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Estimation of Surface Runoff and its Seasonality of Kushkarni River Basin

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Abstract

Kushkarni River Basin, a rarh tract of Chottonagpur plateau, is situated in western part of Birbhum District, West Bengal. Surface runoff, one of the most vital indicators of surface water availability, ground water recharge, soil erosion, agricultural practice etc. Estimation of runoff is needed for water resource planning and environmental impact analysis. Geographical information system (GIS) and remote sensing techniques are used for estimating runoff depth with the help of Arc GIS 9.3 and ERDAS Imagine 9.2. The US Department of Agriculture, Soil Conservation Service Curve Number (SCS-CN) method is used in this study. Runoff curve number is determined based on hydrologic soil group, land use and land cover, and hydrologic condition. The average monthly rainfall data of 23 years (1980-2013) is collected from Suri meteorological station. The computed maximum effective runoff depth is 693.335 mm in monsoon time.

Keywords: Runoff, CN, Hydrological soil group, Land use and land cover, Effective runoff depth..

Introduction

When amount of rainfall is more than the soil infiltration capacity, a part of precipitation would flow along the slope of the basin surface and will be emitted by water bodies. This excess precipitation which is measurable in the river is called surface runoff[1]. Precipitation is most important factor which directly effects on hydrological cycle and estimation of runoff. Runoff is the most vital indicators for measuring soil erosion. For sediment reduction and hazard estimation runoff is dominating factors. For estimating the runoff numerous hydrological models are accessible among them physically based models are limited because of their large number of input parameters and complicated calibration requirements [2-3]. Runoff may be measured by daily, monthly and annually[4]. Runoff of a watershed depends on rainfall intensity and typically it varies seasonally. As a result, the amount of runoff might not be the same throughout the year[4]. This study area falls under hot and sub humid monsoon climatic region. Maximum rainfall (82%) occurs in monsoon time (June to September). In India the accessibility of exact runoff information is rare[5]. But the Soil Conservation Service Curve Number (SCS-CN) model developed by the USDA-Soil Conservation Service in 1972[6] (USDA SCS 1985)[7] is used for the estimating of runoff. This model is a simple and empirical with clearly stated assumptions and few data requirements. So it has been widely used for water resource management, storm water modeling and runoff estimation for individual rainfall events in small agricultural or urban watershed[8-16]. After ponce[17] SCS CN model should be used less than 250 sq km without catchment subdivision. In this study GIS based watershed analysis and remote sensing classification techniques is used for gathering, examine and explaining the parameters of runoff. Basically runoff depended on land use land cover, soil character and rainfall data. Highly urbanized area promotes maximum runoff. Growth of urban settlement reducing infiltration, base flow and lag time, with increasing storm flow volumes, peak discharge, frequency of floods and surface runoff [18-22]. The main objectives of this research are determined spatial distribution of runoff, calculating CN value using ERDAS Imagine 9.2 and Arc GIS 9.1 software, estimating spatially variable runoff depth using raster calculator Arc GIS 9.3.Lastly runoff coefficient is calculated.

Study Area: Kushkarani is an upstream tributary of Mayurakshi River situated in Birbhum district of West Bengal and Jamtara district of Jharkhand. The basin is demarcated by 23°54’ 36” N. to 24° N. latitudes and 87°14’24” E. to 87°30’ E. longitudes with a total area of 172 sq. km. (Figure-1). The east-west elongated basin of the 35 km. long river is situated in the eastern margin of the Chhotonagpur plateau, where the highest elevation (155 metres) is seen in the western side near the source of the river and lowest elevation (62 metres) is seen in the eastern side near its confluence (Figure-1). Maximum area of the basin is occupied by rugged topography with an average elevation of 108 metres. On an average 120 metres contour roughly demarcates upper catchment, 80 metres contour delimits middle catchment and the rest part below 80 metres contour indicates lower catchment of this basin (Figure-1). The basin falls under the hot and sub-humid monsoonal climatic region. There is variation of soil qualities in different parts of the basin viz. upper catchment is dominated by coarse lateritic soil, and rest part is composed with laterite and relatively old alluvial soil. The extreme confluence part of this river frequently submerged by extension of the water logged on Tilpara Barrage.

Materials and Methods

In this study area survey of India (SOI) toposheet no73M/1, 73M/5, 73M/9 of 1:50000 scale was used to extract study area and drainage line. Landsat 8(OLI), February, 2014 (Path/Row: 139/43; Band used: G, R, NIR; Spatial resolution: 30m. was used to delineate land use land cover map. Soil map is collected from NIC Birbhum district centre. Average Rainfall data of 23 years (1980-2013) was collected from Suri meteorological station. For creating spatial data layer maps Arc GIS 9.3 was used. ERDAS Imagine 9.2 was used for generation of landuse landcover (LULC) map (Table-1).

