2025, Vol. 64 : 52-69
ISSN-0972-7434
Original Article
Madhya Bharti Journal of Science

Geomorphic and Climatic Control on Channel Avulsion Associated Hazards in Haridwar District, Uttarakhand

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(Received on12.10.2025 Accepted on 8.11.2025)

ABSTRACT

Nature of geomorphic surfaces and climatic characteristics have significant influence on channel forms and processes of an area. The present work is an effort to relate channel avulsion associated hazards with geomorphic surfaces and extreme climatic events like; seasonal flood in different parts of Haridwar district, Uttarakhand. In Haridwar, length of the Ganga river is about 72.71km.with approximate topographic gradient of 1.24m/km. Geomorphic characteristics of Haridwar district have significant role to control channel avulsion and associated hazards of the area. In tarai zone magnitude of channel shifting and avulsion in the Ganga and its other tributaries is maximum. A number of villages located along the right bank of the river Ganga are facing channel avulsion induced serious soil and bank erosion. Every year about 60900 hectares settlement areas are affected due to flood in tarai surface of the area. Primarily during monsoon period avulsion is noticed in different sites along the rivers. Since 1995 occurrence of major flood is increasing gradually, which will enhance the magnitude and frequency of avulsion related hazards. Several evidences, field recorded data, satellite data (LISS-III2005,LISS-IV 2005,Googleearth 2010,2013,2022),topographic data (1967),GPS data, and change detection study regarding channel bars have helped in understanding the mechanism of channel avulsion.

Keywords: Geomorphic surfaces, flood, channel avulsion, change detention study

INTRODUCTION

Channel avulsion is a fluvial process which is dominantly observed in foothill areas. Present study is mainly focused on the Siwalik Himalayan foothill, part of Upper Ganga Plain,Haridwar district, Uttarakhand, India (Fig:1). Generally, riverbank dwellers are well experienced with flood but they hardly know about the channel avulsion and its mechanism. Most of the fluvial geomorphologists have emphasized their works on flood and other fluvial problems rather on vivid analysis of river channel avulsion. Hence more understanding regarding channel avulsion is required to minimize channel avulsion induced hazards along the active floodplain areas. Though many earlier scientists have contributed their works on different aspects of channel avulsion problems. Jones and Schumm (1999) scientifically analyzed the causes and different types of avulsion.Field (2001) nicely elaborated channel avulsion mechanism on alluvial fan environment. Shukla et al. (2001)vividly elaborated model of the Ganga megafan sedimentation.

Some famous scientists (Srivastavaet al.,2003) broadly analysed varied features of the Ganga river and its characteristics over the Ganga plain. Shukla and Bora (2003) broadly explained the geomorphological and sedimentological characteristics of piedmont zone of the Ganga plain.Dhar and Nandargi (2004) nicely elaborated flood condition in north Indian river systems.Sinha (2005) vividly explained aggrading and degrading characteristics of the river Ganga. Mukhopadhyay (2010) discussed about the fluvial process emphasizing on channel avulsion over the Tista fan area.Dutta (2017) has tried to explain the controlling factors of channel avulsion in Haridwar. Chadwick and Lamb (2021) rightly established the impacts of climate change on river delta avulsion. Dutta (2022) has discussed river dynamics of the Ganga and its tributaries in the Siwalik-Tarai region of Haridwar district, Uttarakhand, India. Undoubtedly, earlier works are remarkable contribution for understanding river channel avulsion mechanism but present study is an unique field based approach to analyse the significant control of geomorphic and climatic characteristics on channel avulsion over alluvial fan based on intensive field recorded information. In the present paper site-specific channel avulsion events (near Chandi bridge, Kangri village, Banganga adjacent areas and other places) and their causes have been tried to discuss with emphasising terrain features and climatic characteristics over the upper Ganga plain under extended alluvial fan environment.

The objective of the present work is to study geomorphic and climatic control on channel avulsion and avulsion associated hazards in Haridwar district, Uttarakhand, India.

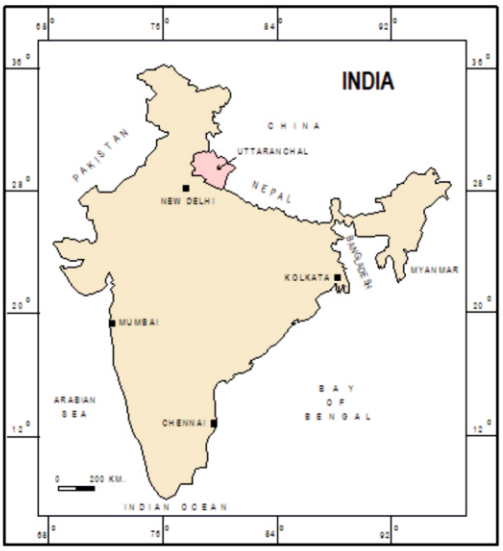
Study area: The study area falls under three tehsils 1)Haridwar, 2)Roorkee, and 3)Laksar. Its covers an area of 1883 sq.km, where the length of the Ganga River is 72.7 km(fig-2) between Bhimgoda reservoir in the north to Gambhirpur village in the south. The study area encompasses

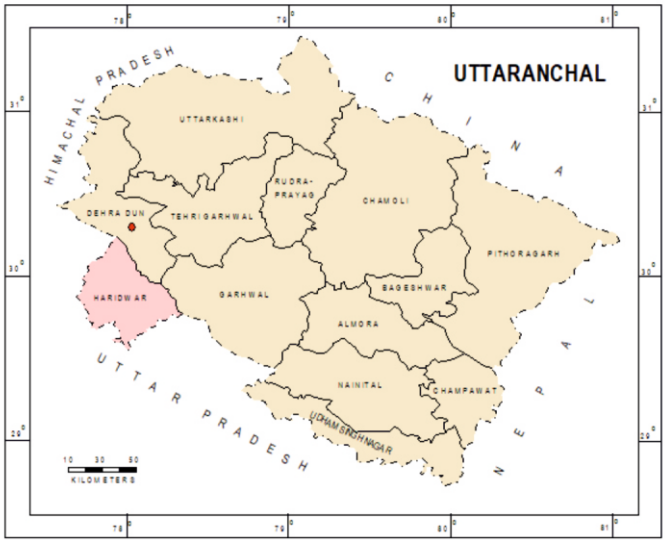
parts of the Siwalik Himalaya and the Tarai formation. The author has observed some sites where channel avulsion process causes flooding, serious top soil erosion and bank erosion hazards. The sites are; near Nildhara (Chandi ghat downstream) in the north of the district, nearBanganga (Khanpur adjacent area), along the Ganga river in Kangri (Fig:3)and Tatwala villages.

