GEOCHEMISTRYOF TERRACE DEPOSITS OF UPPER ALAKNANDA BASIN

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In

Geology

By

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May, 2018

CERTIFICATE

I declare that the project entitled **"GEOCHEMISTRY OF TERRACE DEPOSITS OF UPPER ALAKNANDA BASIN"** has been prepared by me under the guidance of Dr. Jitendra Kumar Pattanaik, Assistant Professor, Department of Geography and Geology, School for Environmental Sciences, Central University of Punjab. No part of this project has formed the basis for the award of any degree or fellowship previously.

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I certify that Mohd Yusuf has prepared his project entitled **“GEOCHEMISTRY OF TERRACE DEPOSITS OF UPPER ALAKNANDA BASIN”** for the award of M.Sc. Geology of the Central University of Punjab, under my guidance. He has carried out this work at the Department of Geography and Geology, School for Environmental Sciences, Central University of Punjab.

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ABSTRACT

GEOCHEMISTRY OF TERRACE DEPOSITS OF UPPER ALAKNANDA BASIN

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Key words: Alaknanda River, Terrace deposits, Clay mineral identification, clay mineralogy, geochemistry.

Geochemical and clay mineralogical study of terrace deposits in the higher altitude will provide the information of nature and extent of chemical weathering in the upper reaches of the river basin. In this study sediment samples from terrace deposits of Badrinath valley, upper Alaknanda basin were collected for clay mineral identification and quantification, and geochemical analysis to understand chemical weathering intensity prevailing during sediment deposits. The deposits are interlayered with the pebble and the boulder layers which are due to the changing energy condition caused by climatic variations. Bulk and clay mineralogy, grain size distribution of <38 micron size suggest that physical weathering is dominated in the study are compare to chemical weathering. Presences of illite in specific site indicate a colder climatic condition (i.e. glacial period) during development of terraces. CIA, A-CN-K, A-CNK-FM ternary diagram suggest low intensity of chemical weathering in the upper catchment area and grain size reduction is mainly due to physical weathering. Bulk geochemistry is indicating felsic source rock.

(Mohd Yusuf) (Dr. Jitendra Kumar Pattanaik)

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Mohd Yusuf

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CHAPTER 1

1.1 Introduction

The fluvial terraces in the Alaknanda Valley, Central Himalaya are depositional in nature formed as a result of filling of valley by alluvial materials. These terraces are formed at different ages, having variable thicknesses due to variable supply of alluvial sediments to the rivers induced by fluctuation in the glacier movements and it gets incised by intense monsoon (Srivastava et al. 2008). Glaciation and de-glaciation during late Pleistocene does extensive aggradations through cycles of erosion and deposition followed by incision (Srivastava et al. 2008; Ray and Srivastava 2010).

Indian summer monsoon (ISM) and mid-latitude westerlies mainly control the Himalayan climate (Mehta et al. 2010). Central Himalaya is dominated by ISM (Owen et al. 1996).

These terraces are in the tectonically active terrains i.e. in the Himalaya having preserved records of tectonic and climatic events so their study is very important for the identification of these significant events. The terrace may form during superimposed climate oscillations that alter the balance between sediment load and transport capacity or from the complex interactions between tectonics.

Terraces are of two types depositional and erosional which may be paired or unpaired.

The depositional terraces result from river aggradations followed by entrenchment though the alluvium (Blum et al. 2000). The preservation potential of depositional terraces are comparatively poor than erosional terraces because depositional terraces are easily erodible. As a result of tectonic upliftment the river entrenches the flat valley floor and forms river terrace. The fluvial system can produce the series of terrace surface; a river terrace is composed of an abandoned surface, tread, and the incised surface or riser. Fluvial terrace contains information about incision deformation and climate change.

According to Juyal et al. 2010 the elongated fluvial terraces are of two basic types – fill (depositional) terraces and strath (erosional) terraces.

Fill terraces are formed by alluvium filling the existing valley. It is classified into cut terrace and nested fill terrace. Cut terraces also known as cut-in-fill terraces, it may also form below the fill terraces. Nested fill terrace is the result of the valley filling with alluvium (Nainwal et al. 2007).

Strath terrace formed from the down-cutting through the bedrock of stream or river. Paired terraces are those which have same elevation opposite side of river or stream. Paired occur when it down cuts equally on both sides and terraces on one side of the river are same in height with those on the other side. According to Sundriyal et al. 2010 when a river encounters material on one side that resists erosion, leaving a single terrace with no corresponding terrace on the resistant side called the unpaired terraces.

At different locations both types of terraces are developed in the Himalaya whose development and preservation are mainly control by climatic and tectonic events. Most of the depositional terraces in the Alaknanda basin formed and modified during Quaternary period. These depositional terraces show different phases of river aggradations and are best preserved in wider valleys. During Quaternary climate is changing which has its major impact in shaping the terraces what we see today. Quaternary records frequently bear the stamp of rhythmic changes in the climate. These are preserved cyclic, predictable variations that are driven largely by astronomical influences, and which operate at frequencies that range from tens or hundreds of thousands of years (Milankovitch Cycle) down to decadal and even annual wavelengths (Lowe et al. 2007).

From the chemical study of the terrace deposits we can tell the nature of weathering at the source, which in turn is controlled by numerous factors such as climate, tectonics, topography, lithology etc. which influences the two processes chemical weathering and mechanical denudation (Singh, 2010).

1.2 Quaternary Climate and Climate Change

The climate during Quaternary is ever changing. The intensities of glaciations changes and so the amplitude of temperatures. During early Quaternary i.e. before 800,000yr there were build-up of small to moderate ice sheets at high northern latitudes and after 800,000yr the glaciations was intensified with repeated growth of continental-scale ice sheets reaching mid-latitudes. During this time period about 8-10 major glaciations have occurred, out of which two are the largest one – the recent Weichselian/Wisconsin glaciation at its maximum about 20,000yrs ago and prior to the last interglacial – the Saolian/Illinoian glaciations, occurring prior to 130,000yrs ago.

In both the major glaciations peaks most of the northern hemisphere were covered by thick ice-sheets, the latitudinal extent is upto 40-50 degree North in both Eurasia and N. America. Throughout the major part of Quaternary there is repeated growth of glaciers at mid and high-latitudes and repeatedly prevailing of cold climate and permafrost in mid-latitude regions.

The climate change during the Quaternary can be seen by repeated glaciations of the major part of the globe. The period in the geological history of the Earth when glaciations extensively happen over its major part of its surface is term as an “ice age”. The evidences of ice ages are depicted by the erosional and depositional features of natural geological agents which establish that a major part of overland surface had been repeatedly covered by glaciers. (Parbin Singh, 2008)

There are 4 major periods of ice ages over the surface of the earth especially in the northern hemisphere since last million years, during which continental scale glaciers are believed to have been extended over most of the Northern Hemisphere continents such as – N. America, N. Europe and England and the northern part of Asia (Smith et al. 2004).

Pleistocene (2.588my ago to 11.7ky ago) ice age is referred as great ice age during which one third of the landmass was covered by continental glaciers. During the ice age exceptionally high snowfall, precipitation occur and repetition of this after almost regular intervals for four times during the last great ice age.

1.3 Upper Alaknanda Basin

Alaknanda River is a major tributary of the Ganga River in the State of Uttarakhand, India. It is a Himalayan river originated from the Bhagirath-Kharak and Satopanth Glaciers near the border with Tibet. At Mana Saraswati river joins with it which is a tributary of the Alaknanda River.

The Bhagirathi River originates at the foot of Gangotri Glacier and Chatting Glacier at Gaumukh, Garhwal Himalaya. The Mandakini River originates from the Gangotri Glacier near Kedarnath at different location and elevation from the Bhagirathi River and confluence with Alaknanda at Rudraprayag.

Bhagirathi and Alaknanda join at Devprayag to form the Ganga River. Rivers originates in the northern mountainous regions of Uttarakhand are Alaknanda,Bhagirathi, Dhauliganga,Mandakini and Pinder and are the major headstreams of the Ganga River.