Estimation of SCS CN: For estimating surface runoff depth various hydrological model are available. Among available model some models are complex and rest is simple, having several formations with input data requirements. Generally Soil Conservation Service (SCS) model is extensively used for estimating runoff depth within various models. On the basis of hydrological soil group, land use and land treatment, hydrologic (draining) conditions and antecedent moisture condition (AMC) the curve number (CN) is determined. Hydrological soil group are divided into four groups A, B, C and D according to their sand size. The CN value may vary from 1 to 100, with higher CN values associated with higher runoff potentiality. In this study annual rainfall map, monsoon rainfall map, pre monsoon rainfall map, land use land cover and soil texture maps are used for CN calculation (Figure-2,3,2,4,5,6).

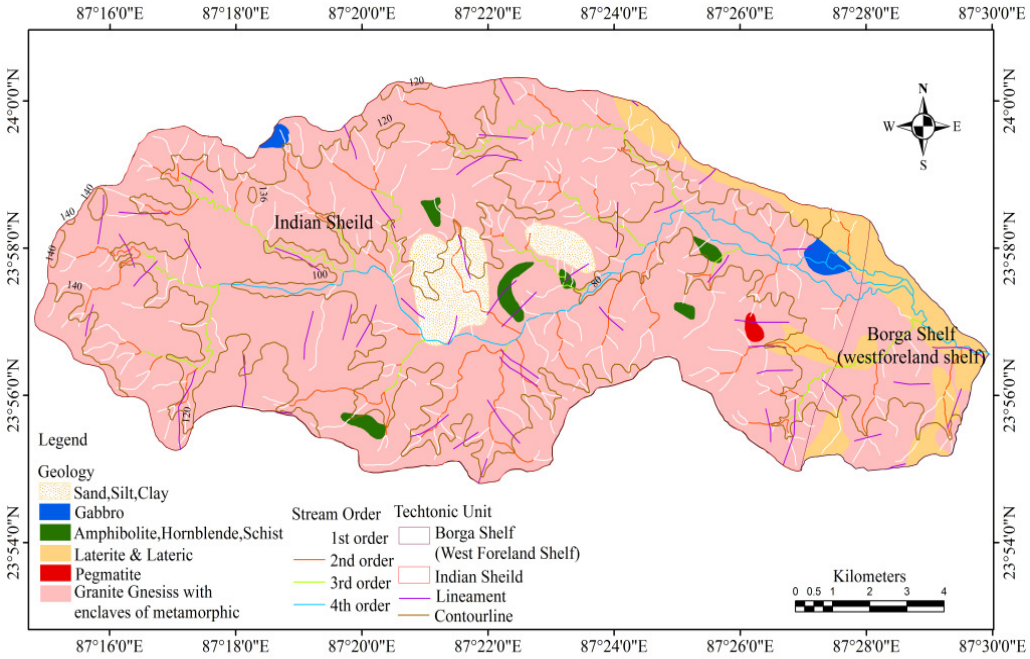

Figure-1
Study Area map

Table-1
Data materials and their sources

Layers	**Source**
Basin boundary and drainage system	Survey of India toposheet of 1:50000 scale
Land use land cover	Sensor: Landsat 8(OLI), Feb., 2014 (Path/Row:139/43; Band used: G, R, NIR; Spatial resolution: 30m.), Land use map, 2014 of Land reform deptt., West Bengal
Hydrological soil group	Soil texture map prepared by NIC Birbhum
Rainfall map (Annual, pre monsoon, monsoon)	Meteorological station of Suri.

