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Glacio-Fluvial Landform Analysis of Upper Pinder River Basin, Central Himalaya

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Abstract

Pindar River originates from Pindari glacier trending from N-W to S-E direction. The present study is an attempt to understand the development of landforms in the upper Pinder river basin. In the selected area prominent glaciers are Pindari (4150 m.), Kaphani (4459 m.) and Sundardhunga (4400 m.). Morphological features caused by glacial action are very important to interpret paleo climate processes. Snow line is retreating rapidly as a result glacial and glacio fluvial actions are found important for land form development in the area. On the basis of altitude, dissection pattern, landform and process the study area is divided into three geomorphic units, e.g. glaciated, depositional and fluvial area. 'U' shaped valleys, hanging valleys, arêtes, crevasses, horns, troughs, ice fields, and moraines are main glacial landforms in the area. Prominent glacio-fluvial landforms are outwash plain, alluvial Fan, debris flow etc. 'V' shaped valley, gorge, waterfall, rapid and river terrace. Some gravity influenced landforms i.e. talus/scree deposits, and fans are also observed in the study area. The length of Pindari glacier is about 6.4 km and retreating rapidly. Total recession of Pindari glacier during 1854 to 1906 was 1600 m while, in 1906-1958 it retreated 1054 m. From 1958 to 2010 it retreated 440 m. Clast analysis based on the field investigation indicates various size, shape, fabric and surface features.

Keywords: Central Himalaya, geomorphic unit, glacial and fluvial landform, glacier retreat

Introduction

Geomorphological study of an area includes identification, mapping and interpretation of forming material and processes of landform. Geomorphological maps are used for land use planning, resource identification & exploration, military and environmental management. Geomorphological mapping was started by *S. Passarge (1914) and* Fenneman (1917) and after II World War scientists and engineers felt the need of such type of geomorphological map for development and planning. Morphological features caused by glacial action are very important to interpret paleo climate processes. To carry out the micro geomorphological mapping drainage basin is an easiest and accepted geomorphic unit. In general in the Himalayan region landforms are the result of

altitude, slope, litho structural characteristics and climatic conditions. From geodynamic point of view the Himalaya is still very active as a result geomorphic processes are very complex. Topography of the study area is dominated by large glaciers, lofty mountains, steep rocky slopes, high ridges and deep gorges, most of which are totally inaccessible for field verification. In this work an attempt is made to identify the various landforms and their forming material and processes. To carry out the geomorphological mapping of the area the objectives of the study are (i) Identification and mapping of the Glacial, Glacio fluvial, fluvial, and gravity inluenced landforms and their forming material & processes and (ii) To understand the glacial retreat based on the secondary data.

Study Area

The area of present study lies in the Kumaun Himalaya in Bageshwar district of Uttarakhand. It is situated ~~in~~ between 30°05'02" to 30°19' 34' N latitude and 79°47'51" E to 80°05'36" E longitude. The total study area is about 348km². The altitude of the area ranges from about 1997 meter to 6855 meter. Pindar River is a tributary of Alaknanda having its confluence at Karanprayag. The upper catchment of Pindar River is formed by the tributaries originating from the glaciers known as Pindari, Sunderdhungha and Kafni. According to Ahmad et.al (1962) the length of Pindari glacier is about 6.4 km. Geologically the area comprises parts of lesser and Great Himalaya. The characteristics of the major glaciers are given in Table 1.

Table 1: Characteristics of Sundardhunga, Pindari and Kafni glaciers

Features	Glaciers		
	Sundardhunga	Pindari	Kafni
No. of glaciers	2	2	1
Length	5km	6.4km	3km
Catchment area	178.5km²	147.75km²	57.05km²
Highest altitude	6855m	6663m	5895m
Altitude at snout	4000m	3750m	3900m
Snow covered area	62.4 km²	58.85 km²	38.3 km²

Source: Topographical Maps and Field Work

Data Base and methodology

An attempt was made to divide the area into different geomorphological units on the basis of Landsat satellite image, topographical maps, google earth map and field work. The accuracy of the field mapping was improved using a Global Positioning System. The main focus of this study was on the features made by glacial, glacio-fluvial and fluvial processes. The methodology for geomorphological mapping is adopted following the works of Cooke and Doornkamp (1973), Gardiner and Dackombe (1983), K.S. Lol et.al. (1985), J. Tricart (1969) and Joshi (2007).First of all a base map is prepared using topographic sheets (53 N/3, 53 N/16, 62 B/3 and 62 B/4) on scale 1:50000. The whole work is divided in three steps. First is pre-field, which includes the collection of information based on earlier works and Landsat satellite data. Second step comprises about the identification of landforms, forming material and process during field work. Third step includes integration of all information and transfer on

