



Inter-decadal Variability of Precipitation Patterns Increasing the Runoff Intensity in Lower Reach of Shilabati River Basin, West Bengal

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Abstract

Spatial and inter-decadal variability of precipitation patterns into different storm periods provides abundant impact on runoff, discharge that create the risk of rain-generated floods in this area. Ghatal subdivision is an administrative subdivision of Paschim Medinipur district in the state of West Bengal, India. This area is largely prone to devastating natural floods on a regular interval because of its shape, geophysical condition and geographical location and it is experiencing with riverine floods mainly by the Shilabati River and its tributaries. Heavy to very heavy rainfall associated with average 5–10 days cyclonic storms and depressions during the monsoon season is important factor for creating the annual flood in this area. The instrumental rainfall records of 20 years (2001–2020) reveal that percentage of average storm rainfall comparing to total annual rainfall has increasing from 63.10 in 2001 to 97.10 in 2020 and the average storm rainfall concentration has also exceeded than annual rainfall of study area in few years. The highest storm rainfall over the area was 612.6 mm in the

year 2017. As side by side percentage of runoff intensity has also increased from 47.36 in 2001 to 52.70 in 2020 that creates the risk of rain-generated floods in this area. Remote sensing data is used as the basic information input for computing runoff using the Soil Conservation Service (SCS) Runoff Curve Number (RCN) model used by US Department of Soil Conservation Service (1972). This empirical model is used for estimation of runoff intensity. So the floodplain users are coped to very heavy flood risks in future.

Keywords

Cyclonic storm and depressions · Monsoon · Runoff · Runoff curve number · Soil conservation service

9.1 Introduction

Rainfall and runoff are significant constitute for generating the river discharge in a watershed. (Zakwan et al. 2017). River basin morphology such as height, length, slope, shape, soil condition and land use have significant impact for the runoff generation in the river basin. Amongst the various methods, Soil Conservation Services and Curve Number (SCS-CN) technique is one of the unique methods for rainfall runoff modelling (Zakwan 2016). Land use and Land cover information is used to estimate the value of

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surface roughness or friction which affects the velocity of the overland flow of water and determine the amount of rainfall that will infiltrate into the soil (Ara 2018 and Zakwan 2016). The data on hydrological soil group, land use, antecedent rainfall, storm duration required to estimate surface runoff in catchments, antecedent soil moisture conditions are the basic catchment characteristics used for curve number calculations (Mockus 1949, Sharma et al. 2001). Based on Geographical Information System and Remote Sensing, land-cover and land use changes are identified (Gangodagamage and Agarwal 2001). The geomorphological factors, land use change affect the runoff volume and the runoff rate significantly through interaction with land uses and soils. (Satheeshkumar et al. 2017). Runoff is the most important hydrological variable used for analysing flood frequency and flood potentiality. Accurate and timely prediction of runoff in a drainage basin is mainly done with equation and models or direct measurement at gauging stations by either using a range of equation and models or direct measurement at gauging stations (Moitra 2008). Soil Conservation Services and Curve Number (SCS-CN) method based on Rainfall and Land use data as inputs and all the three antecedent moisture conditions (AMC-I, AMCII and AMCIII) is used in concerned area. The SCS-CN method is useful for calculating volume of runoff from the land surface meets in the river of streams. Remote sensing data is used as the basic information input for computing runoff using the Soil Conservation Service (SCS) Runoff Curve Number (RCN) model proposed by US Department of Agriculture, 1972. This empirical model is used in the present study for estimation of flood discharge in Shilabati river basin on land use conditions and to evaluate the hydrologic response of these measures on runoff. The soil Conservation Service (1972) developed a method for computing abstractions from storm rainfall. For the storm as a whole, the depth of excess precipitation or direct runoff is always less than or equal to the depth of precipitation, likewise after runoff begins, the additional depth of water retained in the watershed, is less than or equal to

some potential maximum retention S . There is some amount of rainfall I_a (Initial abstraction before ponding) for which no runoff will occur, so the potential runoff is $(P-I_a)$ (Chow et al. 1988). The volume of water available for runoff increases because of the increased impervious cover provided by bare surface, urbanisation, concrete streets etc. reduce the amount of infiltration changes the hydraulic efficiency associated with artificial channels, curbing gutters and storm drainage collection systems increase the velocity of flow and the magnitude of flood peaks. The SCS method for rainfall–runoff analysis is applied to determine the increase in the amount of runoff caused by urbanisation, increase of concrete road etc.