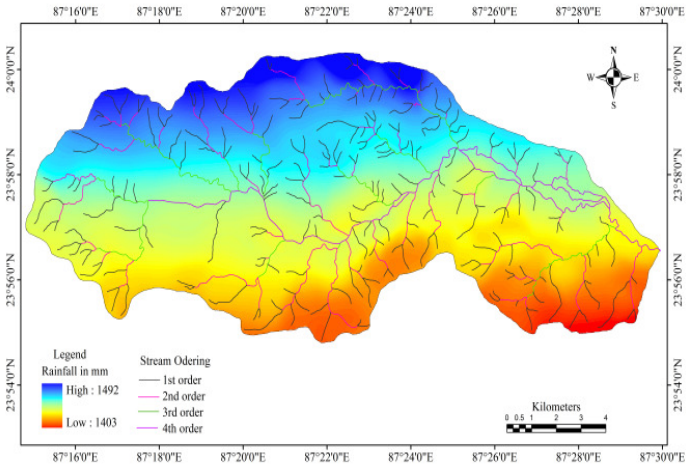

Figure-2
Annual Rainfall map

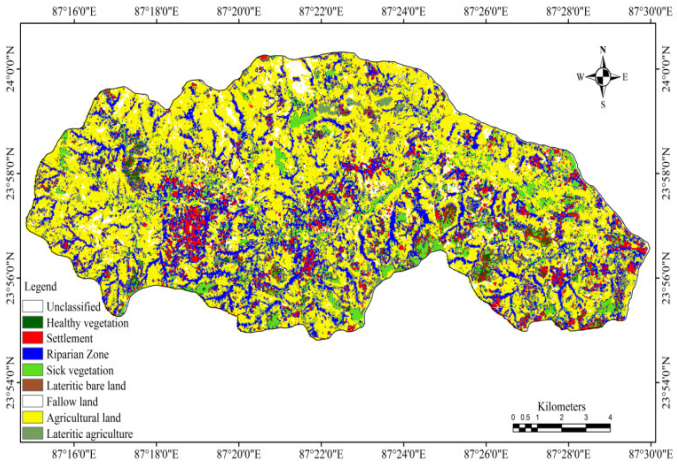

Figure-5
Land Use Land Cover

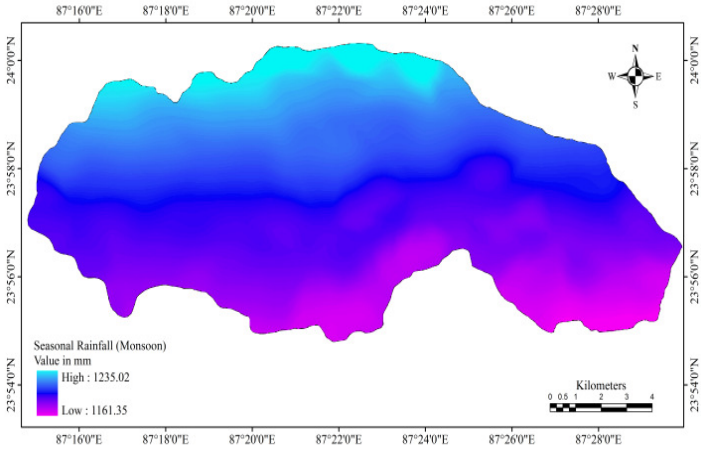

Figure-3
Monsoon Rainfall map

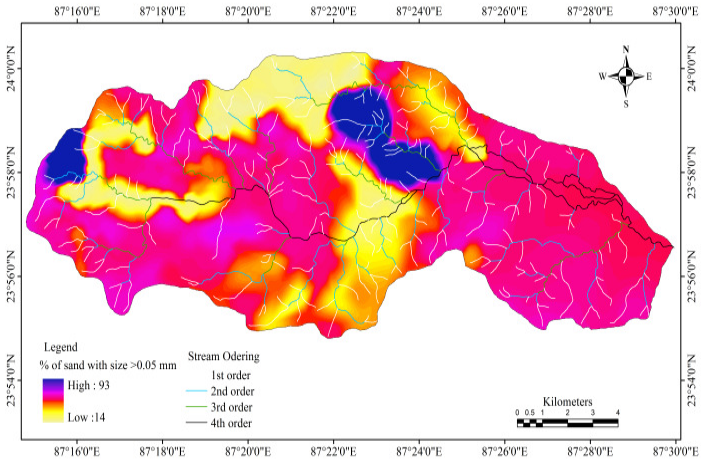

Figure-6
Soil Texture map

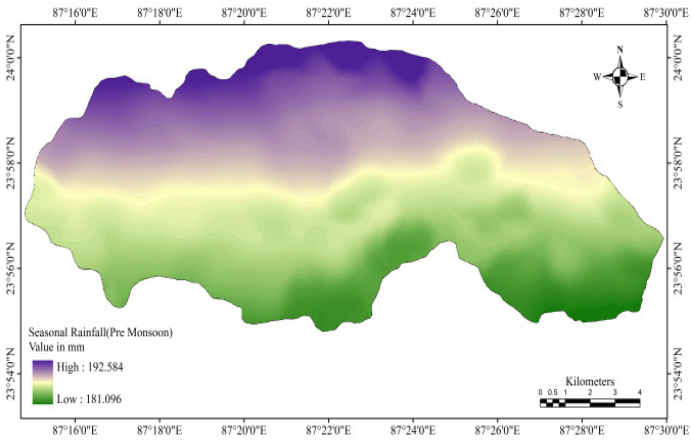

Figure-4
Pre Monsoon Rainfall Map

Methods of Estimating Spatial Surface Runoff: SCS method has been used for estimating surface runoff .For getting consistently usable result The SCS method has been used by numerous researchers [23-25] for runoff estimation. The SCS model computes direct runoff through an empirical equation that required the rainfall and a watershed co-efficient as input. The watershed co-efficient is called the curve number (CN) which represents the runoff potential of the hydrologic soil cover complexes. The SCS model (SCS, 1972)[6] involve relationship between land cover, hydrologic soil classes and curve number. To calculated the surface runoff of a small watershed of a river basin following is equations are used[26].

$$Q = (P - Ia)2 / (P - Ia + S) \quad (1)$$

Where: Q is actual surface runoff in mm, P is rainfall in mm, Ia is Initial abstraction or losses of water before runoff begins by soil and vegetation such as infiltration or runoff interception by vegetation. In this work Ia value is consider as 0.1, 0.2 and 0.3.

[Ia=0.3 for heavy rain in Monsoon period Ia=0.2 for Pre Monsoon period and Ia= 0.1 for average rainfall all over the year.]