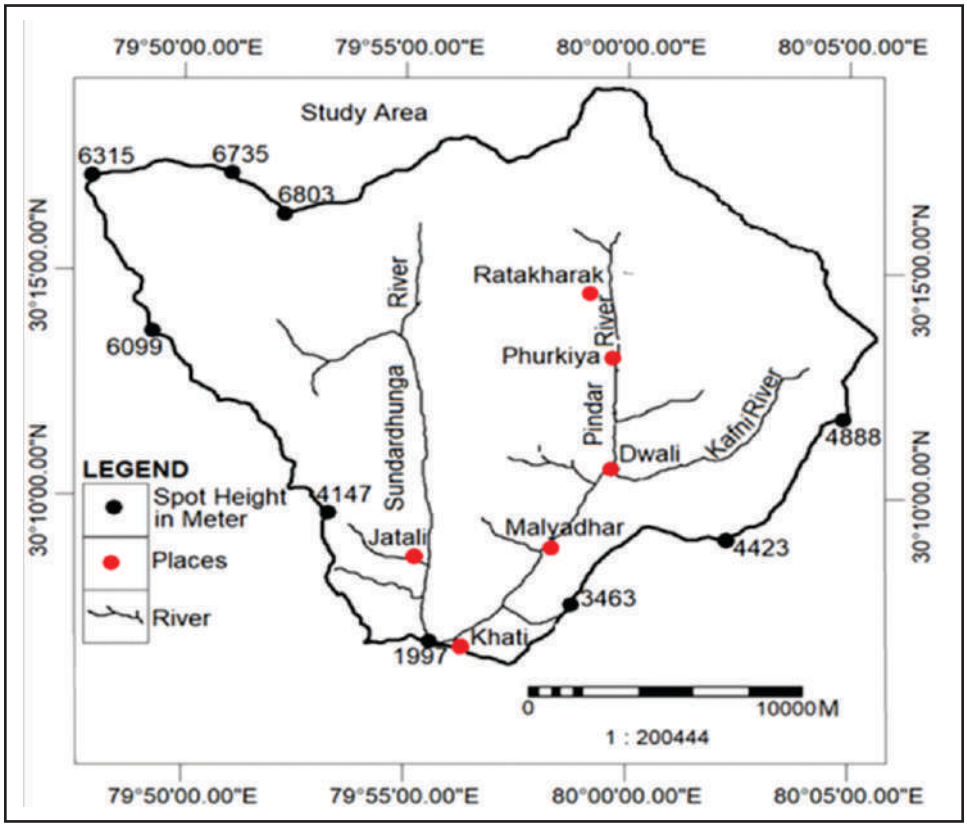

Figure 1: Location of the Upper Pinder River Basin

base map for the preparation of geomorphological map. On the basis of altitude, dissection pattern, landform and processes study area is divided into three main geomorphic units Figure 2, i.e. Snow Cover Area, Glaciated Depositional Area and Fluvial

Table 2: Geomorphic Unit of Upper Pinder River Basin

	Glacial	Colluvial and Fluvial		
	Snow Cover Area	Glaciated Depositional Area	Colluvial	Fluvial
Landform	Horn 'U" Shape Valley Glacial Trough	Lateral Moraine Medial Moraine Frontal Moraine	Alluvial Fan Colluvial Fan	'V' Shape Valley Gorge Waterfall River Terrace Channel Bar