9.2 The Study Area

The Shilabati River originates in the extended part of Chotonagpur Plateau from the Hurra P.S. of Purulia district at west and has been extended up to eastern part of Hooghly district at Bandar in West Bengal, where it is joined Darakeshwar to originate the river Rupnarayan Bankura.gov.in. Location (2009). This river catchment is characterised by rocky and undulating tract for most of its upper part. It is extended on the lateritic flats up to the village Shimulia at Garbeta block, where the river has divided into two channels then it follows alluvial low land up to Bandar of Ghatal (en.wikipedia.org. wiki 2012). The whole catchment lies between $22^{\circ} 30' N$ – $23^{\circ} 15' N$ latitude and $86^{\circ} 40' E$ – $87^{\circ} 55' E$ longitude (concerned Toposheets no, 73I/12, 73 J/16, 73 N/1, 73 N/5, 73 N/6, 73 N/9, 73 N/10, 73 N/11, 73 N/2). The lower catchment extends between $22^{\circ} 30'$ – $22^{\circ} 55' N$ and $87^{\circ} 15'$ – $87^{\circ} 50' E$ and faces the fury of flood almost annually where Ghatal subdivision is an administrative subdivision of Paschim Medinipur district in the state of West Bengal, India. It is located in the eastern part of the Shilabati river basin which extends between $22^{\circ} 30' 30'' N$ – $22^{\circ} 50' 30'' N$ latitude and $87^{\circ} 31' 30'' E$ – $87^{\circ} 55' E$ longitude (concerned Toposheets no 73 N/6, 73 N/9, 73 N/10, 73 N/11). Heavy to very heavy rainfall associated with

average 5–10 days cyclonic storms and depressions appears during the monsoon season in this area (Flood Monograph 2007). The study area faces the fury of flood almost annually. The floods which occurred in 1978, 1982, 1985, 1987, 1988, 1993, 2001, 2007, 2015, 2017 and 2020 were devastating and caused serious damages of lives and livelihood of the majority of people. The inundation was more extensive and loss of life and properties were very severe.

9.3 Materials and Methods

Rainfall data has been collected (2000–2020) from Central Water Commission, Paschim Medinipur, Subdivisional Agricultural Farm Office at Khirpai, Ghatal, Paschim Medinipur. In the present study, the sub-watersheds are identified and the USDA Soil Conservation Service (SCS) runoff curve number (CN) are selected for the Shilabati (main river), Joypanda, Betal, Donai, Tangai, Kubai and Parang (sub-watersheds) from a digitised land use and land cover map derived from ERDAS IMAGINE 9.0 on IRS- LISS-III, Satellite Imagery (2nd April, 2010) and Resourcesat-1 image (2nd May, 2020), Google Map and concerned toposheets no (73I/12, 73I/16, 73 N/1, 73 N/5, 73 N/9, 73 N/10, 73 N/11, 73 M/4, 73 N/2, 73 N/6 etc.) and it is verified through field check. This was accomplished with the help of standard SCS table of runoff curve number modified for Indian conditions. The four hydrological soil groups (A, B, C, D) are used in determining hydrologic soil cover complexes which are used in this method for estimating runoff from rainfall. The soil properties play an important role in the estimation of runoff from the rainfall and in this concern the properties are represented by the hydrological parameters. Direct runoff produced in that watershed by a given precipitation are estimated using the model SCS-CN is widely used and involves the use of simple empirical formulae. The equation requires the rainfall and watershed coefficient as inputs. The Composite Curve Number is computed from the Runoff Curve Number (RCN) which is a quantitative descriptor of the Land and Soil complex and it is derived on

the basis of Soil-Vegetation-Land (SVL) and Antecedent Moisture Condition complex. It takes on values from 0 to 100 (Sharma and Kumar 2002). The AMC value is intended to reflect the effect of infiltration on both the volume and rate of runoff according to the infiltration curve. Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. (Suresh 1997). The watershed coefficient called curve number (CN) which is an index that represents the combination of hydrologic soil group and land use and land treatment classes. The Curve Number in AMC III condition (as the total rainfall corresponds to the AMC III Condition) for each land use category is then applied in order to estimate Weighted Curve Number for each watershed with following formula proposed by (Schwab et al. 1993). The Potential Maximum Retention (S) in mm is then calculated with the Eq. 9.3. The Runoff in cubic meter is then calculated with (Eq. 9.2). The expression used in SCS runoff is presented as following equations (Sect. 9.3.1).

9.3.1 Model and Potential Retention Equation

The runoff Eq. (Handbook of Hydrology 1972).

$$Qt = f(Pt, S, Ia) \quad (9.1)$$

Precipitation –Runoff- Potential Retention equation (Handbook of Hydrology 1972).

$$Q = (P - 0.2S)^2 / (P + 0.8S) \quad (9.2)$$

(Handbook of Hydrology 1972).

$$S = (25400/CN)254 \text{ in mm} \quad (9.3)$$

Q Actual direct runoff (mm).

P Total rainfall mm.