There is a triangular lake at the height of 4350m known as Satopanth situated 6km up from Alaknanda origin at its snout. Alaknanda River has total catchment area of about 10635 sq.km, total length 190km, minimum depth is 1.3m and a maximum depth of 4.4m.

The Alaknanda River traverses through major Himalayan litho-tectonic units starting its journey through Tibetan Sedimentary Series (TSS) then through South Tibetan Detachment System it traverses/flow over high grade metasediments of Higher Himalayan Crystalline Series (HHCS) and enters into the region of Lesser Himalayan Series (LHS) before its confluence with Bhagirathi at Devprayag. HHCS is separatedfrom LHS by Main Crystalline Thrust/Zone (MCT) (Negi et al. 1995). LHS to its southisdelimited by MBT, also forms the northern boundary of Ganges Foreland Basin known as Siwaliks.

1.4 Research Problems

During the Late Quaternary period witnessed to the climatic variation multiple times. These climatic changes are due to glaciation and de-glaciation events during the period, which affecting various geological processes all over the world. These changes are recorded in different parts of the Himalaya as characteristic features. (Owen et al., 2002)

In the upper Alaknanda basin records of late Quaternary glaciations (climatic changes) are found at many places. As during glacial-interglacial period, chemical and physical weathering intensity changes which affect chemistry of the sediments. These changes included with tectonic events are preserved in the sedimentary records.

Different sediment archives such as terrace deposits and pro-glacial deposits which bear the evidence of these climatic (and tectonic) events help us to understand the paleo-weathering intensity of the sediments (when deposited).

1.5 Objectives

To answer the above problem following objectives were taken in this study.

I. Clay mineral identification and quantification of the terrace sediments collected from the Badrinath valley, and
II. Geochemical analysis of the terrace sediments to understand chemical weathering intensity.

1.6 Review of Literature

For this project study, several published scientific papers were reviewed to achieve the necessary information related to this study.

After reviewing several related literatures from different sources, such as Bookhagen et al., 2005; Sundriyal et al., 2007; Juyal et al., 2009; Phartiyal et al., 2009. It suggests that the major factor in these high mountain regions the overall lowering of surface and the evolution of landscape is due to Indian Summer Monsoon (ISM). They studied the type, timing of fan deposition and calculated the rates of fans and bedrock incision (Barnard et al., 2001).

Various factors like lithology, tectonic, climate and structures contribute their part in the evolution and development of landscape. Present approach for this study area is mainly dominated to ISM.

McGregor and Nieuwolt, 1998; Colin et al., 1998,The main component of the tropical climate system is the Indian summer monsoon which originates due to difference in thermal difference between sea and land, causingreversal in wind direction in seasons and during the summer heavy rainfall. Dry cold winds directed from the Asian continent flow offshore in winter, whereas westerly winds flow around the Tibetan Plateau in central Asia.

Our study area is located in the Higher Himalayan Crystalline Series, which is by south Tibetan detachment system on topseparated from Tibettan Sedimentary Succession and bottom by the Vaikrita thrust evident from theAhmad et al. 2000.

Bhakuni(2007) suggested that in the area there is a thrust known as Vaikrita thrust which played an vital role in the upliftment of Greater Himalaya and development of stretching llineations and folds.

Valdiya (1980): The sediments contributed by the Alaknanda and Bhagirathi River are derived mainly from the metasediments of HHCS and sediments of Mandakini river from the Camaro-Ordovian granites. The Ganga River got its composition from these tributaries after their confluence at Deoprayag. There is little contribution of Lesser Himalaya and Siwaliks to the Ganga river sediments.

Berner (1992): The geological processes which chemically weather the rocks affects the atmospheric CO_2, global climate, solute chemistry of the river and nature of sediments. The sediment s produced preserves the original signature of the source.

Goodbred (2003): ISM strongly affects the Himalayan fluvial system upto 80% of the annual flow discharged.

Schmidt and Montgomery (1995): Hill slope erosion accelerates by increasing pore water pressure caused by increase precipitation which caused landslide and the sediments are delivered to the main streams.

Prat et al. (2004): During the intervals of weakened Indian Summer Monsoon during late glacial maxima and the younger Dryas aggradations of the terrace occurred whereas with the strengthened monsoon incision occurred.

Juyal et al. (2010): During the late Quaternary there is climatic changes and seismicity which affect the phases of aggradations. During the early part of fluvial-marine isotopic stage 3 (MIS 3) debris flow terraces develop in the south of the main central thrust which is the oldest fluvial landform preserved. Following this time due to intense rainfall and upliftment erosion is accelerated. After that monsoon strength decline which causes reduced fluvial discharge and lower sediment transport capacity of the Alaknanda river which results in valley fill incision and terrace development.

Singh (2009): The vast terraces of the Ganga river in the middle and lower reaches have sediments of different ages from the Himalayas gives an opportunity to study en-route climate change and many processes on chemistry of sediments as a proxy in interpretation of source region climate in ancient rocks.

Singh (2010): Geochemistry of sediments of upper Ganga and its tributaries in the Himalaya examined to know the dominant source rocks of the sediments in plains and to estimate the weathering in the Himalayan catchment area.

Chapter 2

STUDY AREA

2.1 Upper Alaknanda Basin

Alaknanda River is a major tributary of the Ganga River in the state of Uttarakhand, India. It is a Himalayan river which is originated from the Bhagirath-Kharak and Satopanth Glaciers near the border with Tibet above 3500m msl. There is a triangular lake at the height of 4350m known as Satopanth situated 6km up from Alaknanda origin at its snout (near foot of Satopanth Glacier). These glaciers are located west of Mana. At Mana Saraswati River joins with the Alaknanda. The origin of Saraswati River is high up in the Himalaya (from Indian Institute of Geology AHEC 2011).

Bhagirathi and Alaknanda Rivers joins at Devprayag to form the river Ganga. Alaknanda,Bhagirathi,Pinder, Dhauliganga and Mandakini, rivers originates in the northern mountainous regions of Uttarakhand are the major tributaries or headstreams of the Ganga River. Alaknanda River has a total catchment area of about 11072sq.km. out of which nearly 730 sq. km. is glaciated (Devrani and Singh, 2014). From its origin to its confluence at Devprayag the length is nearly 190km, minimum depth is 1.3m and a maximum depth of 4.4m.

The Alaknanda River traverses through major Himalayan litho-tectonic units starting its journey from Tibetan Sedimentary Series (TSS) then through high grade metasediments of Higher Himalayan Crystalline Series(HHCS) and enter into the region of Lesser Himalayan Series(LHS) before its confluence with Bhagirathi at Devprayag. The major structures that bounds and separate the different litho-tectonic units are South Tibetan Detachment System (separating the TSS and HHCS), Main Crystalline/Central Thrust Zone(MCT) (separating the HHCS and LHS) and Main Boundary Thrust (MBT) (separating the LHS and Siwaliks the Ganges Foreland Basin) (Negi. et.al.1995).

Table 1: Details of major tributaries of the Alaknanda River (From Indian Institute of Geology AHEC 2011).