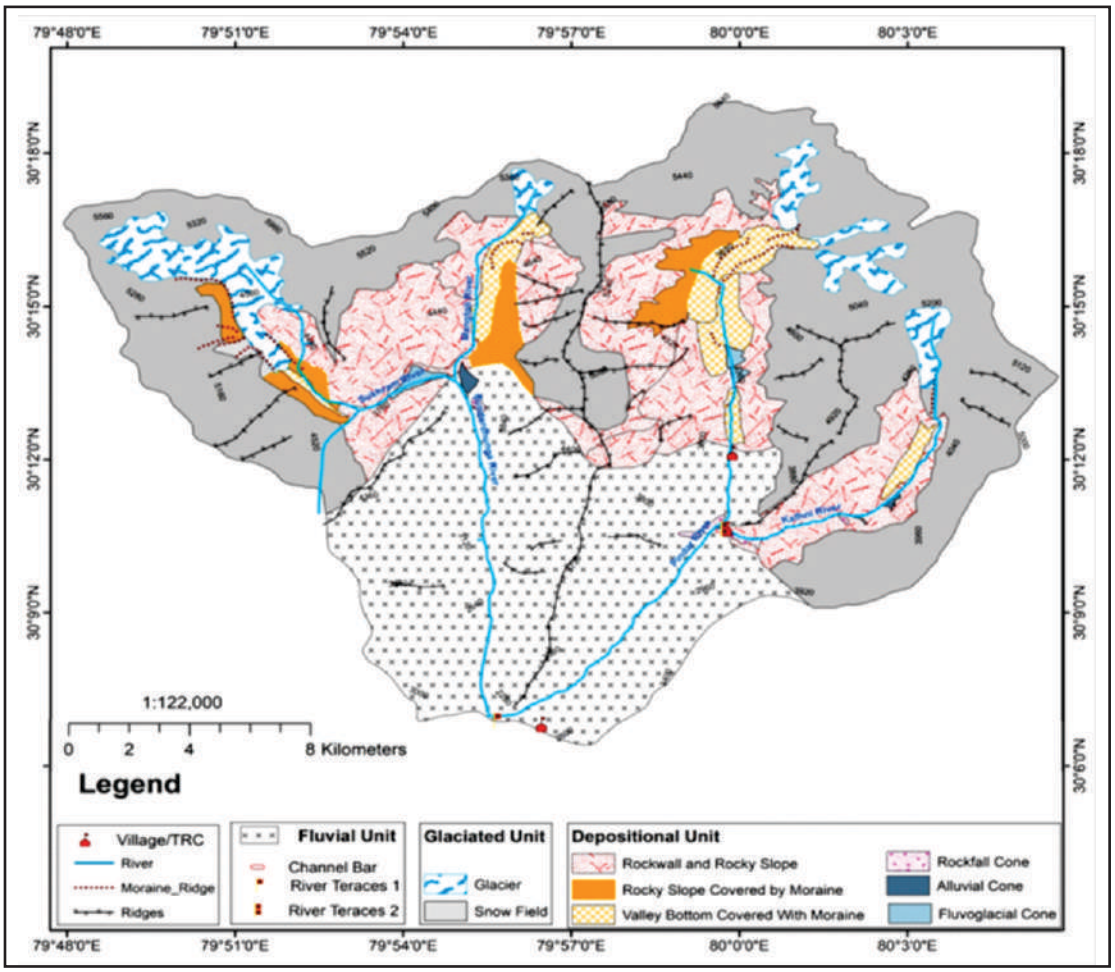

Figure2: Geomorphic Unit of the Upper Pinder River Basin

area. The landforms of each unit are shown in Table 2.

Snow Cover Area

Area under this unit is covered with snow throughout the year. Pindari, Kafni, Mrigthuni, and Mangtoli glacier are the main glaciers of the watershed. Pindar River originated from the Pindari glacier. The Snout of Kafni glacier located at 30º 13' 05" north latitude and 80 º 03' 19" east longitudes and at the altitude of 3900 meter. Mangtoli glacier is the source of Mangtoli river which is the tributary of Sundardhunga River. It is situated at 30º 13' 31" north latitude and 79º 52' 17" east longitude and snout of the Mrigthuni glacier is at the altitude of about 4000 meter. The glaciated area of the watershed contains 159.6 Km², which covers 41.63% part of the basin.

Glaciated Depositional Area

An area influenced by retreating glaciers is delineated as glacial depositional area. In this unit moraines are the prominent features including medial, lateral and terminal moraine. Formation of moraines is caused by the accumulation of debris by the retreating glaciers. This accumulation includes eroded rocks forming different size of boulders, granules and sand by abrasion and plucking

Figure3: Erosional Landform in the Glaciated Area of the Upper Pinder River Basin

during the transportation by glaciers. When glacial debris is accumulated like a ridge along the sides of any glaciers then lateral moraine formed. Lateral moraines are very prominent along both sides of Pindari glacier, Chhanguch glacier, Kafni glacier, Mrigthuni glacier and Mangtoli glacier. The lateral moraine of Pindari glacier along the river is about 1.3km long. Near snout of Pindari glacier a medial moraine is formed by Pindari and Chhanguch glacier. This unit covers 25.13 km² area which is 6.55% part of the entire watershed.

Fluvial Area

River terraces, sand bars and alluvial fans are the main features in fluvial area. Terraces are generally formed due to dissection and down cutting of fluvial sediment of flood plains deposited along the valley floor (Singh, 2008). In the upper Pindar river basin two levels of terraces are noticed near Khati village