S Potential maximum retention mm.

CN = SCS Runoff Curve Number, = f (Soil, land, vegetal cover, antecedent moisture condition etc.)

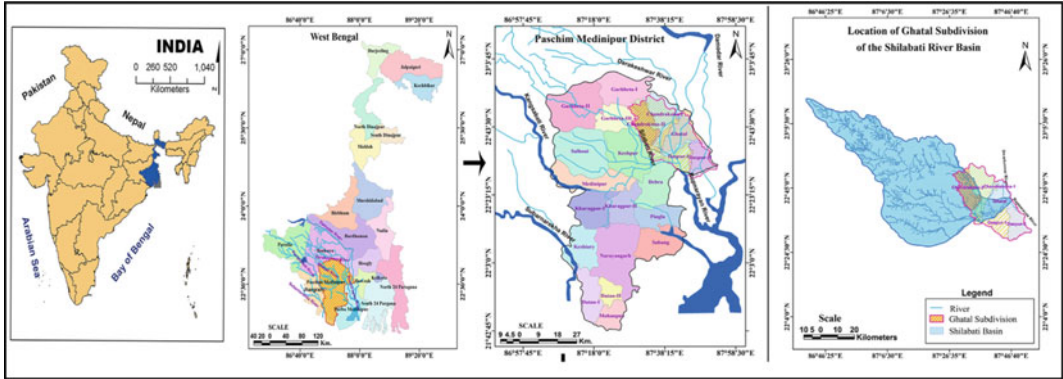
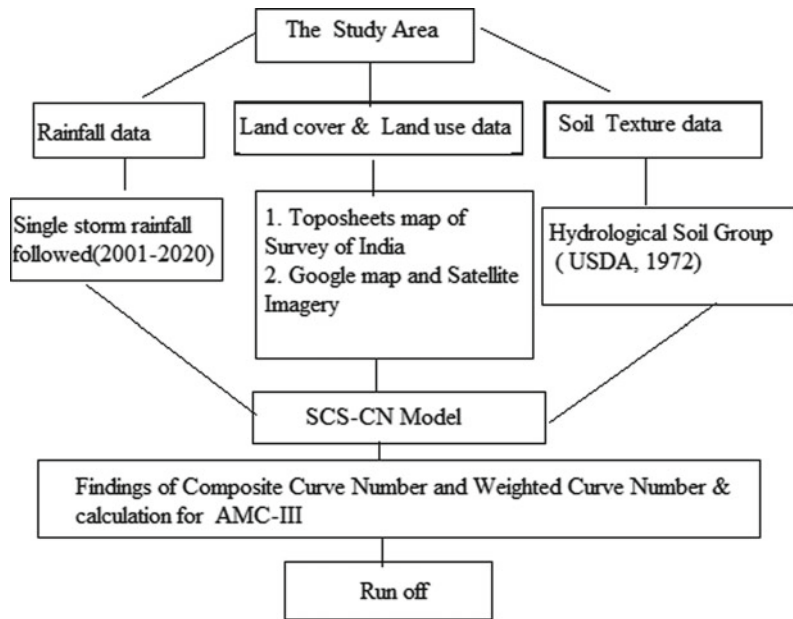


Fig. 9.1 Location of the study area

Fig. 9.2 Flow chart of the methodology of the present study



$$\text{Weighted CN} = \frac{CN_1X_{A_1} + CN_2X_{A_2} \dots CN_nX_{A_n}}{A_1 + A_2 + \dots A_n} \quad (9.4)$$

CN₁, CN₂... Curve Number of respective landuse,
 CN_n
 A₁ % area under respective landuse.

The runoff is then transferred to discharge in m³ by multiplying with watersheds area after Schwab et al. (1993).

9.3.2 Rainfall Characteristics in the Study Area (2001–2020)

Intensity of flood in this area varies considerably from year to year. Table 9.1 and Table 9.2 reflects the substantial inter-annual variation in the monsoon rainfall. Sometimes the rainfall is also maintained chiefly by cyclonic storms. Cyclones from the Bay of Bengal and the south-west monsoon current bring very heavy rainfall

Table 9.1 Average rainfall of highest storm period (2001–2020 year)