S is the potential maximum retention in mm and is calculated using the Equation-2.

$$S = (25400 / CN) - 254 \quad (2)$$

CN value is calculated based on SCS 1986[27] .When Curve Number (CN) value is equals to 100, Potential maximum retention becomes 0 (In waterlogged areas or in wet paddy field). This leads to Runoff = Precipitation. In other cases, when Potential maximum retention 100, Curve Number will be 0, this gives Runoff = 0 [28].

Methods for Effective runoff depth estimation: Estimation of effective runoff depth is same to estimating runoff depth. To estimate effective runoff depth evaporation is deducted from runoff depth model both in monsoon and pre monsoon time. Though the basin is falls under

Methods of calculating Runoff Coefficient: The equation of runoff can be derived from water balance equation under the critical assumption that the ratio of the predicted runoff to the potential runoff (rainfall- less initial abstraction) is equal to the ratio of the actual retention to the potential retention[29]. The simple equation used to calculated runoff [30] is:

$$RC = \frac{F}{S} = \frac{Q}{P}$$

Where: F =Actual retention after runoff begins, S =Potential maximum retention after runoff begins, Q = Actual runoff/ run off depth (mm.), P =Rainfall in mm, RC= runoff coefficient (fraction).

Finally, the runoff zonation map was generated by using a runoff coefficient. Here the runoff coefficient is calculated with ratio between runoff and rainfall.

Results and Discussion

Estimation of annual average runoff: The study area receive different amount of rainfall all over the year. The total rainfall all over the year is 1444.431882 mm and there is no raindrop less month. The maximum amount of rainfall in monsoon period is 1235.02 mm and minimum is 181.096 mm in pre monsoon time. Potential maximum retention (Figure-8): of the study area is 22mm to 103 mm with initial abstraction 6.6-30.9 mm (Figure-9). The annual runoff depth of the study area is 1291.09 mm to 1434.92mm (Figure-10).

The annual runoff depth is so high with CN value 70-90 (Figure-7). Table-2 shows that the total area and percentage of area under different runoff classes.

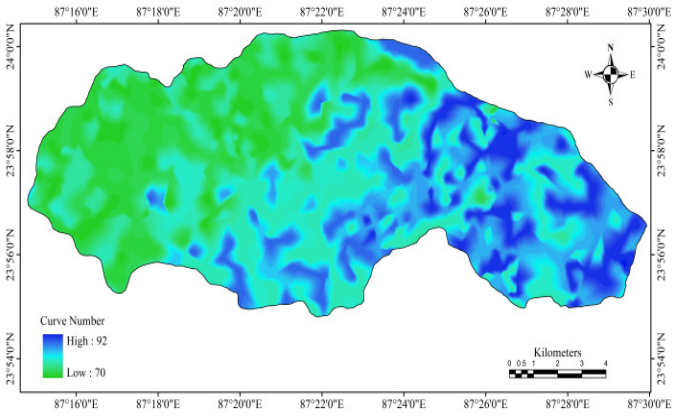

Figure-7
Curve Number

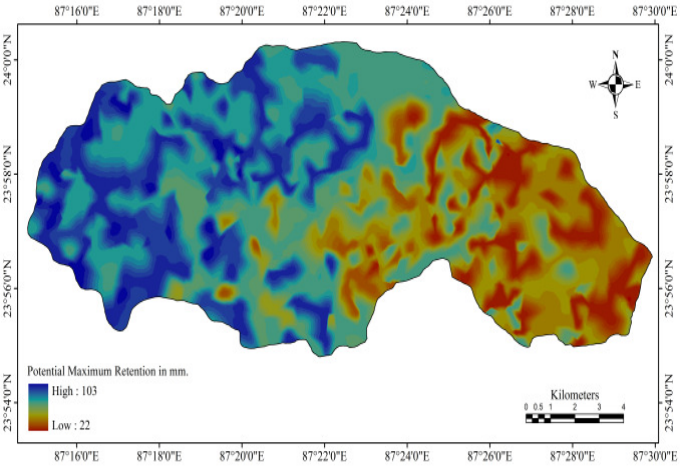

Figure-8
Potential Maximum Retention (S)