MATERIALS AND METHODS

The present work is based on various secondary and primary data with scientific methods.In this work due emphasis has been given on field observations and people perception. As the work is concerned with river channel avulsion, so detailed drainage map (Dutta 2022)has been analyzed to understand the location of the Ganga river and its tributaries.The drainage map has been prepared with the help of toposheets (Survey of India,1967,1971) and satellite images. Few important sites of channel avulsion have been identified based on vivid field observation (2006, 2007,2008, 2010, 2013,2017,2023) and GPS receiver recorded data and avulsion path has been located on satellite images. During the field survey, in above mentioned years field observations have been done to record important data regarding ground truth verification of an abandoned channel and a channel bar.GPS receiver had been used to collect the waypoints to locate their actual position near Nildhar area (situated on left bank of the Ganga close to Haridwar city). Dumpy level had been used to study accurate levelling of the abandoned channel. Dumpy level based recorded data have been used to prepare a cross section of the abandoned channel. Change detection study of the midchannel bar has been made based on field recorded data and other secondary data sources. Perception study of the villagers (Kangri village, Tatwala village, Shyampur village, Nildhar area etc)have been done by the author in different years.Knowledges and experiences of the local people about avulsion and avulsion induced flooding, water logging, channel shifting, bank erosion have been gathered to prepare the present paper.Location of vulnerable and abandoned villages have been identified based on toposheet, satellite images and field observation for understanding about the intensity of channel avulsion. For better explanation of aggrading nature of the Ganga river channel, spatio-temporal changes of channel bars have been analysed. Field recorded photographic evidences regarding avulsion induced hazards (soil erosion, bank erosion, water logging etc.) and man-made protective measures have been illustrated for ground truth verification of the problem. Different types of satellite images (IRS LISS-III,November,1997,2005,IRSLISS-IV, November,2005, Google earth –2010,2013,2017,2022,2023) have been used in this work for vivid analysis of the problem. For getting better idea about the geometric shape of an abandoned Ganga channel where avulsion occurs every year, cross section of the abandoned channel has been illustrated. In order to analyse the role of geomorphic surface on channel avulsion broad physiographic map, geomorphological map of the study area have been studied. Those maps have been prepared with the reference of geological map of Saharanpur (GSI, 1997) and Survey of India toposheets (no:53 K/1, 53 K/2, 53 K/5,53 J/4, 53 G/13, 53 G/14), R.F 1:50000. Apart from geomorphology, climatic influence on channel avulsion has been tried to analyse with temperature data (1987-2006) based on National Institute of Hydrology, Roorkee and rainfall map (District Resource Map of Saharanpur, GSI,1997, District Planning Map of NATMO). Special emphasis has been given on flood related data and information to relate monsoonal flood and channel avulsion. Major flood events and flood affected villages of the study area have been discussed. Based on the comprehensive study important findings and conclusion have been drawn regarding geomorphological and climatic control on the Ganga river channel avulsion.

RESULT AND DISCUSSION





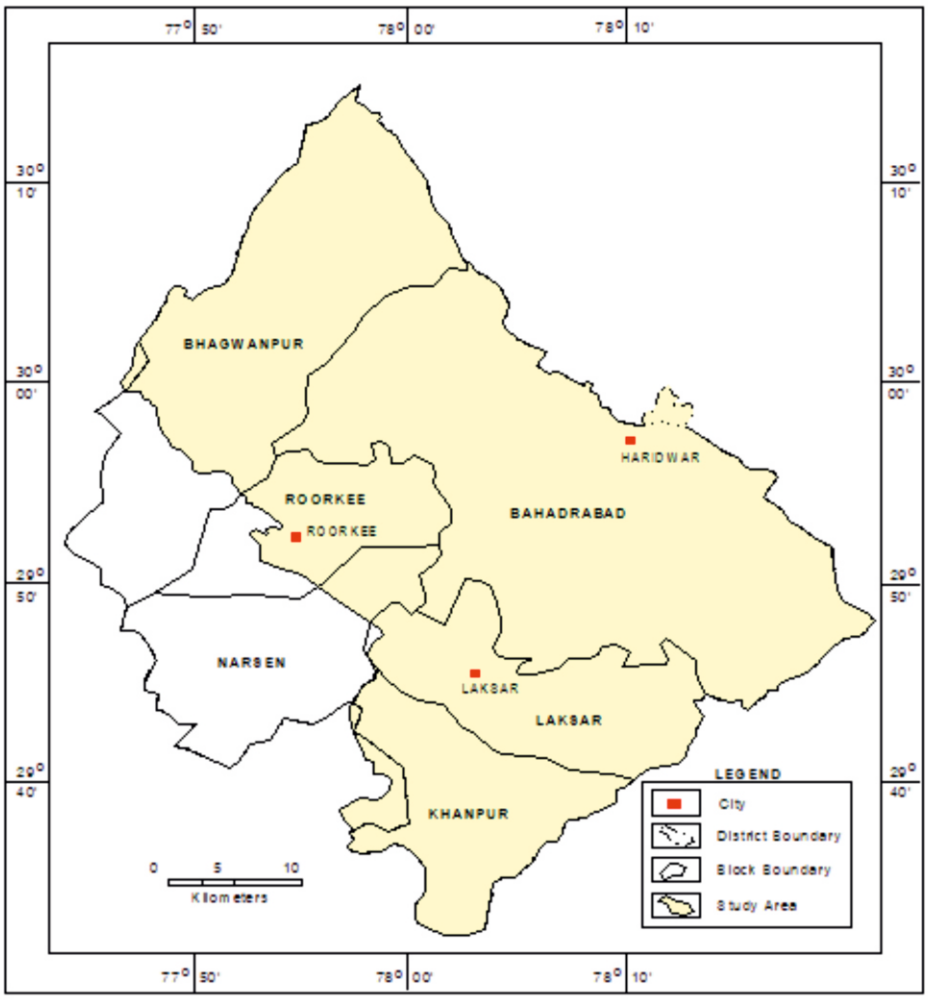


Figure 1: Location map of the study area consists of six block boundaries; Bahadrabad, Roorkee, Laksar, Khanpur, Bhagwanpur,Narseen (Source: Toposheet, SOI, DPMS MAP, NATMO) .

River system of the study area

For better understanding aboutchannel avulsion mechanism and avulsion associated hazards illustration regarding the river system of the study area is required. The entire study area is under the Upper Ganga drainage system. Except the northern Siwalik Himalaya, the remaining part of the study area is a part of the Ganga Plain. Here, Ganga is the main river. It debouches on the alluvial plains from Himalaya at Haridwar city through a well-marked gorge in the Siwalik chain (Ganga-Tear fault). Other important rivers are Solani, Pathrirao, Ratmaorao, Mohand rao, Banganga, rivers, etc. along with Banganga and Jhilmil Jhil wetlands (Dutta,2022).In Haridwar, the main river Ganga and its several tributaries(Fig: 2)have developed yazoo types of drainage pattern (Uniyal 2010)**.**Most of the rivers of Haridwar district are flowing from north-east to south -west according to the slope of the surface. The rivers are ephemeral in nature. The Ganga is only perennial rive. During Monsoon period channel avulsion is noticed in different sites along these rivers. Towards the extreme south of the study area magnitude of channel shifting and avulsion in the Ganga, Solani, and Banganga rivers is maximum.

Channel avulsion

Channel avulsion is the process of rapid abandonment of a river channel and the formation of a new river channel. Avulsion is defined here as the diversion of a majority of flow from one channel into another, leading to a total or partial abandonment of the previous flow path. Its occurrence leads to some serious hydrogeomorphic hazards (serious waterlogging, flood, bank erosion, soil erosion etc.) and hence needs some in-depth studies on its causes and consequences.Channel shifting and avulsion are natural characteristics of rivers in the Himalayan foothill region. However, the mode and magnitude of shifting and avulsion primarily depend ongeomorphic andclimatic factors of an

