runoff potentiality area due to lack of sufficient natural vegetation cover and most of the vacant agricultural land. So, to manage the surface erosion and the fertility of the soil in the upper part of the basin immediate watershed management planning should be implemented.

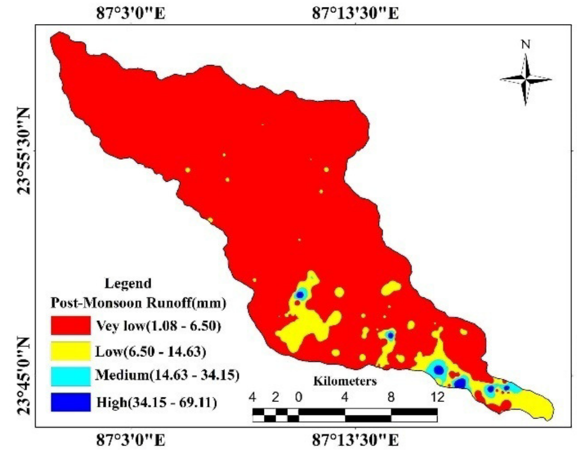

Figure-8: Pre-Monsson Runoff Map

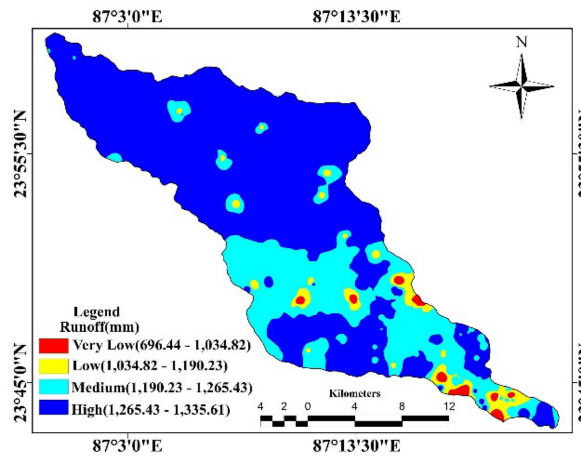

Figure-9: Mons oon Runoff Map

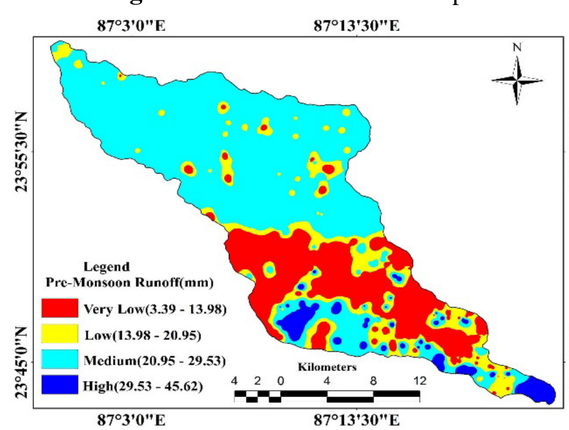

Figure-10: Post-Monsoon Runoff Map

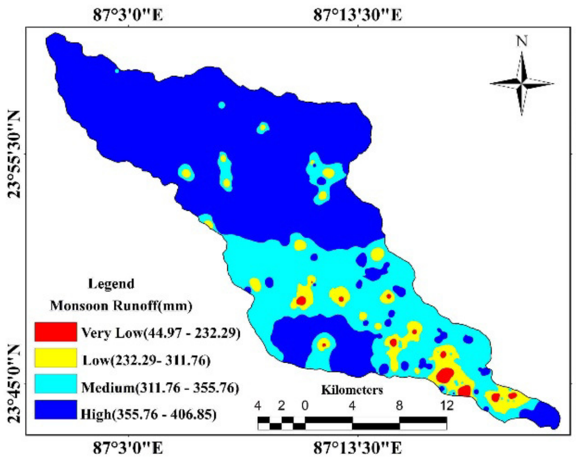

Figure-11: Annual Runoff Map.

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