River Name	Confluence Location	Elevation (M. A.S.L.)	Origin	Origin Elevation (M. A.S.L.)
Saraswati	Mana	3120		
Ghrit Ganga	Hanuman Chatti	2470	Khular Glacier	5400
Khirao Ganga	Benakulli Village	2330	Panpatia Glacier	3800
Dhauli Ganga	Vishnuprayag	1372	Ganesh Parbat Glacier	6000
Garur Ganga	Garur	1305	Gangotri Glacier	
Birahi Ganga	North Chamoli	995	Nanda Glacier	
Nandakini	Nandprayag	870	Nanda Ghungti Glacier	6620
Pinder	Karanprayag	730	Pindari Glacier	5200
Mandakini	Rudraprayag	610	Gangotri Glacier	
Bhagirathi	Devprayag	475	Gangotri Glacier	3892

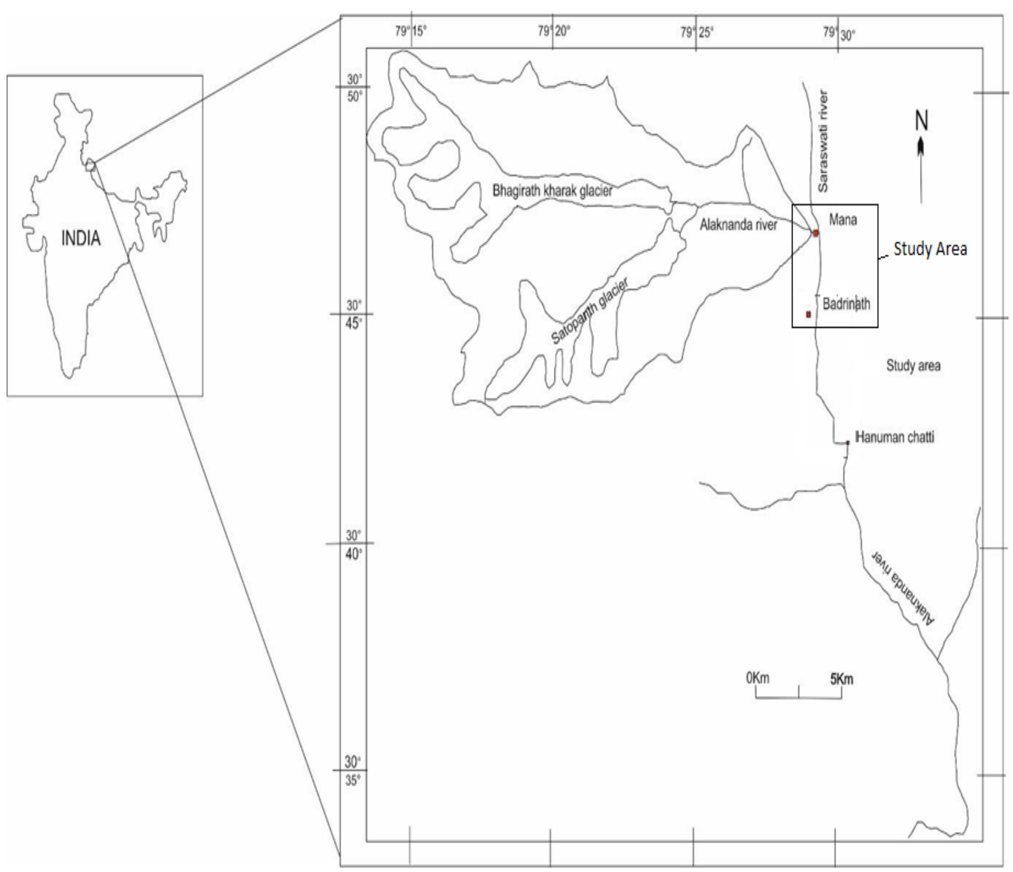


Fig. 1: Location map of the study area. Origin of Alaknanda River from Satopanthand Bhagirath-Kharak glaciers, confluence at Mana of Alaknanda and Saraswati rivers and Upper AlaknandaValley are shown.

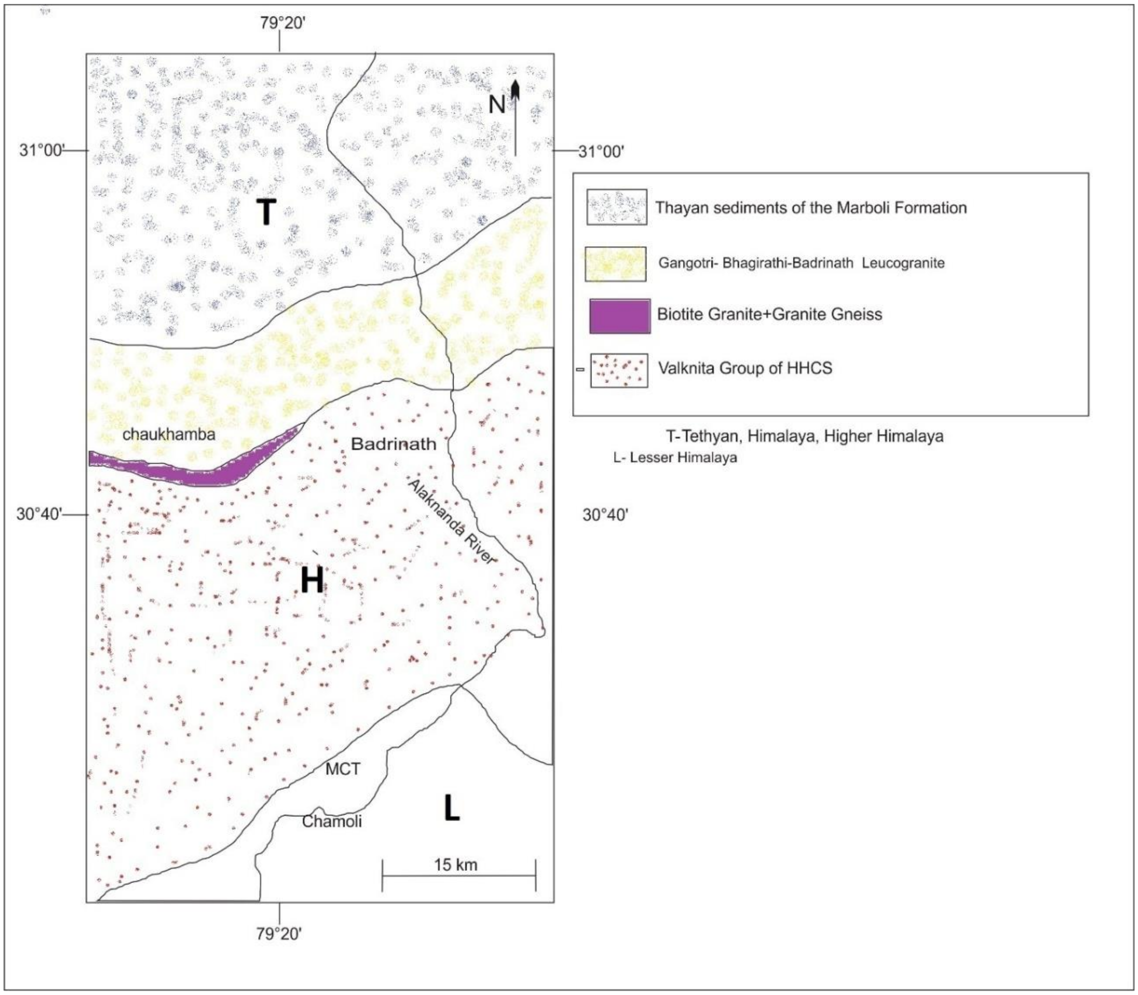


Fig.2 Geological map of the study area showing Saraswati river.

The climate of the Alaknanda basin changes from sub-tropical in the lower valleys to temperate, sub-temperate and alpine in the mountainous region. There is heavy rains due Indian Summer Monsoon during June to October. The basin receives 1000 mm to 2000 mm average annual rainfall by Alternate Hydro Energy Center (2011).

Fluvial terraces of different types are found throughout the basin as during the Late Pleistocene and early Holocene which gives evidence of several phases of aggradations and incisions of the Alaknanda River (Juyal et al., 2010; Ray and Srivastava, 2010).

There are three phases of glaciations during the Late Quaternary evident and inspected from the lateral moraines and other relict periglacial features such as valley fills in the Upper Alaknanda basin (Owen et. al., 2002). These phases are Alaknanda (Stage- I) which is oldest and most extensive that reaches south of Badrinath (2604m asl) predates Last Glacial Maximum (LGM), Alkapuri (Stage-II) terminated around 3550 m asl 12ka during LGM and Satopanth (Stage- III) terminated around 3700 m asl 4.5ka (Nainwal et al. 2007)

2.2 My Study Area - The study area is located at the banks of Alaknanda and one of its major tributaries Saraswati Rivers in the central area of the Himalaya Mountains of India. It is in the Upper Alaknanda basins located between 29°58'11.315" N to 31°6'21.183" N latitude and 78°32'31.400" E to 80°17'26.161" E longitude. Area is under the Chamoli district of Uttarakhand.