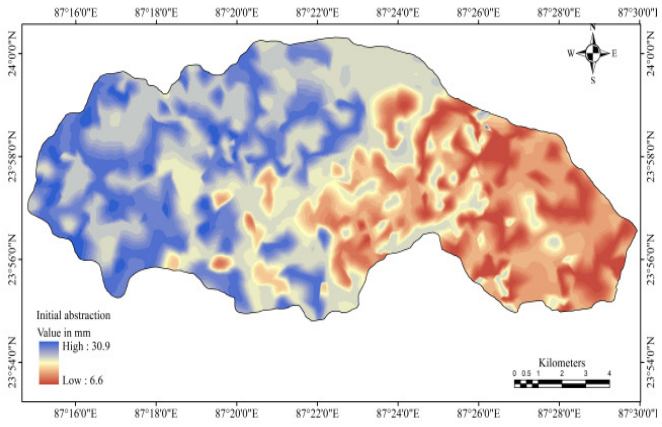

Figure-9
Initial Abstractions for Annual Runoff

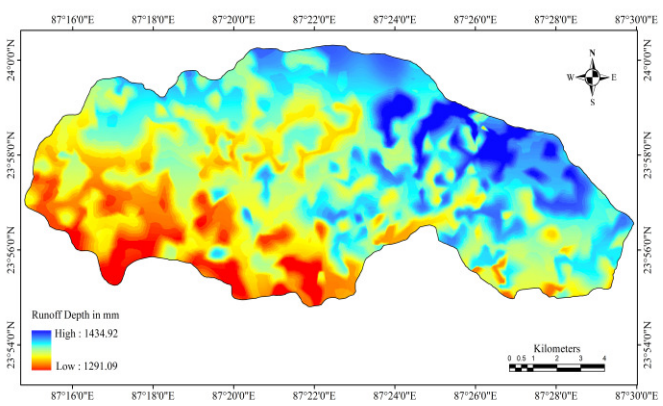

Figure-10
Runoff Depth for Annual Rainfall

Table-2
Area under Annual Runoff depth

Runoff status	Classified score	Area extent (sq.km)	% of total area
Very low	1,291.087 - 1,331.130	23.22367	13.47785
Low	1,331.130 - 1,353.258	40.29934	23.3877
Moderate potentiality	1,353.258 - 1,372.234	45.27113	26.27309
High	1,372.234- 1,393.361	44.08681	25.58577
Very high	1,393.361 - 1,434.921	19.42897	11.2756

Estimation of Seasonal Runoff: In pre monsoon time the average rainfall is 181.096 mm (since 1980-2013) which is used to estimate the runoff. The runoff value ranges between 100.297-163.892 mm (Figure-12) and initial abstraction value ranges between 4.4 -20.6 (Figure-11). This result shows that 4.27-15.05% rainfall loss due to different obstruction and remaining 84.95-95.73% rainfall occurring surface runoff.

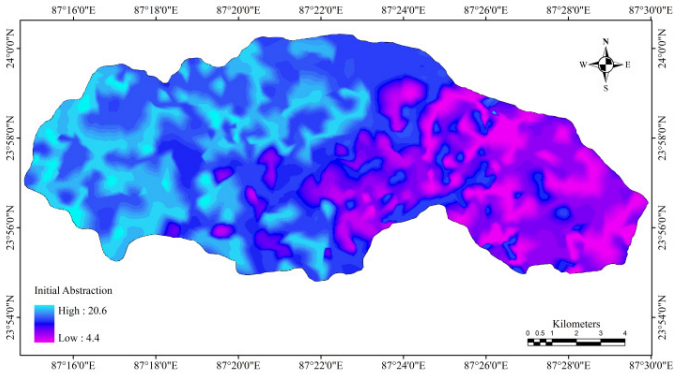

Figure-11
Initial Abstractions for Pre Monsoon

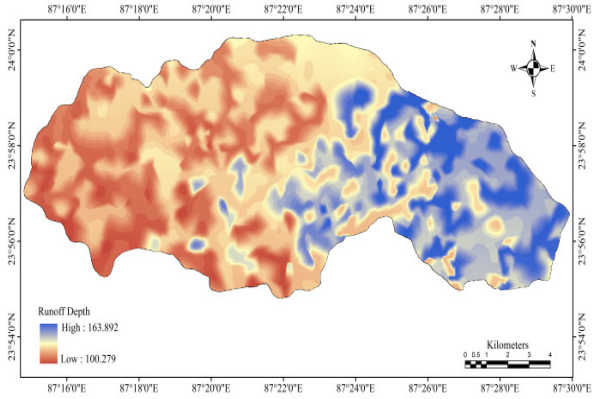

Figure-12
Runoff Depth for Pre Monsoon

In monsoon time the average rainfall is 1235.02 mm (since 1980 to 2013). The calculated runoff is 1049.16 -1182.34mm (Figure-14) and initial abstraction value ranges between 6.6-30.9 (Figure-13). This result shows that 4.27-15.05 % of rainfall is loss in other sector and rest 84.95-95.73% of rainfall flowing through runoff. Maximum amount of runoff occurs in the western and middle part of the basin and minimum amount of runoff happening in the confluence part of the basin.