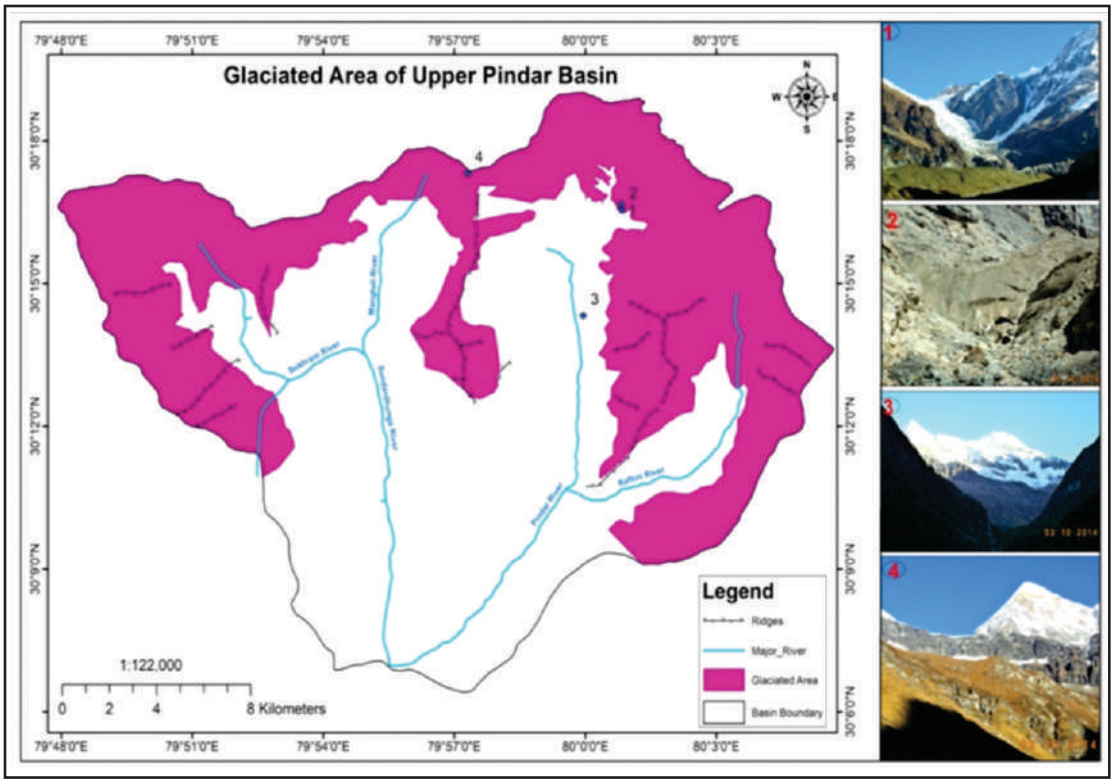

Fig.4: Snow Cover Area of the Upper Pinder River Basin

Table 5: Morphometric parameters of Sundardhunga, Pindari and Kafni Moraines

Moraine	Lateral	Medial	Frontal
		Mrigthuni Glacier	
Length	2.0 km.	-	-
Width	180 m.	-	-
Height	83 m.	-	-
Slope	50º	-	-
		Mangtoli Glacier	
Length	1.68 km.	-	440 m.
Width	191 m.	-	90 m.
Height	38 m.	-	17 m.
Slope	88º	-	47º
		Pindari Glacier	
Length	1.63 km.	765 m.	156 m.
Width	244 m.	191 m.	45 m.
Height	290 m.	284 m.	5 m.
Slope	41º	53º	13º
		Kafni glacier	
Length	785 m.	-	-
Width	128 m.	-	-
Height	68 m.	-	-
Slope	71º	-	-