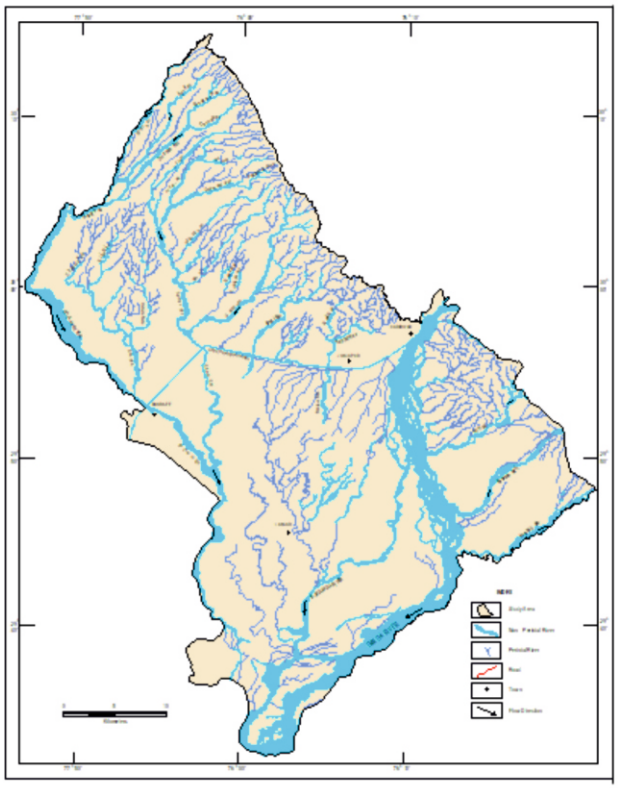


Figure 2: Drainage network of the study area showing yazoo pattern over the Upper Ganga Plain. Main river Ganga flowing from North to South East. Other non-perennial tributaries are debouching from northern Siwalik ridge (Source: Toposheet,1967,1971, SOI & LISS-III, 2005)

area. In the present work the author has tried to illustrate channel avulsion events in different parts of Haridwar district based on field observation. Local villagers and authority have no idea about the channel avulsion events and they are unable to distinguish channel avulsion induced waterlogging and inundation from normal river flood. Hence, sometimes they use the abandoned dry channel for construction of their houses and roads, but during rainy season the abandoned channel part becomes suddenly filled with water under the influence of channel avulsion process, damaging the houses and roads.

Field based observation of the Ganga river channel avulsion

The authors have observed some sites where channel avulsion process causes flooding, serious top soil erosion and bank erosion hazards. Many scientists think that avulsionlocation may also be influenced by sediment supply, with pulses in sediment supply historically linked to avulsion sites (Makaske et al., 2012). Prominent shifting and avulsion of channels of the Ganga and the Solani can be noticed in vast tarai surface where channels are shaped in braided pattern. Near Nildhar (Chandi ghat downstream),avulsion occurs along an abandoned channel of the Ganga (Fig:9 &13)during every monsoon . Another major channel avulsion takes place near Banganga (Khanpur adjacent area). Some other incidences of avulsion features are also observed along the Ganga river causing serious damage in Kangri(Fig:3)and Tatwala villages.

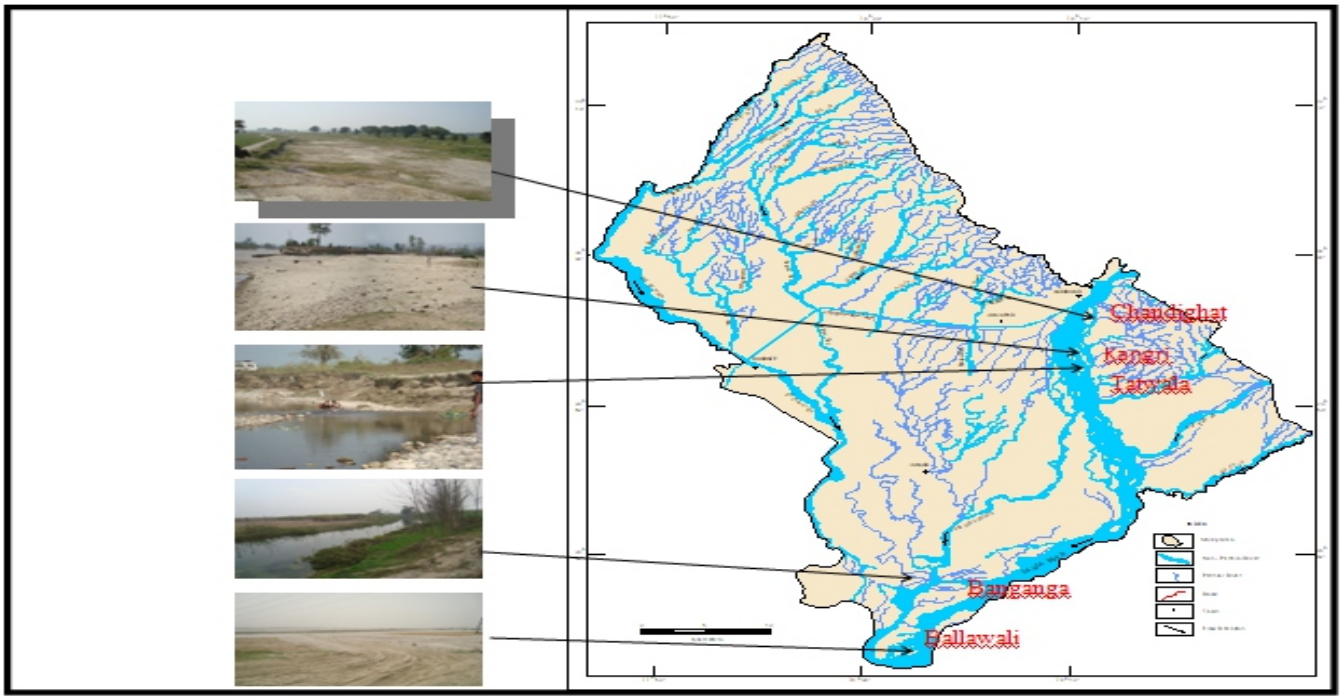


Figure 3:Few selected sites where channel avulsion has been observed during monsoon period in Haridwar district, Uttarakhand from field survey in 2008 and 2010. Most of the avulsion sites are observed in Bhabar and Tarai zones .Source: Field Based observation & Toposheet SOI.

Geomorphological surfaces and channel avulsion of the area

Undoubtedly,characteristics of geomorphic surface have effective role to influence river channel avulsion of an area. Hence, in order to understand the mechanism of channel avulsion vivid analysis about major geomorphic surfaces is required.

Different eminent scientists (Srivastava et al.,2003) have identified the major regional geomorphic surfaces in the Ganga plain. like ; (1)Upland Interfluve Surface ,

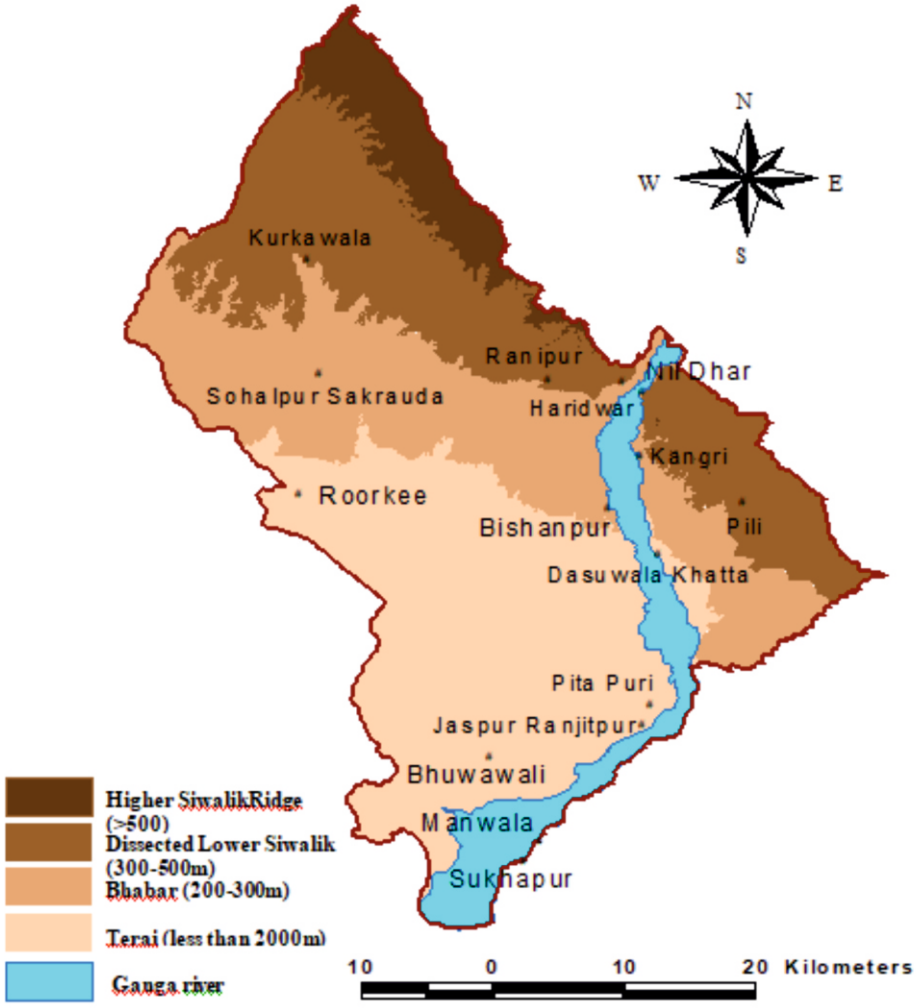


Figure 4:Broad Physiographic Map indicating Higher SiwalikRidge, Dissected Lower Siwalik, Bhabar, Terai zones.