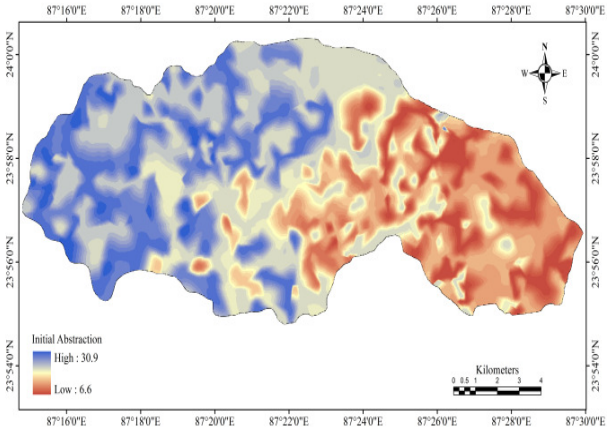

Figure-13
Initial Abstraction of Monsoon

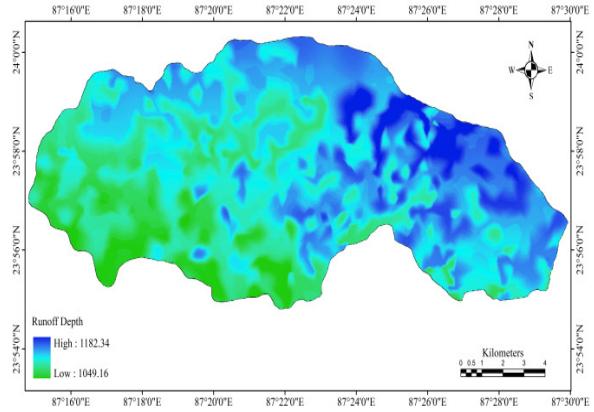

Figure-14
Runoff Depth of Monsoon

Monsoon and pre monsoon runoff maps are classified into five classes on the basis of runoff for estimating total area and percentage of area. Figure-15 and Table-3 shows that out of total area about 12.82% area under very high runoff depth and about 23.73% area under very low runoff depth in pre monsoon time. Figure-16 and table-4 shows that out of total area about 9.01% areas under very high runoff depth and about 13.39% area under very low runoff depth in monsoon time.

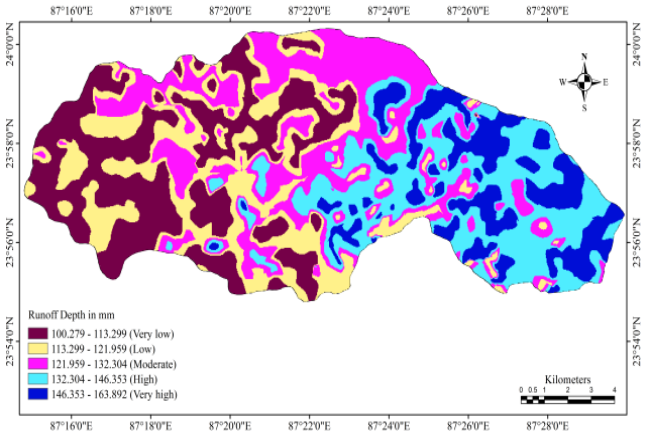

Figure-15
Classified runoff depth of pre monsoon

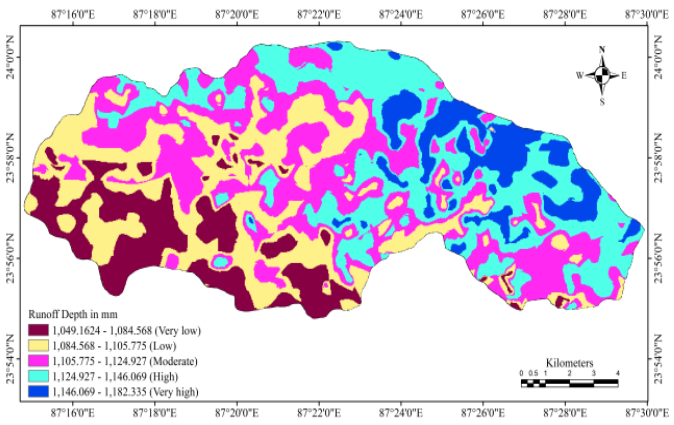

Figure-16
Classified runoff depth of monsoon

Analysis of effective runoff: Effective runoff is calculated for estimating actual runoff. Evaporation rate did not deducted from runoff depth in the time of calculating monsoon and pre monsoon runoff. This study area falls under hot and sub humid monsoon climatic region. So evaporation rate is too much significant on runoff depth. The evaporation rate is 72 cm/year which is almost 50% of the total rainfall.

Table-3
Area under Pre Monsoon Runoff Depth

Runoff status	Classified score	Area extent (sq.km)	% of total area
Very low	100.279 - 113.299	40.89386	23.73274
Low	113.299 - 121.959	35.94231	20.8591
Moderate	121.959 - 132.304	38.71453	22.46796
High	132.304- 146.353	34.65637	20.11281
Very high	146.353 - 163.892	22.10286	12.82739

Table-4
Area under Monsoon Runoff Depth

Runoff status	Classified score	Area extent (sq.km)	% of total area
Very low	1,049.162 - 1,084.568	23.08327	13.39637
Low	1,084.568 - 1,105.775	41.44127	24.05043
Moderate potentiality	1,105.775 - 1,124.927	48.8359	28.34189
High	1,124.927 - 1,146.069	43.40969	25.19279
Very high	1,146.069 - 1,182.335	15.5398	9.018518