Year	Highest Storm Duration in each year	Amount of rainfall in mm in highest storm	Average rainfall in mm during storm periods	Average annual rainfall in mm at total catchment area	Percentage
2001	25.9–4.10	220.6	854.80	1354.76	63.10
2002	27.8–6.9	186.6	932.40	1426.52	55.25
2003	23.7–1.8	267.2	1489.00	1549.20	79.55
2004	12.8–23.8	236.8	1403.60	1553.14	95.87
2005	24.7–4.8	215.2	1363.80	1375.04	102.07
2006	8.7–18.7	263.2	1276.60	1686.28	80.87
2007	10.7–20.7	438.2	2355.00	1298.80	98.29
2008	17.7–27.7	128.8	1227.3	2106.00	111.82
2009	16.8–26.8	206.2	1345.4	1780.44	68.93
2010	23.6–3.7	188.8	992.4	1270.10	105.92
2011	7.8–17.8	519.4	2270.02	1001.10	99.13
2012	11.7–21.7	298.4	1484.60	1717.90	132.13
2013	13.1–23.1	325	1903.2	1113.30	133.35
2014	14.8–25.8	266	1296.60	2331.26	81.64
2015	9.7–20.7	491.4	1653.80	1157.16	112.05
2016	1.8–11.8	308.6	1424.20	1449.70	114.08
2017	18.7–28.7	612.6	1748.40	1371.50	103.84
2018	2.7–12.7	172	954.60	1544.80	113.18
2019	12.8–22.8	232	1228.34	1413.30	67.54
2020	15.7–25.7	248.9	1280.80	1319.02	97.10

over the study area (www.meteoprog.es, 2012). The analysis of the available last 20 year's hydrological data provides the vivid picture of rainfall characteristics over this area. Several extreme flood events have occurred in 2001, 2003, 2005, 2007, 2011, 2015, 2017, 2019 etc. Increasing trends of annual peak rainfall during monsoon period at every year increase the tendency of flood. The comparison and analysis of the 20 years' rainfall data display the character of magnitude of floods in this area. The long instrumental rainfall records of 20 years (2001–2020) reveal that the highest storm rainfall over the area was 612.6 mm in the year 2017 which exceed the average annual rainfall at total catchment area (Table 9.1) and the average rainfall of highest storm duration was exceeded ($347.43-235.16 = 112.27$ mm) before 2010–2020 (Table 9.2). So the flow capacity of this

channel had failed to pass the heavy amount of rain water and accumulated in mouth area and creates the water logging situation in lower reach. That is also responsible for intensification of flood usually developed by huge and concentrated rain during a monsoon trough or a single cyclonic storm in this area.

9.3.3 Identification of Drainage Pattern and Hydrological Soil Groups Map of Catchment Area

The Shilabati river catchment comprises the main six tributaries viz; Joypanda, Betal, Donai, Kubai, Tangai and Parang which have also originated almost from the same height from the eastern part of the Chotanagpur plateau and

Table 9.2 Average rainfall of highest storm period in each year at study area (2001–2020)

Year	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total	Average in mm
Total rainfall in mm of highest storm duration at each year	220.6	186.6	267.2	236.8	215.2	263.2	438.2	128.8	206.2	188.8	2351.6	235.16
Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total	Average
Total rainfall in mm of highest storm duration at each year	519.4	298.4	325	266	491.4	308.6	612.6	172	232	248.9	3474.3	347.43

follow the same gradient of this river (Fig. 9.3). The orientation and distribution of tributary sub-watersheds show that Donai, Kubai-Tangai and Parang join the parent stream Shilabati at its extreme lower catchment within 9 km reach where the river is extremely incapacitated. So similar discharge condition and similar time of runoff create the accumulation of water that develops flood situation. The soil map of study area was obtained from district planning map of concerned districts (Fig. 9.4). The four hydrological soil groups (A, B, C, D) are identified in determining the hydrologic soil cover complexes which are used in this method for estimating runoff from rainfall. Group A, B are sand, loamy sand and sandy loam, silt loam and loam which have low and moderate runoff potentiality but it covered few parts. The transmission rate of these soils is between 0.38 and 0.76 cm /hour and soil group C and D sandy clay loam and clay loam, clay pan or clay layer at or near the surface and shallow soils cover nearly impervious material which are covering most part of the watershed but these soils have moderate to high runoff potentiality because these soils have very slow infiltration rates. These soils have a transmission rate between 0.13 and 0.38 cm/ hour. Basin under study is mostly composed of hydrological soil group D, having high runoff potential. This also contributes high magnitude flood for lower catchment of Shilabati River.

9.3.4 Computation of Curve Number (CN) from Land Use and Hydrological Soil Group

The Curve Number (CN) is computed on the basis of land use and Hydrological soil groups conditions in the catchment area. Eight types of land uses were identified in the Shilabati river basin i.e. fairly dense sal, open scrub, river, wetland, residential area, concrete, metalled and unmetalled road, bare surface, plantation etc. (Fig. 9.5) but it was found that some land use and land cover has been changed and converted between 2010 and 2020 as residential areas,