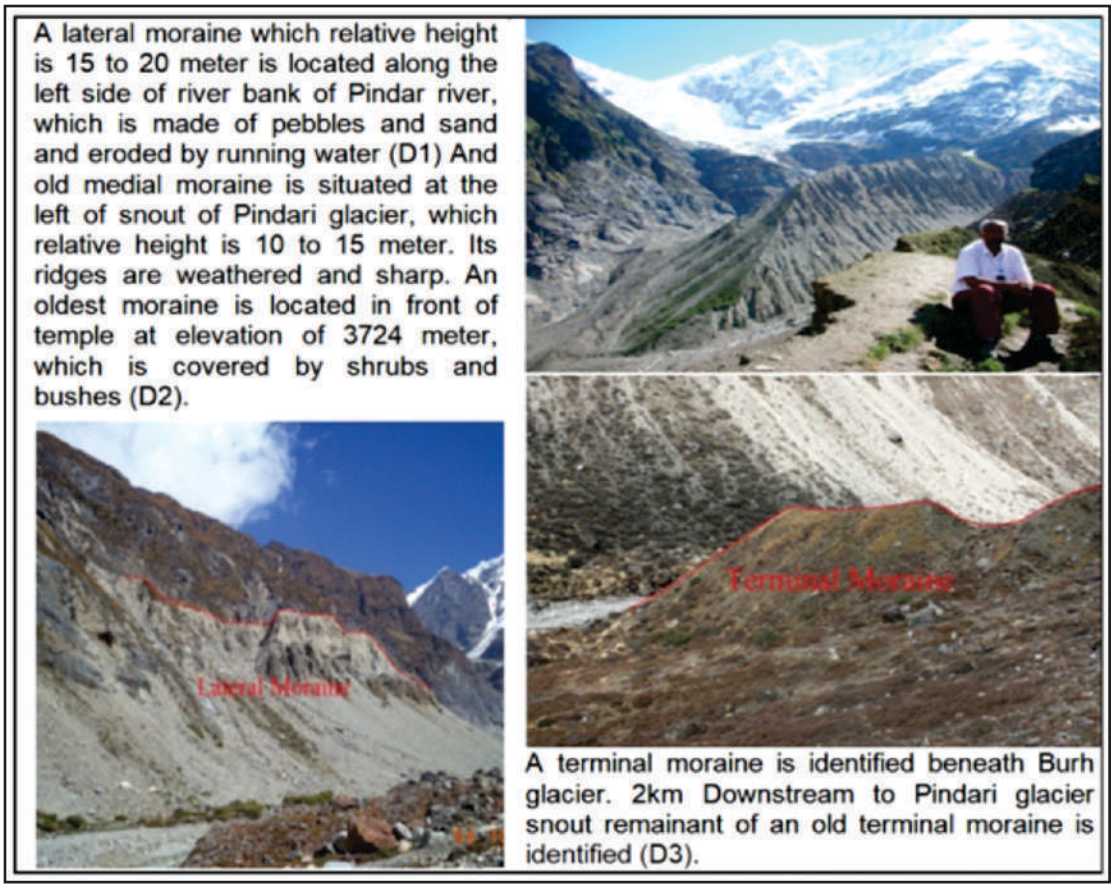

Fig.5: Glacial Depositional Landform of Upper Pinder River Basin

at the confluence of Pindar and Sundardhunga river. A set of river terrace is also observed near Dwali locality. On the right bank of Pindar River at Ratakharak also river terraces are seen. From Khati to upstream many alluvial fans are observed. Wide river channels are including sand bar. This unit covers 123.44 km² area which is 32.41% of the total study area.

Erosional Land form

After crossing the snout area, the melt snow provides a huge amount of water to the downstream channels as a result various landform development takes place. Some of the landforms observed in the study area given in figure 8.

Gravity influenced landform

In this study landform processes comprises the gravity and water influence on the weathered material and soil along the slope. The main landforms identified are Talus Cone, Mud Flow, slide and *colluvial fans* (figure 10).

Clast Material Characteristics

In this study an attempt is made to identify the characteristics of the forming material of depositional landforms made by glaciers, fluvio glacial and fluvial action. A brief description is given in tabular form, (figure 11).

Middle moraine of Pinder and Chhanguch glaciers and lateral moraine in the right side of Chahanguch glacial appears the oldest moraine