Evaporation rate is high in pre monsoon time more than rainfall amount. But monsoon time it is low for high relative humidity. The effective runoff depth is calculated by deducting the evaporation rate from runoff depth, both in monsoon and pre monsoon time. The average effective runoff depth in monsoon time is 624.73 mm and pre monsoon time is -314.16 mm. (Table-5)

In pre monsoon time effective runoff is -400.121mm to -336.508 mm. (Figure-17) the value shows that negative runoff occur in pre monsoon time due to high initial abstraction and greater evaporation. In this time more abstraction comes about confluence part of the basin with -354.047 to -336.508 mm (Figure-19) and very low abstraction falls under upper catchment of the basin area with -400.121mmto -387.100 mm (Figure-19) with 12.83% and 23.696 % areal cover respectively (table-6).

In monsoon time effective runoff value ranges between 560.162-693.335 mm (Figure-18). Very high runoff occurred in lower catchment or confluence part of the basin with 657.069-693.335(Figure-20) mm and less runoff occurred in western and south western part of the study area with 560.162-616.775 mm (Figure-20) with 9.026% and 13.399 % areal cover respectively (table-7).

Table-5
Average effective runoff depth

Runoff depth Type	Average Runoff depth value
Monsoon	624.73
Pre monsoon	-374.16

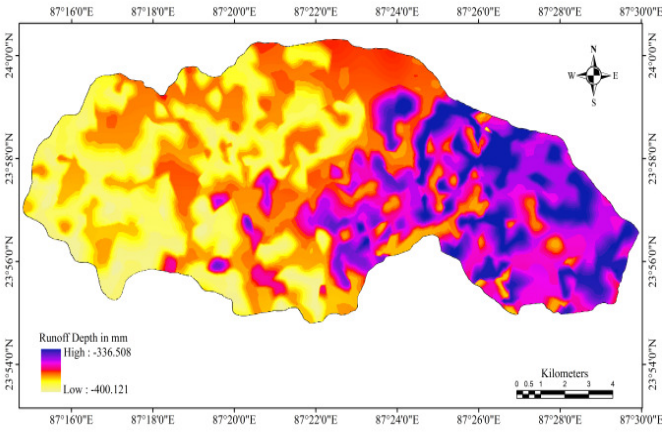

Figure-17
Effective surface runoff depth of pre monsoon

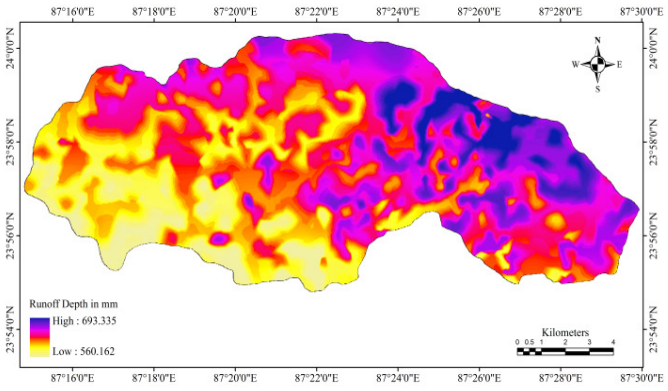

Figure-18
Effective surface runoff depth of monsoon

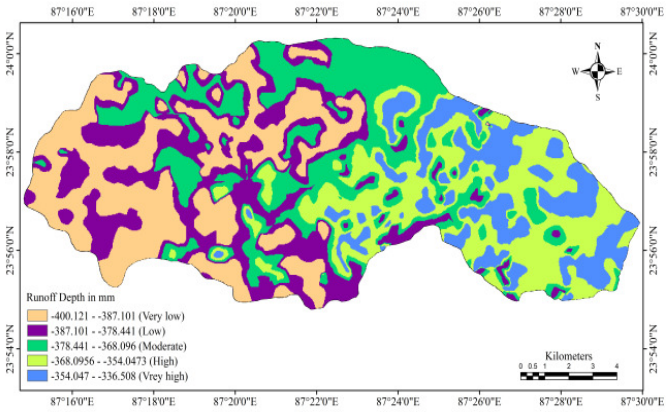

Figure-19
Classified effective surface runoff depth of pre-monsoon

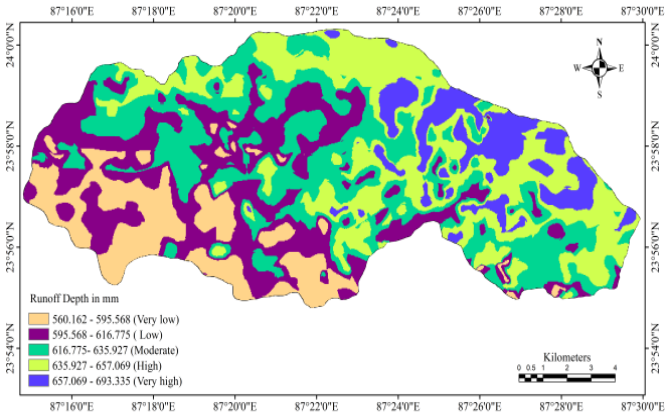

Figure-20
Classified effective surface runoff depth of monsoon

Runoff Coefficient: Runoff co efficient is calculated for estimation the total runoff according to rainfall. In this study in monsoon time (June to September) runoff coefficient value is