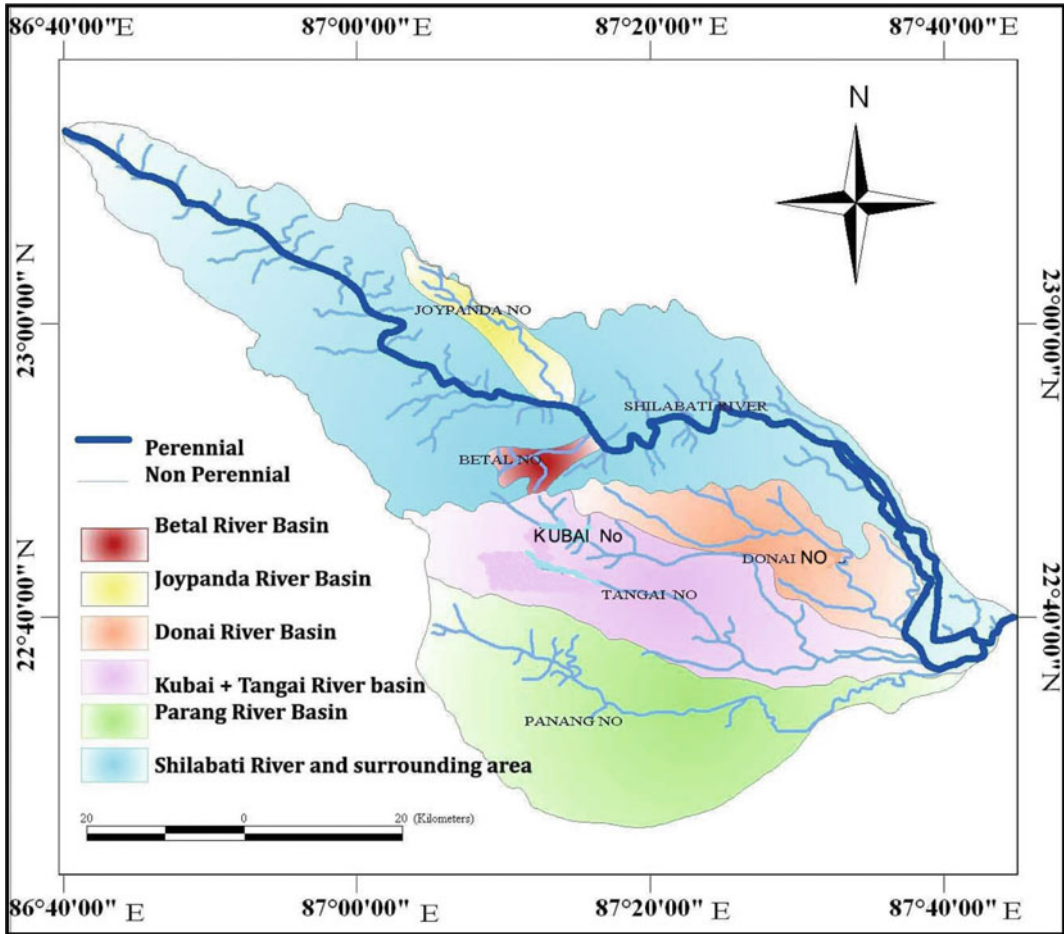


Fig. 9.3 Shilabati River catchment [Source: Survey of India Toposheets no 73I/12, 73J/16,73N/1, 73N/5, 73N/6, 73N/9, 73N/10,73N/11,73N/2], Satellite imagery, Google map (2020)

concrete and metalled roads (Table 9.3 and Fig. 9.6). The Curve Number (CN) and Weighted Curve Number (WCN) of the Shilabati basin and its tributaries were estimated to calculate runoff (Eq. 9.4 and Table 9.4).

9.3.5 Estimation of Runoff Using SCS Curve Number Techniques

Potential retention (S) of rainfall, before 2010 in table no 4 and after 2011–2020 in table no 5 is also calculated on the equation no 3 and Weighted curve number (WCN) reflects in table no 3. Then the Runoff is also estimated on the basis of (eq. no-2) average highest storm rainfall of 235.16 is

385.73 m³ before 2010 rainfall data and then highest storm rainfall of 347.43 mm is 864.30 m³ which exceeds (864.30 m³ – 385.73 m³ = 478.57 m³) that increase the runoff discharge after 2010–2020 (reflected in table no 4 and 5) due to variability of precipitation pattern and changes of land use which also increase the flood magnitude basically at lower reach in that study area.