Source: Field Based observation & Toposheet SOI.

(2) Marginal Plain Upland Surface (3) Megafan Surface (4) Piedmont Fan Surface (5) River Valley Terrace Surface (6) Active Flood Plain Surface.The present author has prominently identified major geomorphic surfaces which have significant role to influence the channel avulsion of the area.

Broadly, the study area falls under the Ganga-Yamuna Mega Fan(MF). At the foothill of the Siwalik Himalaya series of piedmont fan surface are prominently observed by the author. The river Ganga and its several major tributaries in Haridwar having characterized with well-marked river valley terrace surface and active flood plain surface (Fig: 5). Channel behaviours of different rivers are greatly controlled under those major geomorphic surfaces. In order to differentiate the channel characteristics in different physiographic zones the present researcher has divided four physiographic divisions(Fig: 4)depending on major breaks in the longitudinal profile drawn from extreme north to south of the district like; 1)Higher siwalik ridge zone**(more than 500m)**,2) Dissected lower Siwalik**(300-500m)**,3) Bhabar **(200-300m.):** 4)Terai **(less than 200m.)**(Dutta,2022).

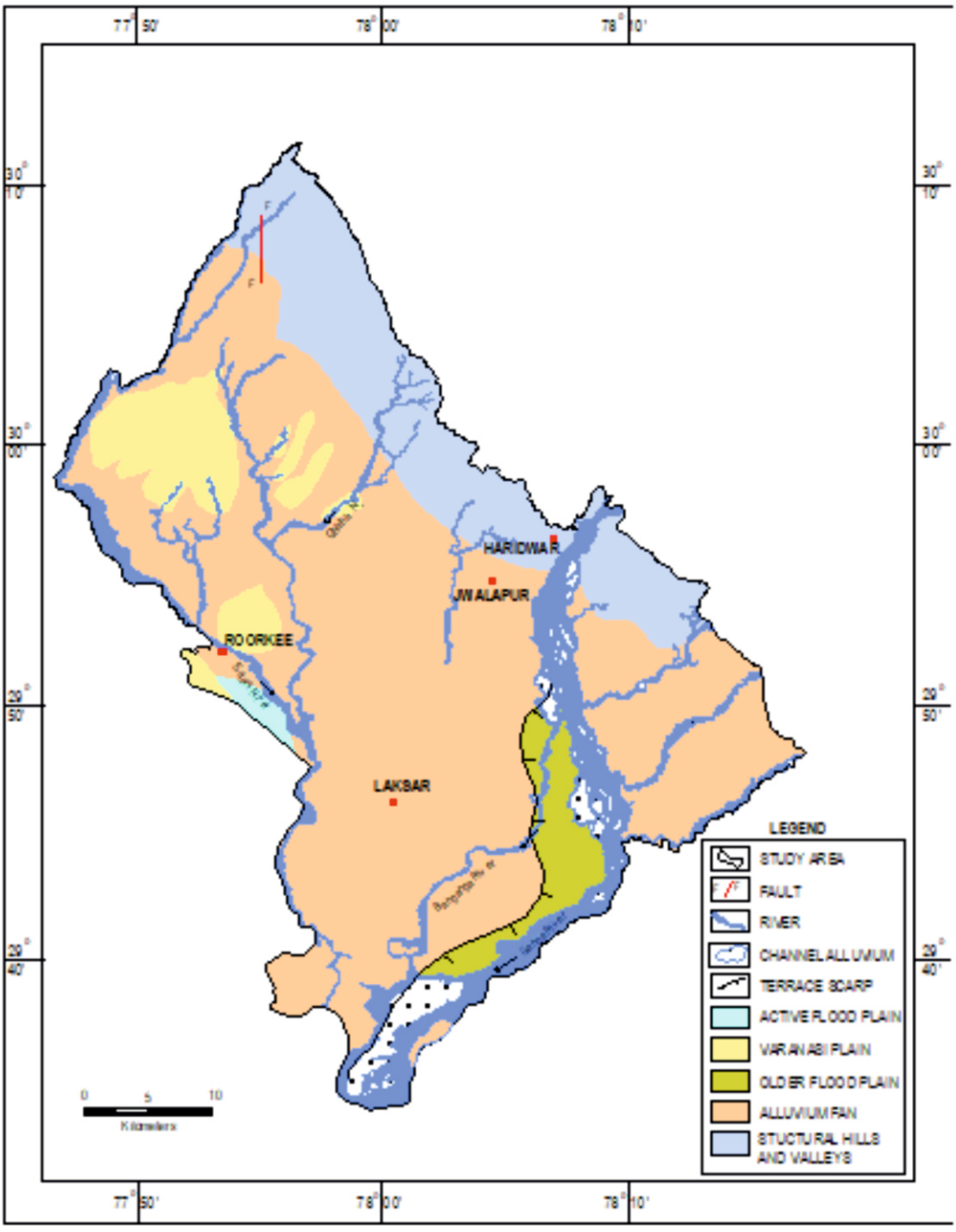


Figure 5:Geomorphological map showing important geomorphic surfaces of the study area. Broad alluvial fan and active flood plain areas observed in map are channel avulsion prone zone. Source: Field based observation & Toposheet SOI. DRMS of GSI,1997)

Channel avulsion in bhabar and tarai surfaces of Haridwar

Dependingupon field observation and other secondary sources it can be said that in tarai zone magnitude of channel avulsion is very high. Mainly in vast southern tarai surface (under the Ganga plain), shifting and avulsion nature of the river Ganga and Solani are frequently observed. Excessive channel sedimentation and very gentle slope of topography are two important hydrogeomorphic factors of channel avulsion in this area. Beside these, every year flood in tarai zone acts as triggering factor of channel avulsion.Terai is the southern extensive physiographic division ofHaridwar(Fig-4). Laksar city is located in the zone within 200 metre altitude from msl., where vast wide braided channel of the river Ganga is observed. Here, Solani river joins with Ganga river, and a vast wetland has been developed at Solani- Ganga confluence. Near Bishanpur a different branch of Ganga river is observed and after its 45 km. journey it joins again into Ganga .The confluence zone of Banganga and Ganga is basically a vast flooded area. Hence,a riverine wetland ecosystem prevails here. This wetland ecosystem is situated in Laksar range and it is called Bangangawetland.NearBallawali the Ganga river channel is characterised with extensive braided pattern mainly filled with coarser and finer sands and silt. In this zone floods occur every year during monsoon period. Flood induced channel shifting and avulsion are the major hydro-geomorphic hazards of the area. Many villages (Kangri, Gajiwala, Shyampur, Noorpur, Baditeep, Daswalakhatta etc.) located along the river Ganga, have rejectedtheirearlier position due to avulsion and shifting of the Ganga river channel.There are many villages(Gurukul, Ramkund, Nokikhatta, Pitapuri, Jaspur, Sukhapur, Raighati etc.) which are almost abandoned by the villagers as a result of serious channel avulsion problems of the river Ganaga.