0.468-0.579 (Figure-22) which indices that 47-58% rainfall flows on the surface like runoff. Runoff coefficient is not same all over the basin, some part of the basin experienced strong runoff coefficient bur some parts are very low runoff coefficient. In pre monsoon time (March to May) runoff coefficient value runs in negative because very little rainfall and excessive evaporation. In this month runoff coefficient value is -2.1461 to -1.8099 (Figure-21), it indicated that pre monsoon time this basin suffer strong water crisis. Table-8 shows the average seasonal runoff coefficient.

Table-6
Area under pre monsoon effective runoff depth

Runoff status	Classified score	Area extent (sq.km)	% of total area
Very low	-400.121—387.100	40.75751	23.69623
Low	-387.100—378.441	35.94195	20.89648
Moderate potentiality	-378.441—368.096	38.64429	22.46761
High	-368.096—354.047	34.59349	20.11249
Very high	-354.047—336.508	22.06276	12.82719

Table-7
Area under monsoon effective runoff depth

Runoff status	Classified score	Area extent (sq.km)	% of total area
Very low	560.16 -595.57	23.04702	13.39943
Low	595.57 - 616.78	41.36002	24.04652
Moderate potentiality	616.78 - 635.93	48.74465	28.33991
High	635.93 - 657.07	43.32277	25.18766
Very high	657.07 - 693.34	15.52554	9.026476

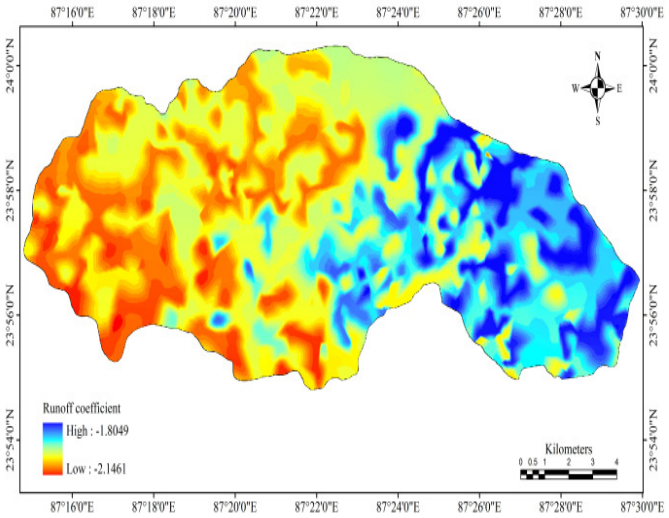

Figure-21
Runoff Coefficient of Pre Monsoon Period

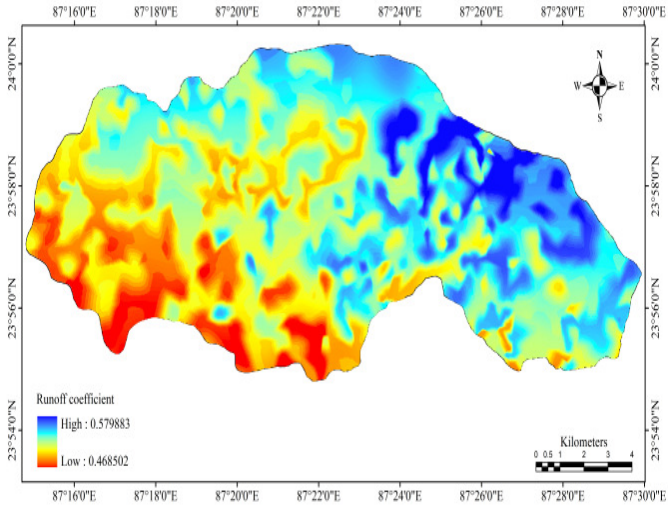

Figure-22
Runoff Coefficient of Monsoon Period

Table-8
Seasonal average runoff coefficient

Period	Ppt.(P)	Average Runoff(Q)	Average Runoff Coefficient (RC)	Remarks
Pre monsoon	186.4411	-374.16	-2.01	Strong water crisis in pre monsoon time runoff is <0.
Monsoon	1195.6467	624.73	0.52	Monsoon condition is favourable for rapid and massive surface runoff.

Conclusion

Runoff estimation of a watershed is a very helpful to analyzed the protection of water resource and maintaining the water quality. In the study area runoff is calculated seasonally because of Seasonality of Monsoon rainfall. In monsoon time this basin faced a strong runoff but pre monsoon time there is a crisis for water. Excessive runoff is not favourable for agriculture not for ecological environment. This basin needs scientific planning and comprehensive treatment for controlling massive surface runoff and better development.

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