9.4 Result and Discussion

The instrumental rainfall records of 20 years (2001–2020) reveal that inter-decadal variability in percentage of average storm rainfall comparing to total annual rainfall has increasing from

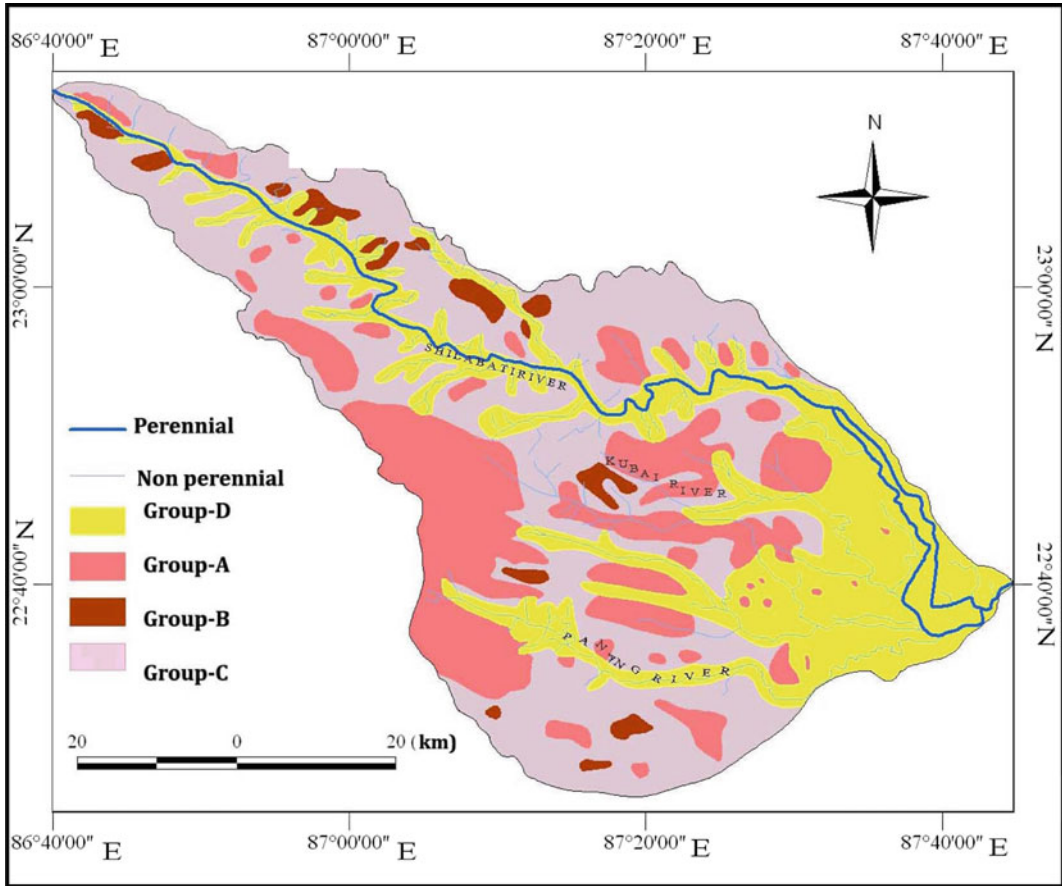


Fig. 9.4 District planning Map of Bankura, Purulia Paschim Medinipur

63.10 in 2001 to 97.10 in 2020 and the average storm rainfall concentration has also exceeded than annual rainfall at study area in few years. The highest storm rainfall over the area was 612.6 mm in the year 2017. After the heavy storm, the low lying depression in the lower reach of this catchment attracts huge flood water and sediments from it upper catchment, sub-tributaries and larger catchments of neighbouring rivers mainly Damodar, Darakeswar and Kangsabati. Most part of the lower catchment lie with a depression of very low gradient and attract huge water from upper catchment. Drainage efficiency of sub-watersheds is estimated in the form of weighted curve number. Shilabati catchment without major tributaries shows lower efficiency of runoff (CN = 63.97) but the maximum drainage efficiency is from the Betal river

due to impervious nature of land uses and lower areal coverage. Runoff efficiency is also high for Kubai and Parang (curve number 78.26 and 78.28). The runoff has been calculated on the basis of given weighted curve numbers (WCN) and potential retention (S) of individual river catchment and the cumulative rain during those storm days duration in a particular year is calculated on average of ten years data. The Table 9.5 shows that the input rainfall of 235.16 mm produces the total **385.73 million cubic meter** runoff discharge after interactions on land use and landcover at the Shilabati river catchment and its sub-tributaries catchment. Out of total 385.73 million cubic meter runoff, the tributaries of Donai, Kubai, Tangai and Parang contribute 182.68Mm³(**47.36%**) which is accumulated in the lower reach of the Shilabati river basin and