2.3 Geology Of The Study Area – The origin of Alaknanda River from the glacier situated in the Vaikrita Group part of the Higher Himalayan Crystalline Series (HHCS) (Ahmad et al. 2000) and the Saraswati River originated from the glaciers situated in the Tibetan Sedimentary Series/rocks (TSS). Both combined at Mana and known Alaknanda afterward. The river then drains through Munsiari Group of the HHCS and then Lesser Himalayan Series after which it finally joins with Bhagirathi at Deoprayag.

Broadly speaking the Alaknanda Valley comprises of three major lithostratigraphic units which are Dhudhotoli Group, Garhwal Group and High Himalayan Central Crystalline Series.

The Vaikrita Group of HHCS start from SouthTibetan Detachment System to the Vaikrita Thrust, these together mark the location of the Main Central Thrust (MCT) (Ahmad et al. 2000).HHCS comprises of old crystalline rocks of the Himalaya and covers the Upper Alaknanda Basins. Vaikrita Group is exposed from Vishnuprayag and Mana Village, it is situated over Garhwal Group and comprises of schists, gneiss and granite rocks. The thrust in this area shows a regular direction of NW-SE parallel to the Himalayan Range but perpendicular to the Alaknanda River.

From the Vaikrita Thrust the Munsiari Group start and end at Munsiari Thrust. After this thrust rocks of the Lesser Himalayan Series starts. The Upper Alaknanda Basin within the MCT zone is in a tectonically active region and at Karnprayag an active

Alaknanda Fault is present. Faults that traverses the Alaknanda River are the Trans-Himalayan Fault, MCT, Alaknanda Fault, and the North Almora Thrust locally called Srinager Fault (Tyagi et al., 2009). Compared toVaikrita Thrust and Munsiari Thrust the above faults are very active, however the Alaknanda Fault is outpacing erosion processes making it the most active (Tyagi et al., 2009).

There is a transition zone between the highly metamorphosed Vaikrita Group and the unmetamorphosed Tethyan sedimentary rocks intruded by extensive package of biotite granites, two-mica granites, tourmaline-bearing leucogranites, aplites, augen gneisses and pegmatites. They are variously called Gangotri, Bhagirathi or Badrinath Granite and are undeformed.Thisleucogranite is a fine-grained (1-2 mm) freshgranite, composed of quartz + K-feldspar + plagioclase+ tourmaline + muscovite+biotite (presentonly in the biotite-rich facies), +garnet (present onlyin the tourmaline-rich facies) +beryl, with apatite asits most abundant accessory mineral (Scaillet et al.,1990).

The sequence of HHCS is 14-20km thick comprising of metapelites and metasammites comprising of Ragsi, Bhimgoraquartzite, Joshimath, Pandukeshwar, and Badrinath Formations.

1. Ragsi Formation - It is connected to Garhwal group along with main central thrust (MCT) and overlie by the Bhimgoraquartizite. The Ragsi formation and Bhimgoraquartizite both are cut-off by MCT in the Pindar River.
2. Bhimoraquartzite – It is present from Bhimgora in Nagol Gad in the Alaknanda valley to the north Helang and exposed near Tapoban in the Dhauliganga part, upstream of Joshimath. It is extended to north of Kalimath as a thin band and progress from west to south of Sonprayag. Bhimagoraquartizites is made up of white coloured, fine grained recrystallized quartizites rich in sericite flakes.
3. Joshimath Formation – Extending westwards and mapped as the Chandersila Schist of Tungnath Formation. Formation composed of psammitic and pelitic sediments which is regionally metamorphosed having interbedded sequence of garnet mica schist, staurolite kyanite schist, sericite quartzite, quartz porphyry, amphibolites and associated coarse-grained biotiteaugen-gneiss.

4. Pandukeshwar Formation – At Pandukeshwar thepsammatic series of Alaknanda consists of regularly bedded quartzite/banded quartzite gneisses in which preservation of sedimentary structure such as cross-bedding.
5. Badrinath Formation –The Badrinath Formation found well exposed between Hanuman Chatti and BadrinathIn the AlaknandaValley. Consists of mica schist, garnet, sillimanite, muscovite and kyanite-bearing gneiss, garnet amphibolites and calc-silicates intruded bypegmatite and leucogranite. The formation is well exposed around Kosa in Dhauliganga.

The HHCS is bounded by Vaikrita Thrust at the base and South Tibetan Detachment at its top by which high grade HHCS is placed on top of the low grade LHS.

In HHCS the contacts are purely depositional grading from the primarily metapelitic Joshimath formaton at the base, to the arkosequartzitic Pandukeshwar Formation, to the metapelitic Badrinath Formation at the top (Nayak, 2015).

Dhudhotoli Group is found exposed between Koteshwar andDevprayag. It is separated by North Almora Thrust (NAT)from the Garhwal group.North Almora Thrust (NAT) is trending in NW-SE. The Garhwal group is present between Koteshwar to Vishnuprayag. It is distncted from the Higher Himalaya Central Crystalline group by Main Central Thrust (MCT) which is trending NW-SE direction. It contains number of fracture zones and shear.

2.4 Geomorphology–From the origin of the Alaknanda Valley in the High Himalayan Zone to the Gangetic Plain region through Lesser Himalaya there are variations in the characteristics.

The shape of the Alaknanda River Valley changes from U-shape from its origin to Badrinath (in the northern High Himalayan Zone) because of the glacial actions. The area is highly prone to landslides, debris flow, debris avalanche and debris fall due to the abundantly present overburden material by the glacial and glacio-fluvial action with a steep gradient.

Moraines, cirque, glacial horns, glacial cones/fans, U-shaped glacial valleys, waterfalls and hanging valleys are the prominent glacial features giving the evidence of major phase of glacial activity in the area during Pleistocene period.

Between Mana and Badrinath a relict glaciated basin is present (4000m asl).Due the dominance of the fluvial processes the shape of the valley changes to wide V-shape downstream near Nandprayag in the Lesser Himalaya(Ray and Srivastava 2010). River terraces, point bars, sand bars, narrow deep gorges, ‘U’, ‘V’ and ‘S’ shaped sinuosity or meandering are observed in the area.Mountains in the study area are conical in shape, with high peaks. The hill slopes Talus or Scree with vegetation.

The gradient of the river are steep near the origin due to which coarse materials are deposited there. Further downstream the gradient decreases and become very gentle near the Gangetic Plain (Ray and Srivastava 2010) resulting in the deposition of fine materials.

After flowing from the Mana village the river shows braided meandering in the Badrinath basin. On leaving Badrinath basin, it overflows forcefully which results in incision of deep gorge in the crystalline rocks.

The landforms present in the study area may be classified into glacial, glacial-fluvial, fluvial and denudation. The main geomorphic features shown by the study area are high to medium dissected hills, river terraces, talus and scree deposits and fluvio-glacial material.

Alakananda fault within the study area is believed to be the most active fault in the region (Tyagi et al., 2009). According to Tyagi et al., 2009, evidence of such activity stems from the findings that the fault uplift is outpacing erosion processes.

Fluvial terraces of cut and fill type are common throughout and continue downstream as gradient decreases. Along the Alaknanda Riverfluvial terraces are developed and preserved by the relationship of tectonic and climatic relationship.

The fluvial terraces are of varying heights and ages which are formed from cycles of aggradation and incision of fluvial detritus or were cut into the underlying bedrock material creating steps during the late Pleistocene (Srivastava et al., 2010). The aggradation phases are due to deglaciation in the past nearly 63ka (Ray and Srivastava. 2010) while incision has been attributed due to increased rainfall after 11ka (Srivastava et al., 2008 and Ray and Srivastava, 2010).

Table2. Periglacial and Glacial landforms in the study area (Nainwal *et al*., 2007).

Process	Landforms
Glacial	U-shaped valley, moraines, proglacial lakes, and fans, ice caves, aretes horns, cirques, hanging and avalanche chute.
Perigalcial	Moraines, terraces, lake deposits, patterned ground, outwash plains, proglacial relict, drumlins, talus cone, alluvial fan, talus fans, solifluction lobes, debris cone.

2.5 Climate– The climate throughout the Alaknanda Basin changes from sub-tropical in the lower valleys to, temperate, sub-temperate, and alpine in the mountainous region.