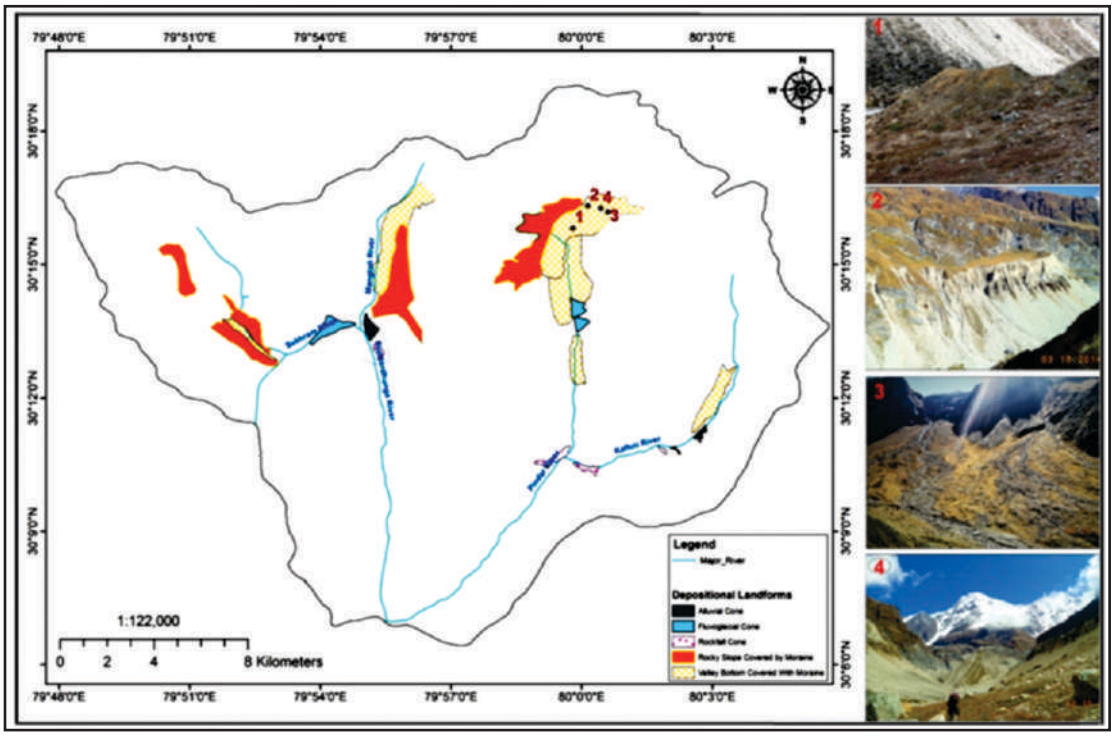

Fig.6: Glacial Depositional Area of the Upper Pinder River Basin

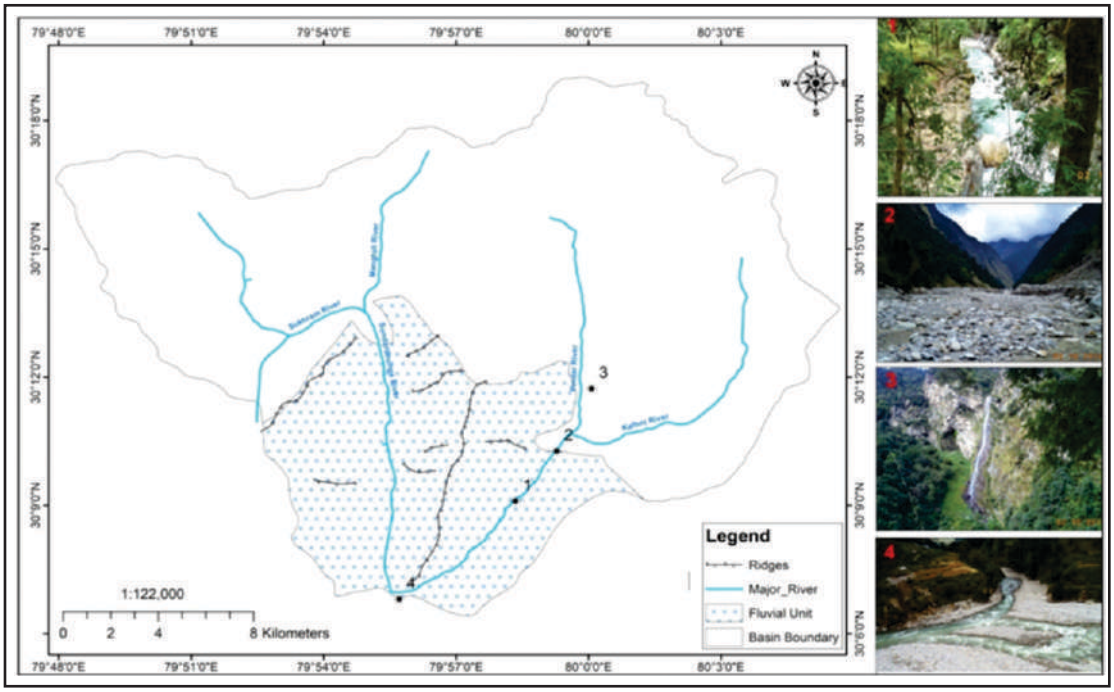

Figure7: Fluvial Area of the Upper Pinder River Basin

River Terrace Near Khati village two levels of terraces can be observed there. Near Maliyadhaur along the Pindar river. Same things may be seen in the opposite of the bank of river. A new formed set of river terraces is located in Dwali at the confluence of Pindar and K afni river	
Channel Bar In the study area channel bar are found near Khati at the confluence of Pindar and Sundardhunga river. In this part valley is wide and river bed slope is also low as a result deposition takes place leading the development of Chanel bar	
Flood Plain It is a flat area of land along the river that stretches from the banks of its channel to the base of the enclosing valley walls and which experiences flooding during the period of high discharge. Flood plains are found in the study area at near Dw ali and Maliyadhaur. These are the new flood plain formed in 2013 disaster.	

Figure 8: Fluvial Depositional Landform of the Upper Pinder River Basin

'V' shaped valley Pindar river, Kafni river and Sundardhunga river flow in a 'V' shaped valley in downstream. From Khati to Dwali Pindar river flows in an asymmetrical 'V' shaped valley. In the upstream from Dwali valley becomes narrow and the right slope is steeper than left slope.	
Gorge In Pindar river valley river flows through a gorge upstream to Khati near Maliyadhaur localities. The side walls are steep and formed by hard rock. This gorge is about 8 meter to 10 meter deep and 10 meter wide. In Kafni and Sundardhunga valley some other small gorge can be observed.	
Waterfall In Pindar valley downstream to Dwali, two waterfalls are located which heights are 40 meter and 50 meter. A 30 meter high waterfall situated in Jarthi river, which is a tributary of Pindar river. A waterfall near Phurkiya is located which height is 70 meter. There are many seasonal and perennial waterfalls found in the area	

Rapids Small step like features on the bed of river through which water flows forms rapis. In the present study area many rapids are found in Pindar, Sundardhunga and Kafni river. These rapids are not sTable. Every rainy season these rapids destroyed and new rapids developed in river course	

Figure 9: Fluvial Erosional Landform of the Upper Pinder River Basin

Talus Cone Abundant rock falls are seen in this study area near Mangtoli, Nag Kund, Cheper Choti and Rata Kharak. Talus cone upstream to Phurkiya along Pindar river is shown in the photograph.	
Flows Flows occurs when a loose mixture of debris, water and air move down slope in a fluid like manner. While returning from zero point we could not cross for some time as mud flow like mortar started to flow along the slope near Maliyadhaur on the way to Phurkia rest house.	
Slides When blocks of rocks and soil move from higher slope to lower slope then it is called a landslide. Image show a huge landslide near Dwali along Kafni river.	
Colluvial Fan Colluvial fans are formed dominantly by gravitational force along the slope. Colluvial fans are identified along both sides of Kafni river, near Rata Kharak, Phurkiya and at Kupi Dhaura.	