Sedimentation in the Ganga river channel

Excessive channel sedimentation in Ganga and itstributaries in Haridwar district is one of the important controlling factors of channel avulsion. Early experimental efforts showed higher sediment supply is associated with enhanced aggradation and greater avulsion frequency .The rivers draining the study area (siwalik to terai alluvial plain) exhibit significant channel sedimentation process that are reflected in the form of numerous braided channel bars in the entire Gangariver course of Haridwar district (Sinha,2005).Active depositional channel features over vast river channels are the geomorphological evidences of the aggrading Ganga river system. Due to abrupt decrease in gradient of slope, the loads carried by streams are deposited in this bhabar and tarai zone as rivers drop their velocities. That is why, gradually sands, gravels, boulders etc. are deposited in channel, which aggrades river beds (Dutta,2017).Based on Survey of India Toposheet, the author has calculated channel gradient of the river Ganga in Haridwar district. In Haridwar district the actual length of the Ganga river is 72.71km. and average topographic gradient of the Ganga river is 1.24m /km. In Haridwar district, with in 6.27 km from the upstream of the

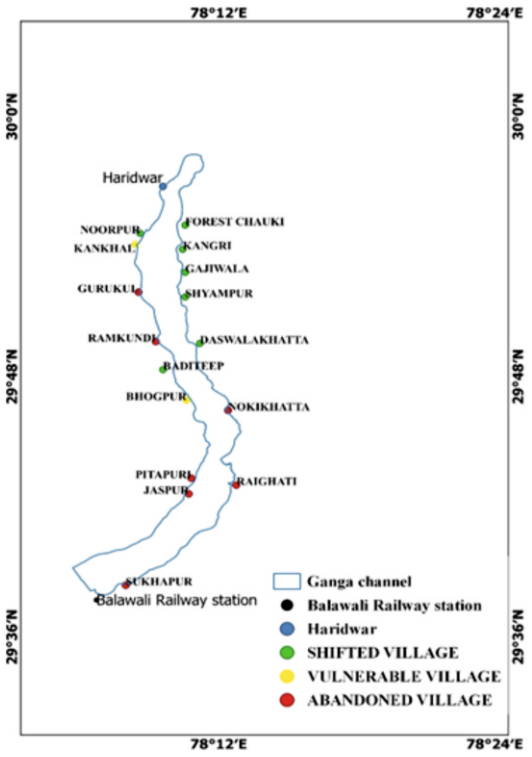


Figure 6: Shifted,vulnerable and abandoned villages due to avulsion and flood along the Ganga,
Source: toposheet, IISS-III, 2005 Source: Field Based observation & Toposheet SOI, LISS-III, 2005

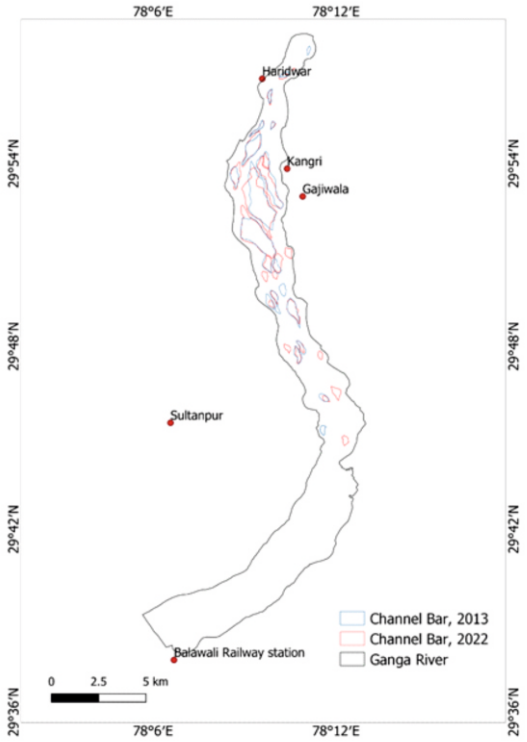


Figure 7: Spatio- temporal changes of the Ganga channel bars from 2013-2022.
Source: Toposheet, goole earth satellite images 2013&2022.

river Ganga the average gradient is 3.19m/km. From 6.27 km to 17.01km (10.74km distance) the average gradient of the Ganga river is 3.69m/km. From 17.01 km to 32.82 km downstream (15.81km distance) the average gradient of the river is 1.27m/km. Very gentle gradient of the river Ganga towards southern part of the study area (vast tarai zone) causes flood induced avulsion near Laksar areas.Excessive suspended load is deposited on the river bed.Several centimeters thick muddy sediment is found deposited on top of channel bars of the Ganga river after each flood, basically representing the suspended load. As a result of excessive sedimentation sometimes few channel bars are joining with their adjacent bars ,that reduces cross sectional area of the Ganga river channel. This mechanism influences changing nature of channel bars. Spatio -temporal changes of channel bars (Fig: 7 and 8)directly and indirectly influence channel dynamics as well as channel avulsion. For the better understanding of the vegetation covered permanent channel bars in the Ganga river channel, a change detection map of vegetation covered channel bars(Fig: 8)from 2013 to 2022 has been prepared. From the change detection map it is clearly expressed that near Kangri and Gajiwala villages vegetation covered braided bars are gradually join with each others. As a result, channel cross sectional area of the river in this part is reduced and channels are diverted towards both banks causing bank erosion and serious water logging problem in adjacent settlement areas. Integration of the permanent braided bars indicates not only excessive channel sedimentation but also enhances channel instability resulting diversion in channel flow.

The active channels of many rivers of the Ganga plain show increase in thearea of active sand bars, indicating ongoing aggradation process. The authors have analysed a Ganga mid-channel bar (Dutta,2017) which is also increasing its size in the last three decades enhancing significant channel instability. The area of the mid channel bar was 6.31 hectare in 1971 and its size has increased gradually (Table:1). In 2023 (22nd May) the area was 15.80 Hectare.

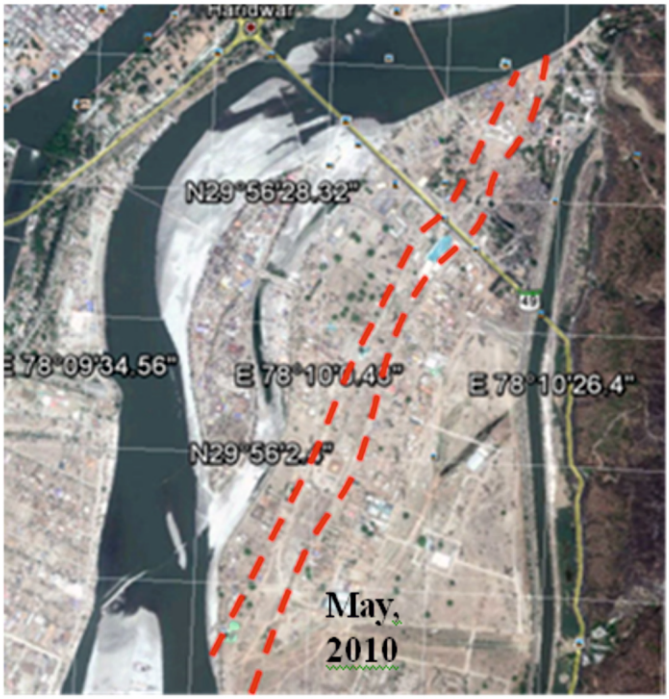


Figure 8:Spatio-temporal changes of vegetation covered permanent channel bars in Ganga river (2013-2022). Right side map indicates channel bars (near Kangri and Gajiwala) are joining with each others as a result of active channel sedimentation. Source: toposheet, google earth images 2013 & 2022.