The Alaknanda Basin receives snowfall and heavy rain during the summers due to Indian Summer Monsoon(ISM) (Ben and Owen 1998). The climate of the study area is basically monsoon type with rain storms ranging between 200 to 1000mm/hr. The basin receives rainfall during monsoon from June to September and the mean annual rainfall over the basin ranges from 1000mm to 2000mm (Alternate Hydro Energy Centre). In the basin places with high elevations receives more rainfall than low elevations and the sites facing north i.e. windward direction(slopes) receives more rainfall than facing south i.e. leeward (Joshimath) (Sati 2009).

Table 3: Average monthly rainfall in mm for Uttarakhand from 1951 to 2000(From Central Water Commission 2008)

January	**February**	**March**	**April**	**May**	**June**
52.1	54.1	57.6	33.3	65.1	167.8
July	**August**	**September**	**October**	**November**	**December**
428.1	426.3	206.9	58.6	9.7	21.3

Chapter 3

SAMPLING AND ANALYTICAL METHODS

3.1 Sampling – To achieve the objectives as outlined earlier, sediments were collected from different terrace deposits developed at various locations from Badrinath Valley and bedload sediments were collected from the Alaknanda and Saraswati rivers to compare with terrace deposits.

A total of 8 sediment samples from river terraces and bedload of Alaknanda and Saraswati Rivers were collected from six different locations situated in Badrinath Valley, Chamoli district Uttarakhand by my seniors for the textural and mineralogical analysis. The sample with proper name, symbol and locations were listed in the table4.

Table4: Description of sample location with name, latitude and longitude.

Sample Name	Locality	Latitude	Longitude	Elevation (m)
SR-BL	Bedload collected from Saraswati river Upstream of Mana	30°46.382	79°29.667	3185
SR-1	Right bank terrace of Saraswati River	30°46.241	79°29.672	3449
SR-2	Right bank terrace of Saraswati River	30°46.241	79°29.672	3450
HP-1	Helipad terrace – Bottom layer	30°45.018	79°29.782	3160
HP-2	Helipad terrace – Middle layer	30°45.018	79°29.782	3160
HP-3	Helipad terrace – Top layer	30°45.018	79°29.782	3160
KB-1	Terrace near Kokila Ben Building	30°44.375	79°29.634	3112
KB-2	Terrace near Kokila Ben Building	30°44.375	79°29.634	3112

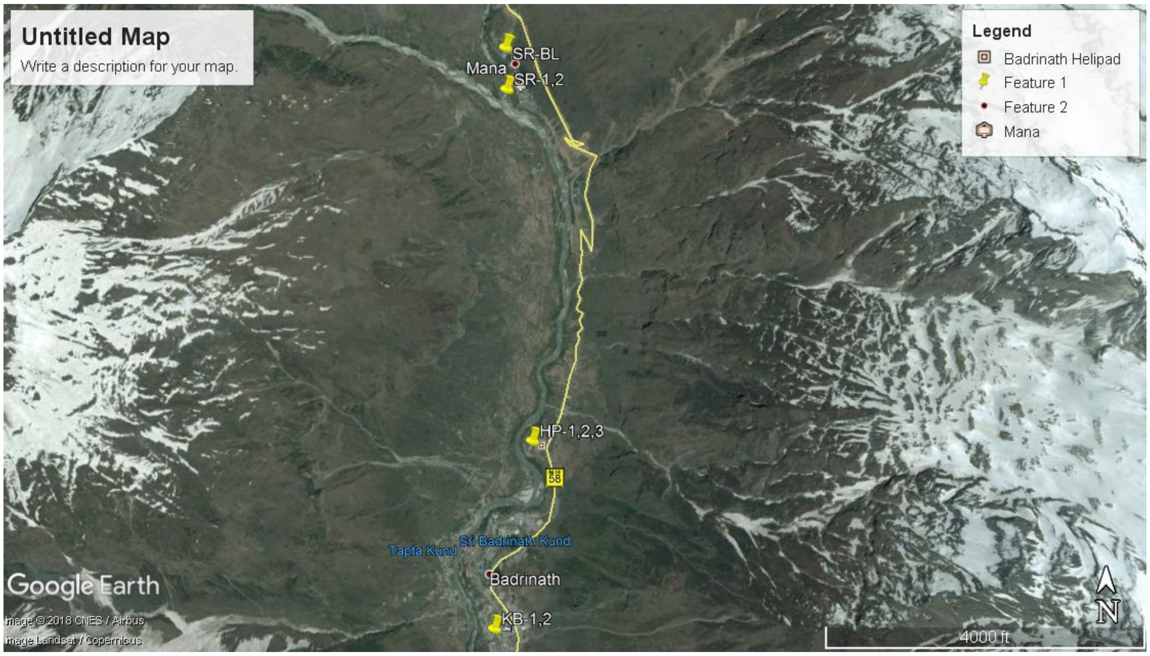


Fig.3 – Google map showing sample location of the upper Alaknanda Basin.

From the terrace developed along the Saraswati River upstream of Mana village two samples labeled with SR were collected. It is important to collect bedload from both the rivers before and after confluence. To compare with the terrace sediments and to identify the contribution from each river three bedload samples were collected from Alaknanda and Saraswati rivers.

From the terrace developed in the left bank of Alaknanda River in the Badrinath Town a total of four samples namely KB-1, and KB-2 were collected from the section exposed near Kokila Ben building. KB-1 and KB-2 were collected from the lower part (fig.4). The sequence of KB samples from lower to upper part is KB-2, andKB-1.Most part of the terraces are covered with building and other constructions, hence at very few places exposed section shows the different layers of deposits.

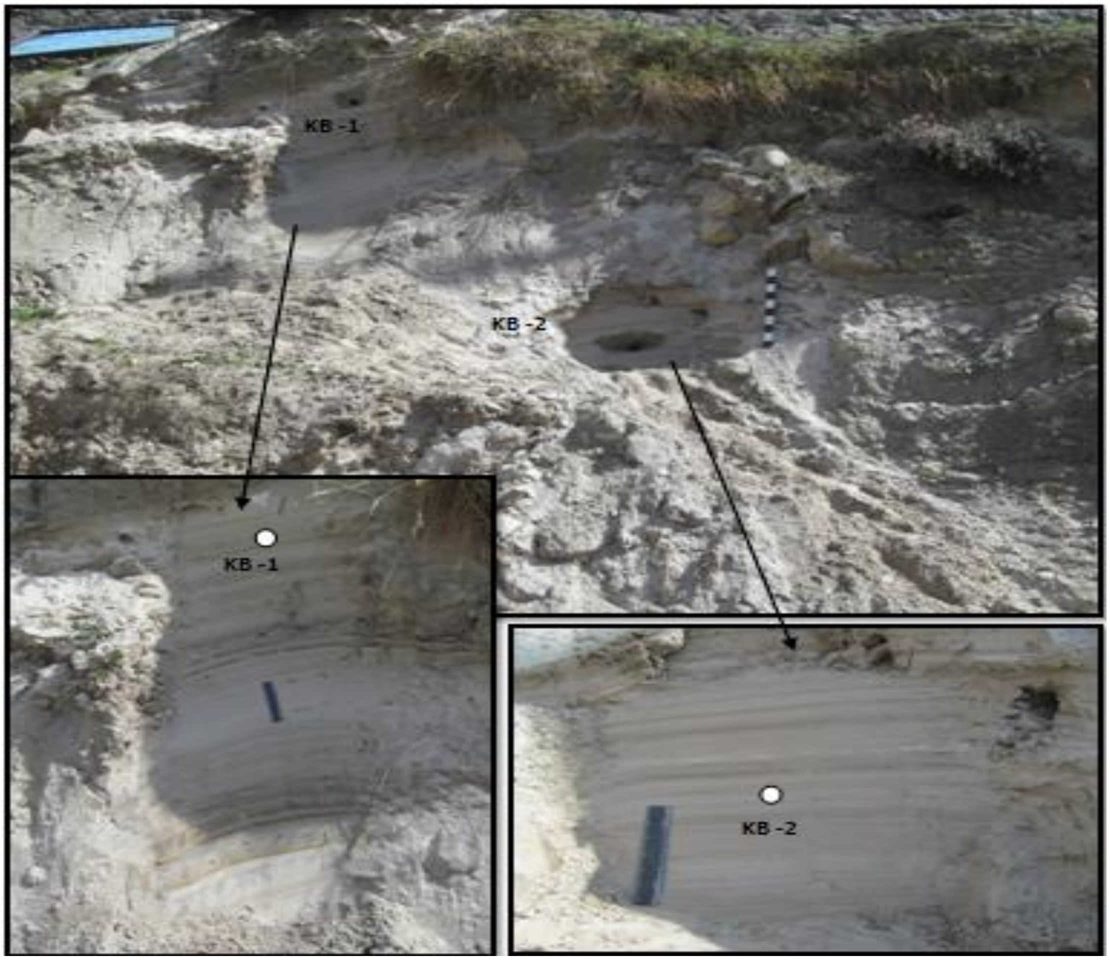


Fig.4 –Sampling sites of KB-1 and KB-2.