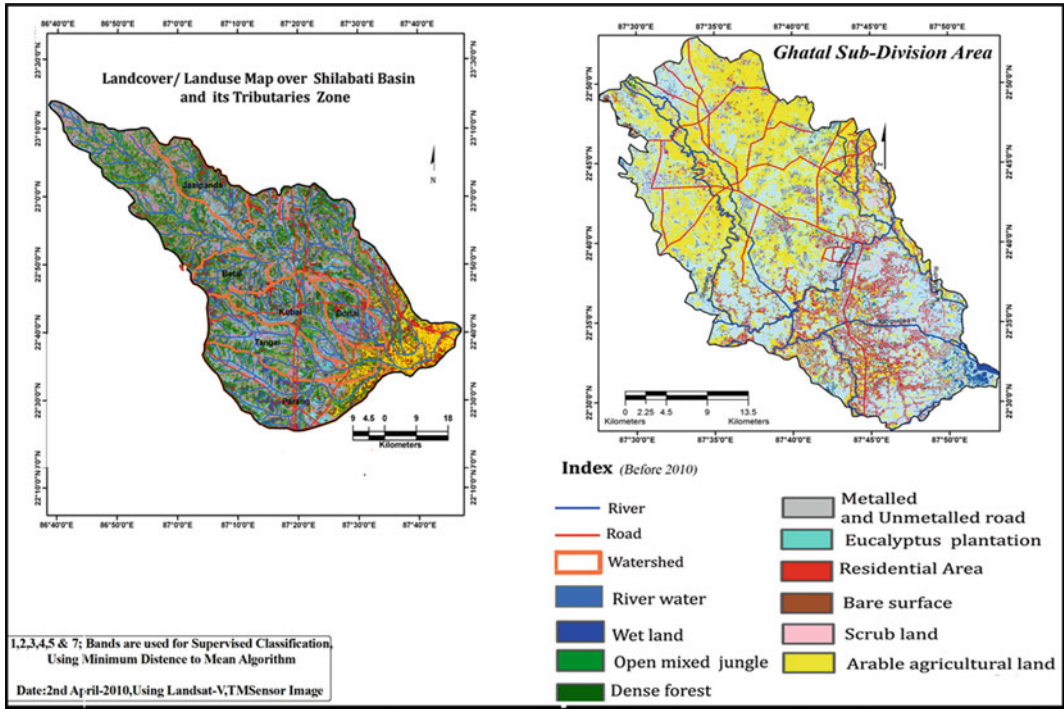


Fig. 9.5 The land covers and land uses in Shilabati basin and Ghatal Subdivision (before 2010)

develops the flood situation. The Table 9.2 also shows that the input rainfall of **347.43 mm** (2011–2020) produces the total 864.30 million cubic meter runoff after interactions on land use and landcover at the Shilabati river catchment and its main tributaries catchment. Out of total **864.30 million cubic meter** runoff, the tributaries of Donai, Kubai, Tangai and Parang contribute **455.50 Mm³(52.70%)** which has been increased **(52.70%-47.30% = 5.4%) almost 6%** from last 2010 in the lower reach of the Shilabati river basin. So the inter-decadal variability of precipitation pattern and land use change accentuates the severity of the flood discharge at main stream and its incapacitated parts of lower reach specially Ghatal Subdivision before 2010 to 2020.

9.5 Conclusion

Inter-decadal variability of rainfall and the maximum runoff efficiency is high at the sub-tributaries mainly Betal, Kubai and Parang river due to impervious nature of land uses and lower areal coverage. The tributaries which have higher drainage efficiency bring more discharge to the main stream at its incapacitated parts. Basin under study is mostly composed of hydrological soil group D, having high runoff potential. This runoff cannot be managed at its lower and sluggish stage, so the trend of increasing runoff will be high risks and contributes regular and high magnitude flood in future at lower reach of Shilabati river specially at Ghatal Subdivision.

Table 9.3 The calculation runoff curve number of Shilabati River by SCS method

Sl No	Catchment area	Soil types	Year	Forest land	River water	Wet land	Bare surface	Open scrub	Plantation	Arable land	Residential area	Concrete, metalled and un-metalled road	Weighted CN
1	Shilabati (Except tributaries)	A, B, C, D	2010		Composite curve number								
				73	66.85	66.23	63.51	64.09	58.7	62.69	60.21	60.01	63.97
			2017	73	66.85	66.23	60.5	60.09	58.7	81.09	69.21	74.08	67.8
2	Joypanda	A, B, C, D	2010	78	83.75	79.68	0	66.42	56.4	84.58	69.27	83.13	75.13
			2017	75	83.75	79.68	0	62.42	56.4	86.64	78.67	86.43	76.1
3	Betal	C, D	2010	88	85.5	80.75	0	88.27	87	89.72	85.35	76.67	85.1
			2017	81	85.5	80.75	0	78.27	87	98.87	94.75	91.82	87.21
4	Tangai + Kubai	A, B, C, D	2010	67	82.03	76.9	85.46	65.87	0	76.48	77.05	88.13	78.26
			2017	67	82.03	78.36	77.46	60.87	0	98.72	97.3	97.24	82.54
5	Donai	A, B, C, D	2010	71	77	83.68	84.36	64.87	0	72.17	75.65	86.17	76.91
			2017	71	77	83.68	74.36	64.87	0	84.17	95.57	95.34	80.29
6	Parang	A, B, C, D	2010	63	83.31	80	83.71	63.72	0	88.9	75.87	86.7	80.48
			2017	55	83.31	80	73.71	63.03	0	95.6	95.87	98.42	78.28