Figure 9: The right side image (May,2023) shows increasing area and changing shape of the midchannel bar and inleft side (May,2010)image identification of abandoned channel of the Ganga river using GPS way track (2010) showed on image by doted red lines, near Nildhar area, below the Chandi bridge where channel avulsion occurs during every monsoon period. The active channel of the river Ganga is shifting towards west where Haridwar city is located. Source: Field survey (2007-2010) by GPS, Google image, 2010, 2023

Table 1:Increasing area of a mid-channel bar in Ganga River near Chandi bridge from 1971-2023

Year	Area of the midchannel bar (Hectare)	Data source
1971	6.31	Toposheet (Survey of India)
27th November,1997	11.68	LISS-III (NRSC)
24th November,2005	12.65	LISS-III (NRSC)
3rd May,2010	12.90	Field survey with GPS
22nd May,2023	15.80	Google earth Image

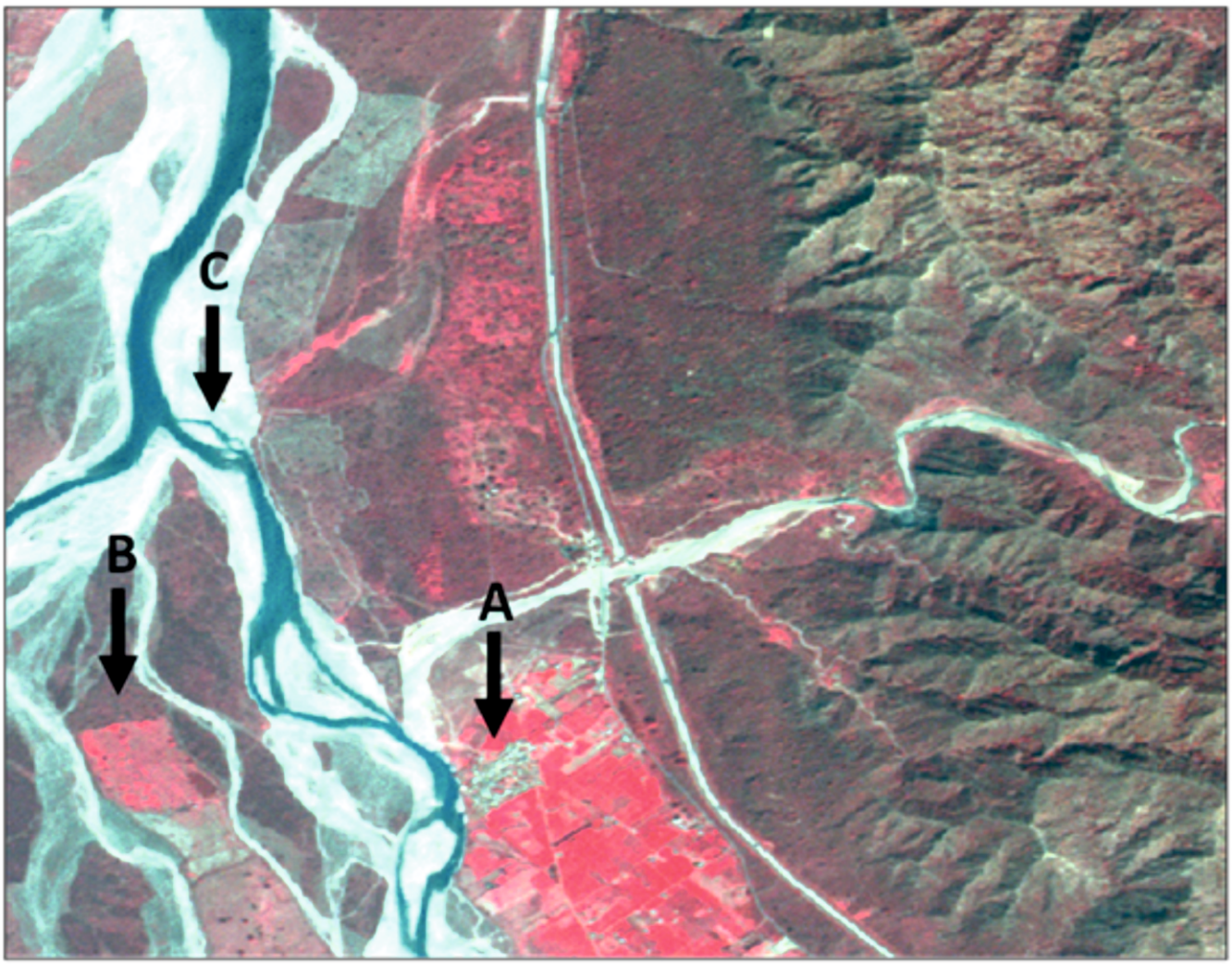


Figure 10: LISS IV Image showing channel avulsion near Kangri village

A. Vulnerable location of the village Kangri on the left bank of the river Ganga

B. Abandoned part of the Kangri village , C. New avulsion channel of the Ganga developed during 1924 devastating flood, Source: LISS IV 2005, NRSC.



Figure 11:Villagers of Kangri constructed embankment to protect the village from flood induced avulsion(Source: Photograph taken by author, 2017)



Figure 12:A- Extended areas of abandoned part of Kangri village due to Ganga channel avulsion, B-Damage of roads along Chandi bridge, near Chandighat. C-Destruction of agricultural land due to Sheet erosion by avulsion near Nildhara area, D- Revived abandoned channel near the mid-channel bar during 2010 flood, E- Serious top soil erosion during 2013 flood induced avulsion near Chandi bridge, F-The local man showing height of water level observed during monsoon periodnearBanganga wetland adjacent areas. Source: Field survey,2010,



Figure13:An abandoned channel of the Ganga river located parallel to the present Ganga river near Nildhar, below Chandi bridge. The abandoned channel has been located in google satellite image. Field recorded photograph indicates fallow land of the abandoned channel. A profile of the cross section AB has been prepared with the help of dumpy level and GPS receiver. The cross section clearly indicates dry abandoned asymmetrical channel which causes avulsion during monsoon damaging roads and adjacent houses.
Source: field survey on 18.02.2017.

Climatic control on channel avulsion:

Climate has direct and indirect control on landscape evolution of an area, because it determines the geomorphic processes. The present study area is a part of fluvial landscape under the influence of Tropical Monsoon type (modified) of climate. Climatic condition of the study area is greatly influenced because of its vicinity to the Himalaya. With the help of temperature data of nineteen years collected from the National Institute of Hydrology of Roorkee an average temperature curve has been prepared by the researchers. The temperature curve(Fig-14) depicts the mean temperature of Roorkee city from the year 1987 to 2006.

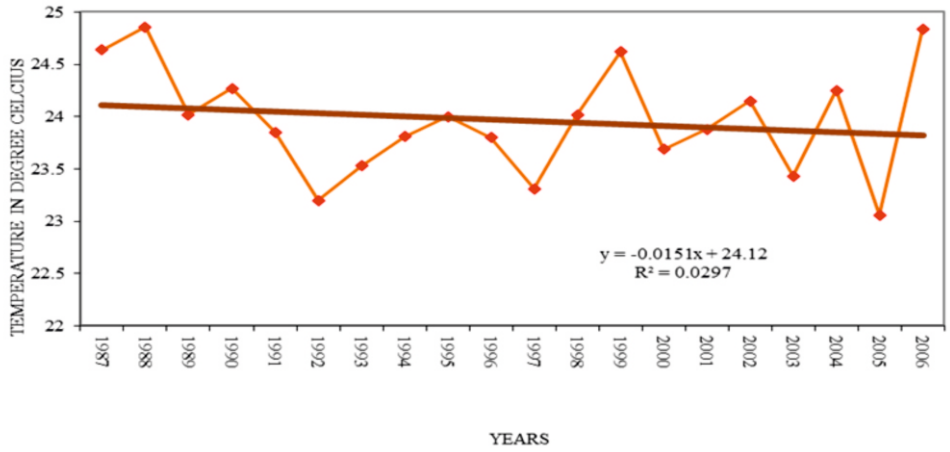


Figure 14: Temperature curve and trend from 1987 to 2006 indicate mean temperature of the study area. Source: National Institute of Hydrology, Roorkee.