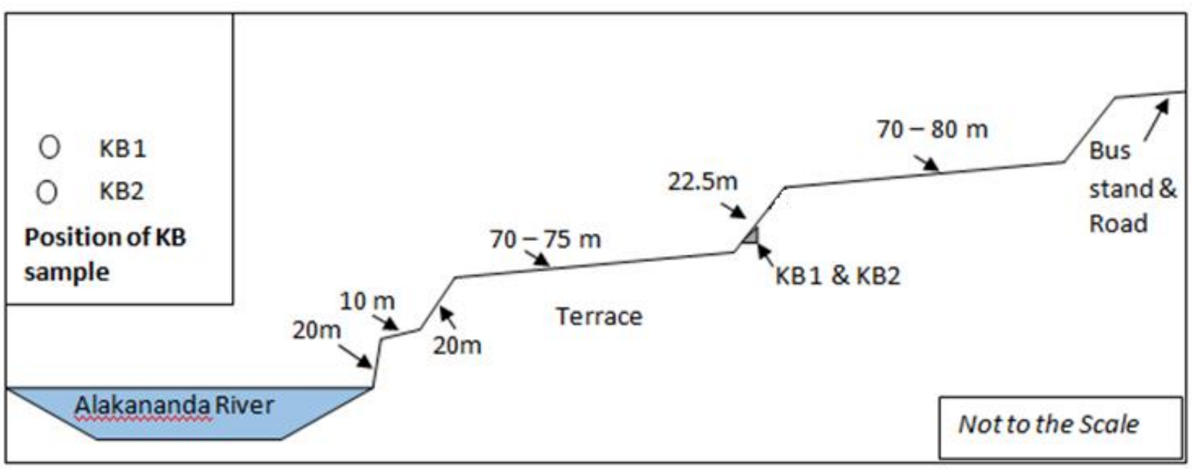


Fig.5 – KB-1 and KB- 2 sampling site positions with respect to the terrace and the river. This is the left bank cross-section near Kokila Ben building.

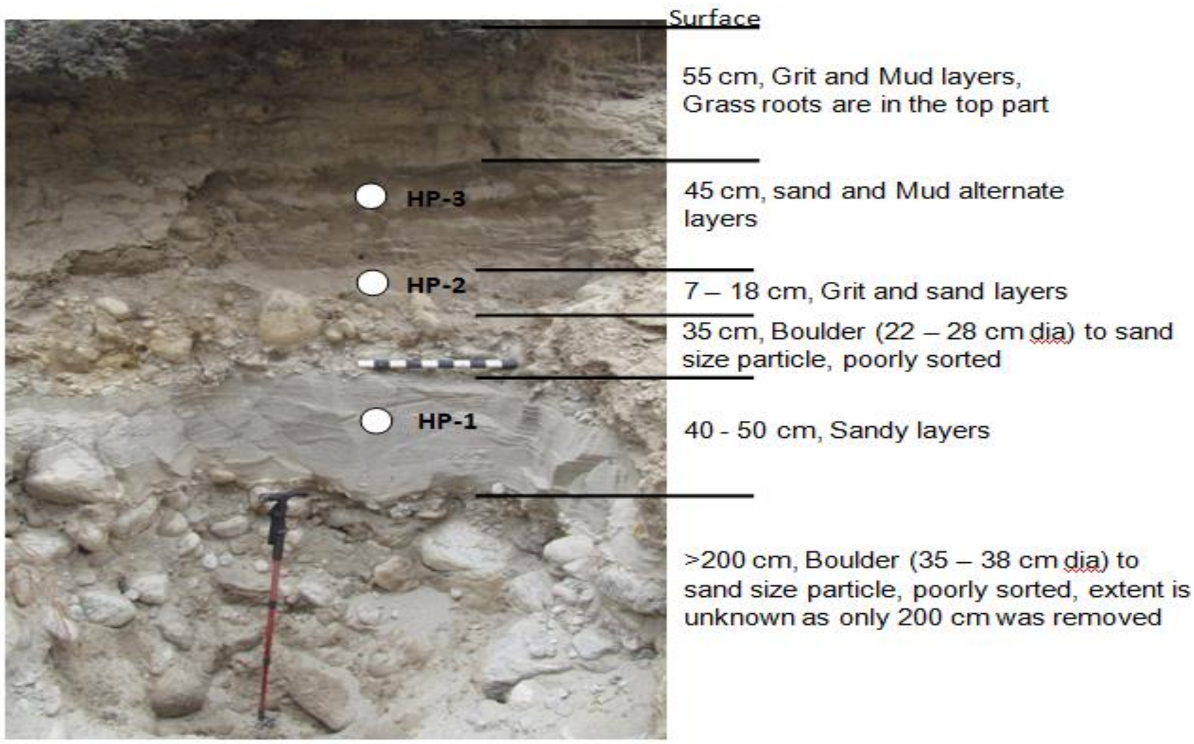


Fig.6 – Profile section photograph of Helipad (HP) terrace with the thicknesses of layers on right side with description and sample names.

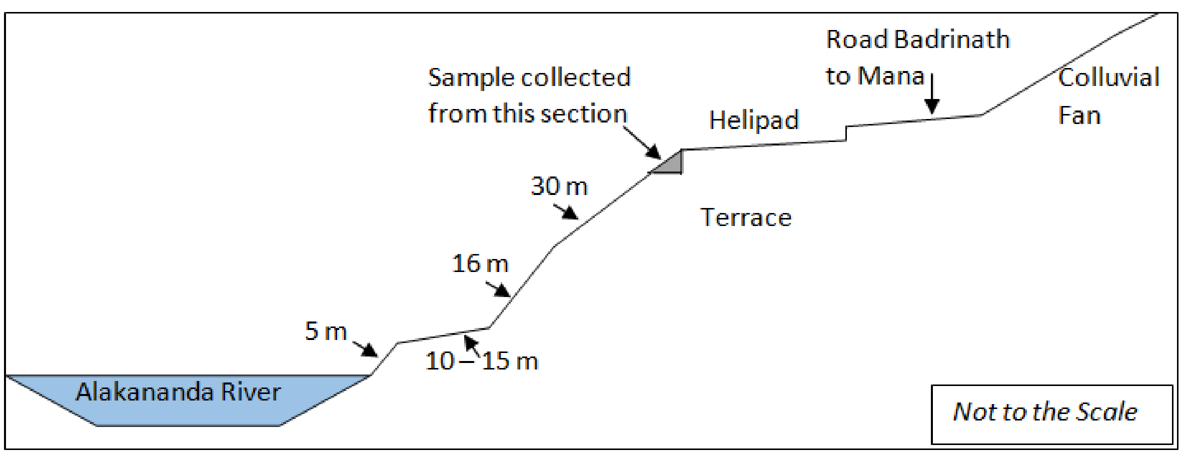


Fig.7 – With respect to the terrace and river the position of sampling site is depicted in this diagram. This cross section is in the left bank near helipad.