Source Satellite Imagery of concerned area, Topo-sheets and Wiki map of concerned area

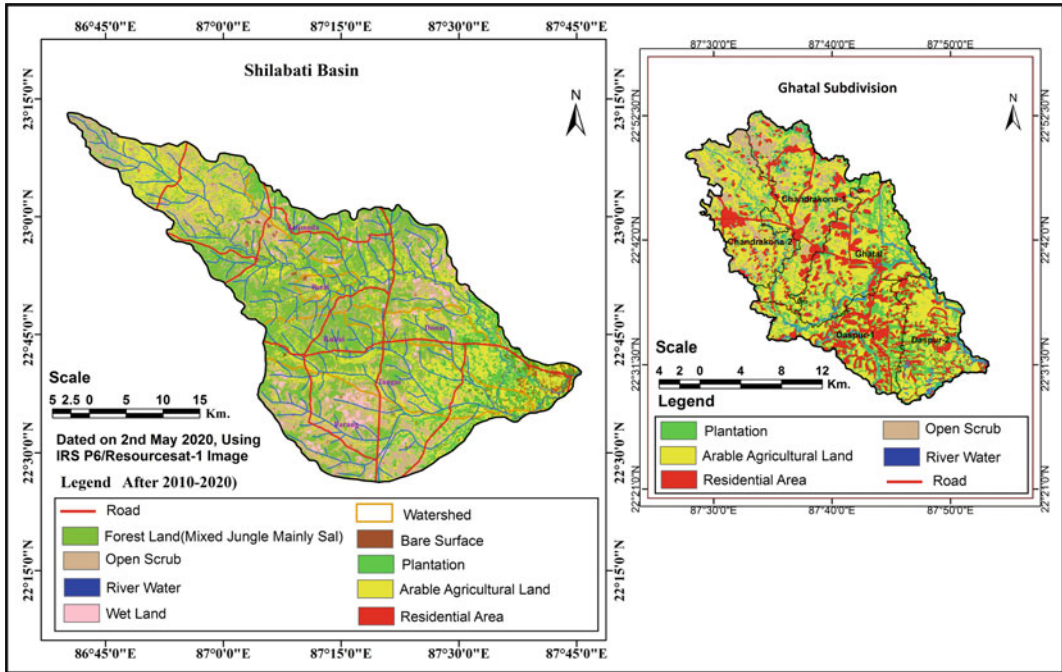


Fig. 9.6 The land covers and land uses in Shilabati basin and Ghatal subdivision area (after 2010)

Table 9.4 Calculation of runoff (in Cubic meter) from the average of highest storm rainfall of 235.16 mm

Name of the main river and Tributaries	Average Rainfall in mm during highest storm period of each year from (2001–2010)	S (potential retention) in mm	Area in km ²	Weighted curve number	Runoff in Mm ³
Shilabati (only the main stream except the mentioned tributaries)	235.16	143.06	1712.5	63.97	173.90
Joypanda	235.16	84.08	125.5	75.13	17.80
Betal	235.16	44.47	63.5	85.10	11.35
Donai	235.16	76.2	239	76.91	35.46
Kubai + Tangai	235.16	70.56	440.8	78.26	67.58
Parang	235.16	70.48	519.2	78.28	79.64
Total runoff in lower catchment (35.46 + 67.58 + 79.64) = 182.68Mm ³ = 47.36%					385.73

Bold digits indicate total runoff in storm discharge in whole catchment before 2010

Table 9.5 Calculation of runoff in (Cubic meter) from the average of highest storm rainfall of 347.43 mm

Name of the main river and Tributaries	Average Rainfall in mm during highest storm period of each year from (2011–2020)	S (potential retention) in mm	Area in km ²	Weighted curve number	Runoff in Mm ³
Shilabati (only the main stream except the mentioned tributaries)	347.43	124.30	1712.5	67.80	358.62
Joypanda	347.43	79.77	125.5	76.10	31.33
Betal	347.43	37.25	63.5	87.21	18.85
Donai	347.43	59.93	239	80.91	64.65
Kubai + Tangai	347.43	53.72	440.8	82.54	122.26
Parang	347.43	61.60	519.2	80.48	268.59
Total runoff in lower catchment (64.65 + 122.26 + 268.59) = 455.50 Mm ³ = 52.70%					864. 30

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