Crucial climatic hazards in the study area are flood, flash floods, cloud burst, which are mainly , controlled by climatic components. Each year during monsoon one or two incidents of cloud burst and flash floods occur e. g. Mansa Devi –Haridwar(1991).Seasonal floods occur in every year in Haridwar mainly at Laksar areas, often with loss of life and properties(Table:3). In the year 2010 during July –August excessive rainfalls caused major flood and water logging problems in the plain areas and landslide rockfall in siwalik hills. Excessive rainfall (Fig:15) is one of the reasons of flood in the study area. Two types of storms initiate most rain-caused floods: the violent thundershower, which is of short duration and produces a flashflood, and the prolonged, widespread rain which, creates extensive flooding over entire area. Flash floods are most common in those regions which experience heavy thunderstorms, but they should be regarded as a potential hazard whenever intense rainfall occurs.

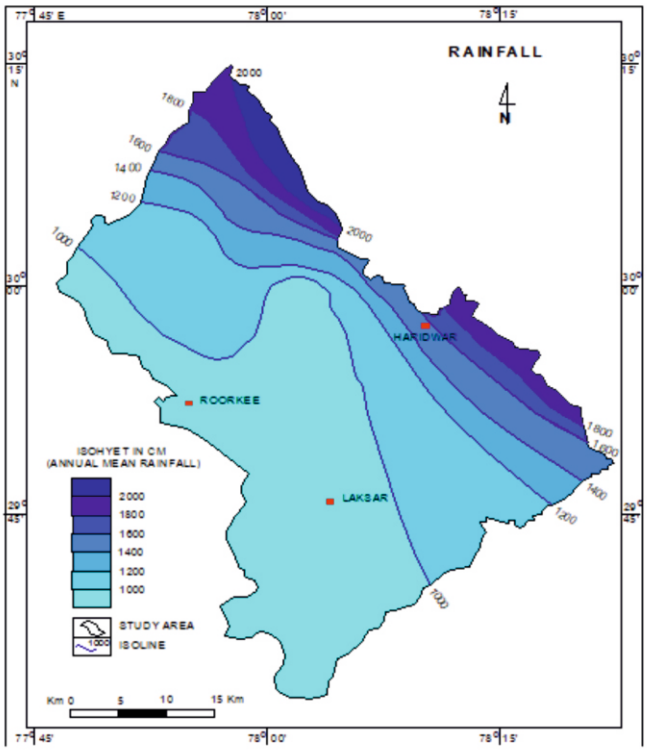


Figure15:Isohyet showing distribution of rainfall from north to south Haridwar.Maximum rainfall occur on higher Siwalik ridge causing flashflood and rockfall. Though Laksar (located in tarai zone) receives comparatively lesser rainfall but prolonged rain in upper catchment causes seasonal flood and flood induced channel avulsion.Source: DRM,GSI,1997and DPM of NATMO.

Monsoon induced channel avulsion:

During monsoon period, channel avulsion becomes very active mainly in the southern part. It creates great loss to agricultural land and road network. This area is also flood - prone during rainy season. Chadwick et al.(2021) established that increased flood frequency causes less frequent avulsions .Flood regimes can also affect avulsion location .Flood regimes control the aggradations of both channel and floodplain with potential consequences for river avulsion Over the gentle slope and under active fluvial deposition many channel bars have developed, which lead to frequent diversion of the channels. Along the Ganga river both the nodal and the random type of avulsion have been noticed. Generally, avulsion frequency depends on how the processes inducing channel instability interact with the triggering events (Jones and Schumm 1999). Near Haridwar city, in the braided channel of the Ganga river flood is the triggering factor for random avulsion. Hence, during monsoon period, many abandoned channels are filled with water indicating channel avulsion. When water level rises more than one metre than the Danger Level (DL) of a gauge site then the flood is considered as major flood (Dhar &Nandargi, 2004).From 1894 to 2010 nine major flood peaks have been recorded in the area. From this data it is noticed that frequency of flood in the study area is low, but we should worry about the matter that since 1995 occurrence of major flood is observed every one or two years interval. It means occurrence of major flood is increasing gradually. The major flood in the area took place in the year of 1910,1914,1924,1963,1978,1995,1997,1998,2010.Approxi mate water discharge of different river during flood years were recorded shown in the Table:2.

Table2:Occurrence of major flood and maximum water discharge in different flood years, Haridwar district

Year	Approximate maximum water discharge (cucecs)
1910	475000
1914	390000
1924	655000
1963	350000
1978	460000
1995	420000
1997	400000
1998	310000
2010	480000
source: Disaster Management and Mitigation Office, Haridwar,2010	

From 1986 to 2001, the study area faced eleven floods and out of eleven floods, three major floods took place in the study area in the year of 1995,1997,1998.The Danger Level for the gauge site of Haridwar is 294m. The river Ganga and its important tributaries cause high, moderate and low flood situation resulting loss of agricultural land. During dry season many tributaries become dry or very little base flow is observed. On the other hand, the dry channels are completely filled with water and sometimes few of them cause flashflood.So, variability of water discharge in Ganga and its other tributaries is very high. In 2010 maximum water discharge in Solani and Pathri river were recorded about twenty-fivethousand cusecs, Ratmarao was recorded maximum fifti-five thousand cusecs.

Table 3: Agricultural land Affected by Low, Moderate and High Flood in Haridwar district

RIVER NAME	FLOOD CONTROL OFFICE	LOCATION	LOW FLOOD VILLAGE	MODERATE VILLAGE FLOOD	HIGH FLOOD VILLAGE	EFFECTED AREA (Ha)	EFFECTED AGRICULTURAL FIELD (Ha)
SOLANI RIVER	GORDHANPUR	GODHANPUR	DHARAMPUR	-	-	140	105
			SAHAPUR	-	-	80	50
			RAKHPUR	-	-	120	75
			MADHARPUR	-	-	100	70
			SIKANDARPUR	-	-	105	80
			PAHLADAPUR	-	-	150	100
				JIBARAHEDI	-	130	110
				SAHIPUR	-	65	50
				YAHIYAPUR	-	120	95
				IBRAHIMPUR	-	200	150
					ABDIPUR	215	150
					ALAMPUR	90	80
					HASTMOLI	190	100
	KHANPUR	KHANPUR	TUGALPUR	-	-	20	20
			KABALPUR	-	-	40	40
			BAHADARPUR	-	-	10	10
				EDRISHPUR	-	50	50
				MADABELA	-	100	80
					DUDLA	80	80
					DALLABALA	150	100
					JOGABALA	1000	800
					CHANDPURI KHAO	180	160
					CHANDPURI BAO	190	160
					BANUBALA	120	75
					BADSHAPUR	300	250
					CHAKHERI	100	80
					SORPURBELA HRDAYRAMPUR	120	60
					SORPURBELA MAHAGITIP	270	200
GANGA RIVER	RYSI	RYSI	HABIPUR KUDI			400	300
			RAISI			300	200
	SHYAMPUR				KANGRI	495	98
					GAJIBALI	520	365
					SHYAMPUR	890	173
					NOYABAD	760	345