From the Helipad section (fig.6) three samples HP-1, HP-2 and HP-3 were collected and this location is exposed between Badrinath and Mana village. The top 55cm of this deposit shows mud and grit layers, below this top layer, thick alternate sand and mud layers of 45cm, followed by 7-18cm variable layers of sand and grit, then 35cm of poorly sorted thick boulder and sand layers. Towards the deeper part of the section 40-50cm thick sandy layers and more than 2m thick boulder layers were observed. The variations in grain size in different layers indicate the energy condition during deposition. With respect to the terrace and the river position of sampling site is depicted in fig.7.

From the right bank terrace deposits of Saraswati river, upstream of Mana village two samples were collected namely SR-1 and SR-2 from 60cm and 8.5m down the surface from the exposed section of 59m. From the left bank of the Saraswati River, upstream of bridge connecting Mana and Ghatsoli bedload sample named SR-BL is collected.

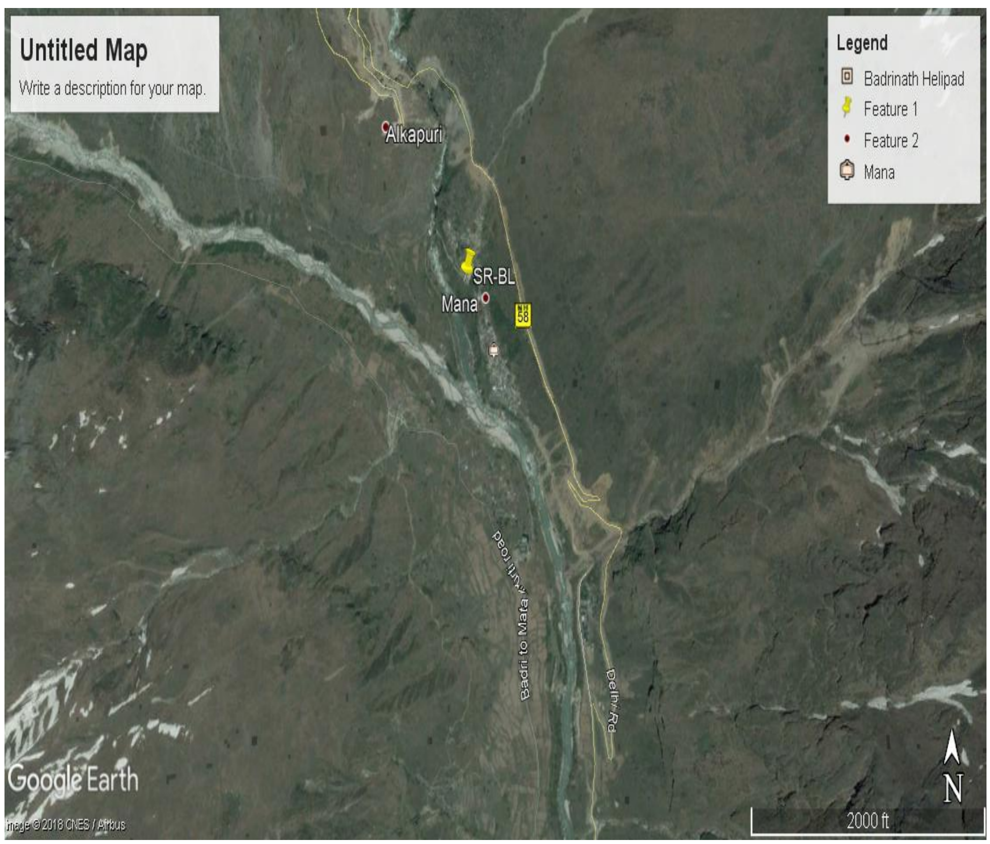


Fig.8 – Map showing sampling location of bedload, Mana, Saraswati river and Alaknanada river.

3.2 Analytical Methods

To identify the clay minerals and their percentage in samples SR-BL, KB-1 and KB-2 using XRD analysis and the geochemical analysis of the samples SR-BL, SR-1, SR-2, HP-1, HP-2, and HP-3 using XRF analysis different sample preparation processes were followed prior to XRD and XRF analysis.

Cone and Quartering– This method is done to homogenize, well mixing and to removing the biasness of the samples before taking it for further analysis and to reduce the quantity of the sample by forming a conical heap, then mixing it , then make flat cake and then finally divide radially into quarters. The opposite quarters were combined and the other two are stored in the zip lock bags. This is repeated as many times as required for obtaining the necessary amount of sample for final use. For example from 100gm sample 25gms is needed then two times cone and quartering is done.

Clay Separation– To separate clays from the already sieved samples of <38 micron sizes by gravitative settling method. 10gm samples of KB1, KB2 and SR-BL are taken by doing cone and quartering method.

i. Apparatus required are three settling columns of 1000ml capacity for each samples, beakers of 1000ml, samples of <38microns, suction pipette.
ii. Wash the columns with tap water, then with soap solution, then tap water and then finally with Milli Q grade water.
iii. Pour the samples carefully in the columns and then add Milli Q upto 1000ml mark carefully. Do this for each sample.
iv. Mix the samples in the columns thoroughly by holding firmly for about 2-3minutes for proper mixing. After that place it on a safe site and write the starting and ending time and set the alarm.
v. Do the same with the remaining two columns but with taking time intervals between the two.
vi. After the completion of settling, time the slurry containing the required clay size particles were taken or sucked by the suction pipette. For particles of less than 4micrometers size upto 5cm depth of slurry containing suspended clays were taken and upto 10cm for particles of 4-16micrometers size.

vii. The taken samples were put in the properly labeled 1000ml beaker.

viii. Do the step (vi) for other two columns.

ix. After that level the columns with the milli Q to 1000ml level mark and mix thoroughly for 2-3 minutes. And then repeat the (iv), (v), (vi) and(vii) steps until the upper 5cm and 10cm supernatant water become clear for <4µm particles and 4-16µm particles.

x. Above steps are repeated for separating the different clay size particles in which different settling time is required with proper labeling and by noting the starting and ending time respectively.

xi. After that, centrifugation of all the taken samples were done at 4000rpm for 20minutes at 25^{o}Cand the water were decanted without disturbing the clay particles which were settled at the bottom.

xii. The samples were preserved for the slides making.

Principle of Gravitational Grain Size Separation Method

To separate the clays from sieved samples of <38micron size containing clay and silt particles only a low energy wet gravitational method is applied in a thermostatic condition without using chemicals to preserved unchanged physical and chemical properties of the heterogeneous particles. The water used as dispersive phase is deionised for gravitational separation of silt and clay sequentially.

To calculate the time of settlement of fraction Stoke’s law is used and after settling of silt, the clays in the resulting supernatant is taken out by the suction pipette. This method is proved to be very good and reproducible and the purity of clay is more than 90%.

From the Stoke’s law, the settling time for silt fractions is calculated using diameter of the grains, dynamic viscosity, distance between water surface and bottom of the settling cylinder, densities of the particles and deionised water (milli Q) at constant temperature.

STOKE'S LAW FORMULA

$$V = \frac{g\left(\rho_1/\rho\ - 1\right)d^2}{18\vartheta}$$

where V= settling velocity of the solid

g= acceleration due to gravity

ρ_1= mass density of the solid

ρ =mass density of the fluid

D= diameter of the solid (assuming spherical)

ϑ = kinematic viscosity of the fluid

After the settling time for silt fraction was elapsed, silt >4micron particles were settled at the bottom of the cylinder and we get clays in the supernatant water in dispersion as the clay particles take more time to settle. The supernatant water containing dispersed or suspended clays are taken by the suction pipette and stored in a separate beaker. Then the level of cylinder is maintained by the deionized water to the initial level and repeat the process of clay separation until the supernatant was clear.