Figure10: Gravity Influenced Landforms of the Upper Pinder River Basin

remains of the area. During field work these deposits could not observed very closely as these areas are not reachable.

In the present study area clast size is mainly influenced by running water and gravity in lower part and by glacial action in upper part. From Khati village, along the Pindar river, big boulders are found. At the confluence of Pindar and Kafani River a huge amount of the debris or sediment deposition (5-8m. thick) is seen. Side slopes of Kafani River are made of very loose material consisting boulder (unsorted), small piece of stone and soil.

<table>
<tr><td colspan="3">Location</td><td>Clast Characterises</td></tr>
<tr><td>Latitude</td><td>Longitude</td><td>Elevation</td><td rowspan="2">This matter is deposition along the slope. It is consisting huge boulders (12×10feet) mixed with sandy material with fine clay, cobbles and pebbles. Maximum boulders are having sharp edges. Some boulders are with smooth edge and randomly lying along the s lope. In general shape of the material is angular to elongated with the orientation of 100^0-280^0 . It is very difficult to identify the forming process. It may be speculated that there is influence of colluvial processes on glacial deposits.</td></tr>
<tr><td>30 ^{0} 13’ 29.1”</td><td>79 ^{0} 59’ 57.6”</td><td>3357m</td></tr>
<tr><td colspan="3">  </td></tr>
<tr><td>Latitude</td><td>Longitude</td><td>Elevation</td><td rowspan="2">Just after Bhujyani tapar along the nala a deposition is observed. Deposition is about 7 meter thick. The boulder sizes in the river bed are blocky with size of 3x3 meter, whereas in the deposition boulders are not angular. The size of the boulder is rangi ng from sandy particles to boulders with blocky and elongated (5x4feet). All boulders appear to be aligned along the surfacial slope. It appears that this material is of colluvial nature having an orientation of 145º-325º. However, there is a possibility of glacial action influence as material appears as the rework of glacial deposit.</td></tr>
<tr><td>30º14’00.3”</td><td>79º59’50.6 ”</td><td>3479m</td></tr>
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</table>

Figure11: Characteristics of Non Glacial Deposit of the Upper Pinder River Basin

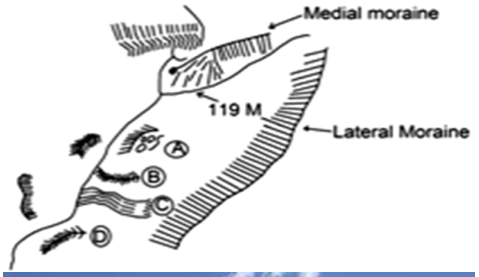
Glacial Retreat

Most of the Himalayan glaciers are currently retreating (Bloch et al. 2012). The recession rate varies from one glacier to another. According to Mayewski and Jeschke (1979), the glaciers in the Himalaya have been continuously retreating since the year 1850 and the recession of the Pindari glacier has been the most prominent in the years 1850-1979. During this period it retreated about 2600m.

Earlier workers reported that in the past Pindari valley was intensely glaciated and experienced two major glacial advances. Terra and Paterson (1939) and Heim & Gansser (1939), have recorded that in most parts of the Himalaya the advance of glaciers was down to about 1829m, but unfortunately this valley does not show any definite evidence of glacial advances below 2743m. Terra and Paterson (1939) suggested the first three Himalayan glaciations stages might have been in the valley. According to Tiwari (1973) the Pindari and Chhanguch glaciers had a common tongue but separated afterwards.

Conclusion

Main glaciers of the study area are Mrigthuni , Mangtoli, Pindari, Chhanguch and Kafni. On the basis of altitude, dissection pattern, landform and processes area is divided into three geomorphic units i.e. Snow Cover Area, Glacial Depositional Area and Fluvial Area. Snow Cover Area comprises Horn,



Location		
Latitude	Longitude	Elevation
30 ^{0} 55’ 55.4”	79 ^{0} 59’ 54”	3633m

A. This mound is very closed to the Pindari snout and made of slaty schist rocks. These boulders are not big in size. The maximum length appears 2 meters with the thickness of ½ feet. The big boulders which are very big in size appears have fallen from the older lateral moraine.
B. Height of B is more than A and having crescent shape. Convex part is towards the flow of Pindar river. It is lying below highest older lateral moraine.
C. While coming from B we have to climb at the bottom of C. there is a small dry pond type feature.
D. After coming down from C huge deposit (like heap of stones) is seen. The amount of soil is almost nil in the upper horizon.