	GEDIK HATA	KIO SEO KO			RASULPUR MITHIBERI	2940	1234
					DUDLA DAYALBALA	710	675
RATMAU RIVER	JASWA BALA	JASWABA LA	JASWABALA			2300	130
			KOTA MURAD NAGAR			4100	204
						1600	115
			HAZARGRANT			4300	190
GANGA RIVER	SAHAN PUR				BISHANPUR	1100	270
RATMAU RIVER	FIROZP URE / BUGAB ALA	POLICE CHOWKI BUGABA LA	FIROZPURE / BUGABALA			2410	337
			MAZAHIDPUR SATIBALA			1510	519
			LAMGRANT			630	309
			LALBALAKHA LSA			618	360
			NOKRAGRANT			3187	556
			SAHIDBALAG RANT			2557	613
			DOWLATPURE			2511	1192
			HARIPURE TOGIYA			270	70
GANGA RIVER	MIKKA MPURE JITPUR E	MIKKAM PURE JITPURE	FATBA AHYATMAL		-	-	50
			RAMPURE RAYGHATI RAMPURE RAYGHATI JASPURE RANJIT SHIVPURE JASPURE RANJIT	LASKAR TOWN LASKARI SHEKPUR I NASIRAB AD NAROJPU R	-	-	200
			LADPUR KALA	FATEHUL LAPURE	-	1600	250
			LADPUR KALA	OURANGJ EBPUR	-	-	50
			JAINPUR	BANJARE BALA	-	-	40
			JAINPUR		-	900	50
			KUNAKHEDA				
PATHRI RIVER	LASKA R	LASKAR	KUNAKHEDA		-	2000	30
			TATEKI TANA		-	500	30

			MAJAHIDPUR		-	400	40
			TATEKI TANA		-		35
			MAJAHIDPUR		-	250	60
			MO PUR MU0				
SOLANI RIVER	MO PUR BUJUR G		MO PUR MU0		-	-	250
			AKBARPUR MAJRI		-	2200	120
OTHER HILLY STREAMS	FATEH ULLAP URE\TE LPURA	TELPURA				1848	377
RATMAU RIVER	BAHAD ARPUR SANI	BAHADA RPURSAN I			BAHADURPURE	785	161
					SANTARSAH		120
					BICHGHARI	-	80
SOLANI RIVER	LANTO RA	LANTOR A			KHEMPURE	350	78
					HANJJARPURE	325	81
					JORASI	340	90
					RAJPURE	0	300

Source:D.Moffice,Haridwar

Flood problem in Haridwar 2023

In the month of July,2023 serious flood took place in Laksar and Khanpur area which are located under vast terai zone in Haridwar. The flood and water logging situation affected normal life style of many people of the area. Under the influence of flood in Laksar and Khanpur area many crocodiles and reptiles entered the residential zonethrough flooded water of Solani and Banganga river. Due to heavy rain water level of Ganga risen flooding Khanpur and Laksar. Breach in embankment on Solani river has deteriorated the situation. Crops sown in over53000 hectares in Khanpur and Manglaur in Haridwar district of Uttarakhand have been damaged in 2023 flood. Frequency as well as magnitude of flood and avulsion are very high in the villages of tarai zone(Table: 3). Flooding and the flood induced avulsion events cause loss of agricultural production and properties. Table:3 gives vivid idea about the flood affected village areas and agricultural lands over extended geomorphic surface of the tarai zone .

CONCLUSION

From the above discussion it can be said that Haridwar city and its adjacent many villages located along the river Ganga and other tributaries, are facing river channel shifting and avulsion induced flooding, water logging and bank erosion hazards for a longtime. Over vast tarai zone in Haridwar, magnitude and frequency of avulsion are higher in compare to bhabar and siwalik zones. Every year about 60900 hectares settlement areas are affected due to flood in tarai part of the district. Sudden drop of topographic slope at the siwalik foothill and very gentle slope over tarai part accelerate magnitude of river channel sedimentation and ultimately causes avulsion process mainly during monsoon. In Haridwar district the actual length of the Ganga river is about 72.71km. and average topographic gradient of the river has been calculate about 1.24m /km. Since 1995 occurrence of major flood is observed every one or two years interval. It indicates occurrence of major flood is increasing gradually, which will enhance the magnitude and frequency of avulsion related hazards in the area. Monsoon induced flood acts as triggering factor of avulsion in the area. Near Chandi bridge (along the right bank of the Ganga), construction of new concretized embankment, and other anthropogenic encroachment over the active floodplain of the aggrading Ganga river channel can intensify the magnitude of avulsion near Haridwar city or downstream in future.

Depending upon the comprehensive study few recommendations have been suggested here;

1) Avulsion susceptibility map over active floodplain can be prepared along the river channels. This kind of map will be very useful for planning future riverside land use planning. Construction of embankments along the villages which are located beside of vulnerable river bank zones or avulsion prone area are required.

2) Awareness programmes regarding river avulsion and its impacts should be organised with the participation of the bank dwellers of different villages to enhance consciousness about cause-effect relationship of avulsion among them.

3) As the foothill rivers are more dynamic in terms of annual variability of their channel courses and water discharge magnitude, so unscientific anthropogenic interferences like; inconsiderate channel material mining should be stopped to minimise the adverse impacts of channel avulsion. Scientific channel mining techniques and floodplain management policy should be implemented properly.

4) Avulsion mainly occurs during monsoon, so evacuation of the flood and avulsion susceptible villagers to safe shelters should be properly implemented during active monsoon period for the safety of local people and their properties.

REFERENCES

Chadwick, A. J.,Lamb, M. P. (2021).Climate-change controls on riverdelta avulsion location and frequency.*Journal of Geophysical Research*: EarthSurface, 126,e2020JF005950. https://doi.org/10.1029/2020JF005950

Dhar, O. N., Nandargi, S. (2004). Flood in North Indian river systems. *In Copping with naturalhazards: Indian Context,Orient Longman private Limited,*pp. 104–111

Dutta, R. K. (2017). Controlling factors of channel shifting and avulsion in Haridwar district,Uttarakhand, *Geographical Review of India. Geographical Society of India, Kolkata,* 79(20),pp.153–167

Dutta,R.K.(2022).River dynamics of the Ganga and its tributaries in the Siwalik-Tarai regionof Haridwar district, Uttarakhand, India, *Anthropogeomorphology,Geography of the PhysicalEnvironment,* https://doi.org/10.1007/978-3-030-77572-8_8,pp.145-172

Field,J.(2001). Channel avulsion on alluvial fans in southern Arizona, *Elsevier, Geomorphology,* 37(2001),pp.93–104

Jones,L.S.,Schumm,S.A.(1999). Causes of Avulsion :An overview, *The International Association of Sedimentologists,* 28, pp.171–178

Mukhopadhyay, S.C. (2010). Fluvial processes with special reference to avulsion in the flood plains of the Unstable Mahananda-Sankoshinterfluvial areas, West Bengal, *Indian jr. of Landscape system and cological studies, ILEE, Calcutta*, 32, pp.521-538

Shukla, U. K., Singh, I. B., Sharma, M., & Sharma, S. (2001). A model of alluvial megafan sedimentation: Ganga Megafan. Sedimentary Geology, 14, 243–262.

Srivastava,P., Singh, I.B., Sharma, M., Singhvi, A.K.(2003). Luminescence chronometry and Late Quaternary geomorphic history of the Ganga Plain India,*Elsevier Palaeoecology,* 197, pp.15-41

Shukla, U. K., Bora, D. S.(2003).Geomorphology and sedimentology of Piedmont zone, Ganga Plain, India,*Current Science 84(8)*, pp.1034-1039

Sinha, R. (2005). Why do Gangetic rivers aggrade or degrade? *Current Science*, 89(5), pp.836–839.

Uniyal, A., Ravindran, K. V., Prasad, C. (2010). Tectonic control on alluvial fans, piedmontstreams and Ganga River in western Ganga Plain (India) using satellite remote sensing data,*Current Science*, 99(1), 91–97.