Latitude	Longitude	Elevation
30^{0} 55’54.4”	79^{0} 59’54.6”	3553m

This material is deposited along the river in front of medial moraine. It is consisting elongated clast of different size mixed with sandy material. Maximum clast material is having sharp edges with angular and elongated shape. The size of this moraine depositional material is a few cm to 1m having an orientation of 100^{0}-280^{0}. This unsorted material is moraine deposition. It use to be covered by seasonal snowfall and due to melting in summer fine material is taken away by water. Heap of unsorted material brought by glacier is seen without fine material in all three glacial vallies i.e. Pinder, Sunderdhunga and Kafni.

Fig.12: Characteristics of Glacial Deposit of the Upper Pinder River Basin

Table 4 : Rates of the Pindari Glacier Recession

Period	Recession (m)	Duration (Years)	Rate (m /year)
1854-1906	1600	61	26.23
1906-1958	1040	52	20.00
1958-1966	61	8	7.62
1966-2007	262	41	6.39
2007-2010	117	3	39.00

Source: Tewari 1973; Bali et al. 2011-13

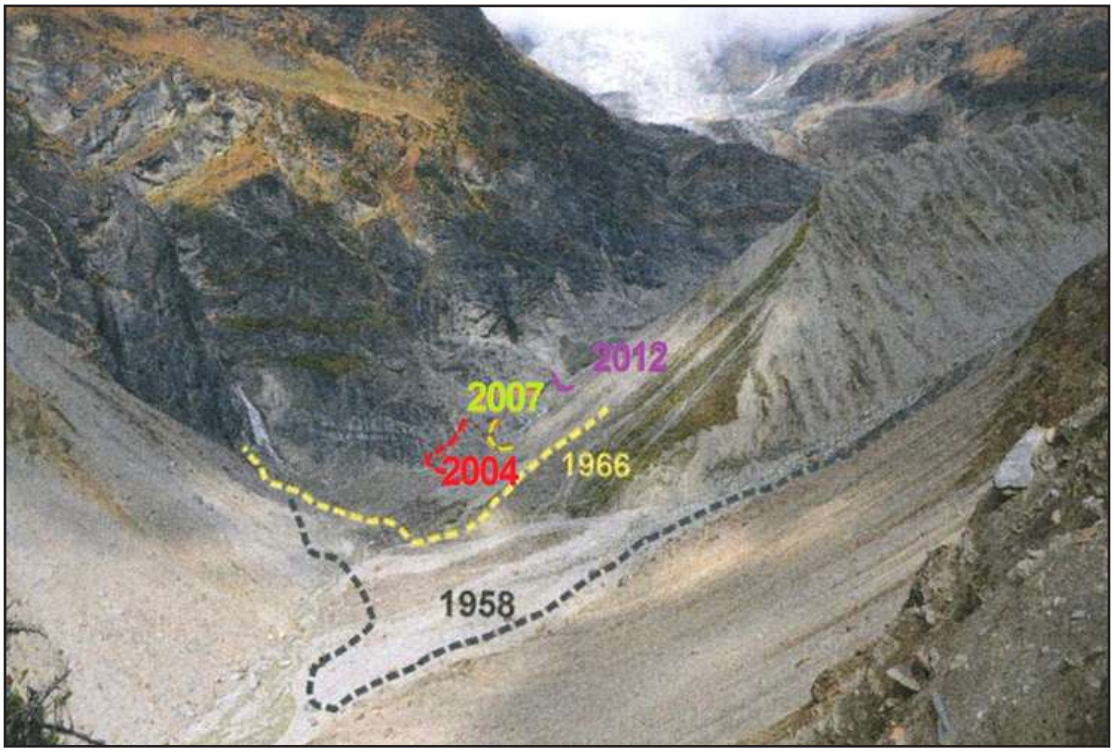


Figure 13: Glacial extension during different Years of the Upper Pinder River Basin (Raczkowska & Joshi 2016)

Cirque, 'U" Shape Valley, and Glacial Trough. Glacial Depositional Area includes Moraines and Glacio fluvial area includes, Alluvial Fan, Debris Flow, Alluvial Cone, V' Shape Valley, Gorge, Waterfall, River Terrace, and Channel Bar. Lateral moraines are very prominent along both sides of Pindari glacier, Chhanguch glacier, Kafni glacier, Mrigthuni glacier and Mangtoli glaciers. The medial moraine near snout of Pindari glacier is made by Pindari glacier and Chhanguch glacier. Earlier record indicates the total retreat from 2007-2010 was 39.00m per year. After travelling about 500m from Phurkia locality, moraine deposits can be seen as small remnant of the frontal moraines. Valley is not very wide as a result water derived from deglciation erodes the existing moraine deposits.

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