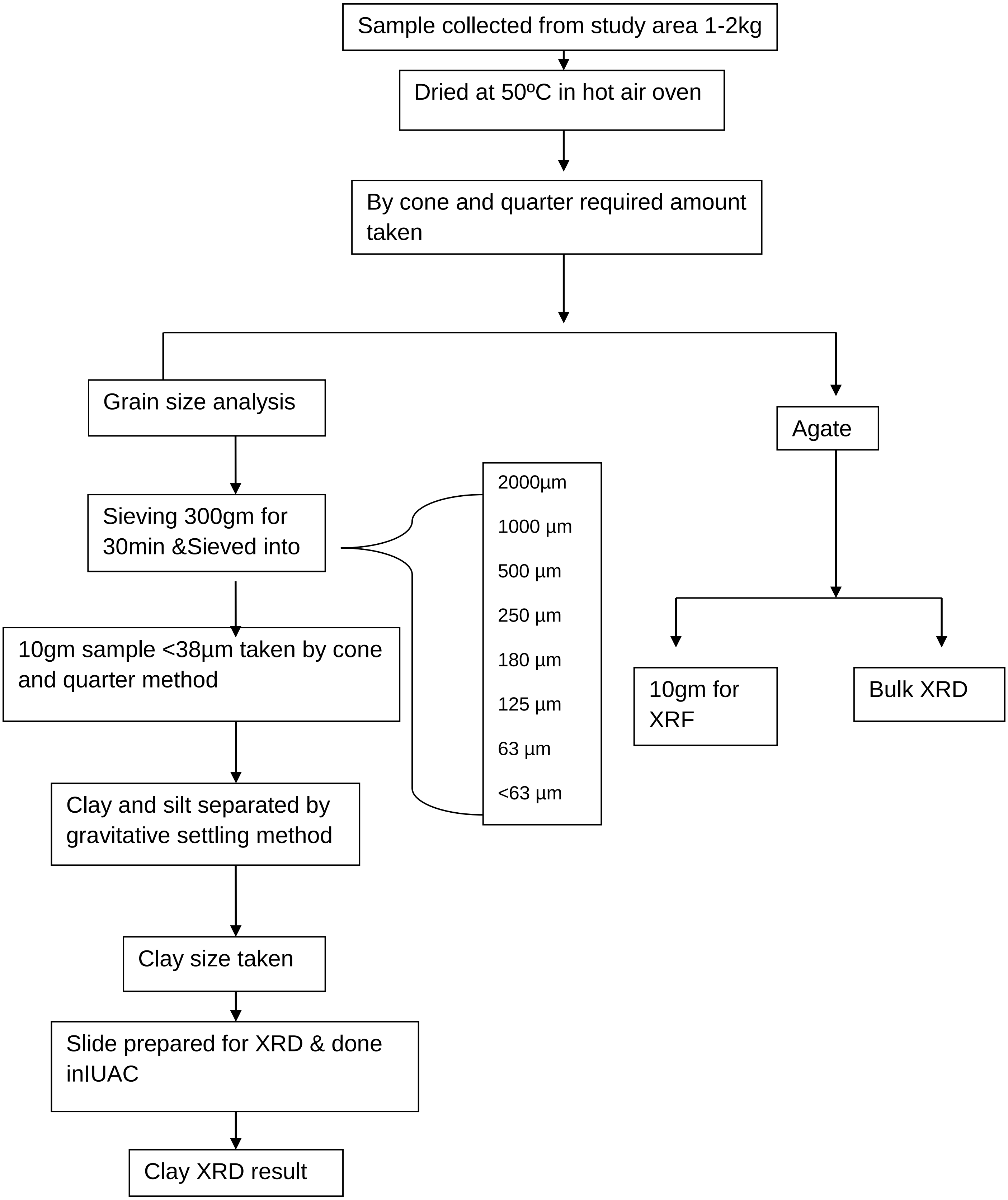
Table.5: Different settling times are used for the separation of different clay and silt size particles (Maurice Tucker, Book-Techniques in sedimentology)

SETTLING TIME	**PARTICLE SIZE**		Particle Size
3 hr 36 min	<2 microns	Clay mineral	Clay
54 min 2 sec	2-4 microns		
27 min 1 sec	4-8 microns		Silt
6 min 45 sec	8-38 microns		

Oriented clay slide preparation for identification:

i. One mole solutions of $CaCl_2$ and KCl was prepared in separate volumetric flask.
ii. Decant maximum water of the clay samples after centrifuge and then make the slurry with the help of vortex shaker.
iii. Two test tubes of 50 ml are taken and labeled Ca and K and the original one is without additional name.
iv. Three-pipette tube of 1 ml was taken to put the respective samples and solutions in the test tube and each pipette tube is marked withname of the respective solutions/samples.
v. For K-saturated samples making, 3 ml of slurry sample and then 3 ml of 1 molar of KCl solution is taken in a 50 ml test tube K labeled.
vi. For Ca saturated samplemaking, 3 ml of slurry sample and then 3 ml of 1 molar Ca solution taken in a 50 mltest tube Ca labeled.
vii. By vortex shaker the samples with K and Ca solutions were shake it for few minutes and for 5 minutesleft aside.
viii. After that, the samples were centrifuged for at 7000 rpm for 10 minutes, followed by decanting the water, and repeatthe same process.
ix. After centrifuge, the remaining residue is saturated with 1 ml Milli-Q and 1 ml ethanol for both K, Ca and original sample and left aside for 5 minutes after shaking on vortex shaker.
x. After that, again centrifuged the sample at 7000 rpm for 10 minutes and decant the water.
xi. After that treat the samples with 1 ml ethanol and shake the sample on vortex shaker again and repeat the step X.
xii. At last, we treat the sample with Milli-Q and repeat the step X again.
xiii. After that make the residue sample slurry forslide making.
xiv. The slides are cleaned with Milli-Q properly and labeled on bottom side with proper sample name and marking for targeting the sample at proper position.
xv. The slurry is taken with the respective labeled pipette tube and then poured in the middle of the slide and slowly moves the samples to the respective border markings.
xvi. The slides are prepared now and kept for drying on a clean,safe place for few hours.

Methodology Flow Chart



Bulk geochemical analysis using XRF:

Sample processing – Here the aim is to grind the requisite amount of 6 samples namely SR-BL, SR-1, SR-2, HP-1, HP-2, and HP-3 which is already dried and homogenized in agate mortar for further finer consistency. This process is done for better digestion of the samples in acids for further analysis such as XRF etc.

i. From each 6 samples 80gms of samples were taken and by homogenizing them through cone and quartering method to 20gms sample which is taken for grinding in steel mortar and finally in agate mortar.
ii. Each 20gms of homogenized samples were taken and grind in steel mortar for about 3 hours and then agate mortar for about 5 hours at the place which is properly cleaned and in the mortars which is properly washed to avoid any contamination. These two steps were done for each 6 samples properly.
iii. For cleaning of the mortars, first rinse with tap water, then apply soap solution then wash with tap water and finally wash them with Elix water or Milli Q (distilled water). After that the mortars must be dried before grinding so the steel mortar is dried in oven and the agate mortar is dried using tissue paper. After drying the mortars with their pestle apply acetone or ethanol just before the grinding. This step is repeated each time for each sample.
iv. The grinding is performed on cleaned butter sheet each time for both mortars.
v. After grinding in the agate mortar the samples were packed in zip lock bags or in the containers with proper names.
vi. For XRF 10gms from each 20gms samples were packed in the buttersheet and then in zip lock bags with proper labeling.
vii. The remaining samples were kept for further analysis.

X-ray Fluorescence (XRF) measurement–

X-ray fluorescence is a powerful qualitative and quantitative analytical tool for determining the chemical composition of materials. It requires minimal sample preparation, it is non-destructive, fast and accurate. Due to low of sample preparation, relative ease it is widely used for bulk elemental analysis of big fractions of geological materials. This is one of the best method for major and trace (ppm level) element concentrations for all kinds of samples which may be liquid, solid, thin-film or loose materials.

The principle behind XRF is that when an atom is excited with high energy beam such as X-rays, if the inner electrons gets the sufficient energy it dislodge from the shell and the atom become ionized. The electrons in the higher shells fill the space of inner electron. In doing so, they emit energy equal to the difference between the shells in terms of photons. The photon emitted having energy than that the incident X-rays and is called fluorescence radiation. The emitted X-ray photons is of characteristic energy or wavelength for a particular elements energy shells. So, the elements present may be identified and quantified by counting the number of X-ray photons of each energy photon emitted from a material.

Processed samples were analyzed using XRF facility at Indian Institute of Science Education and Research (IISER), Kolkata.

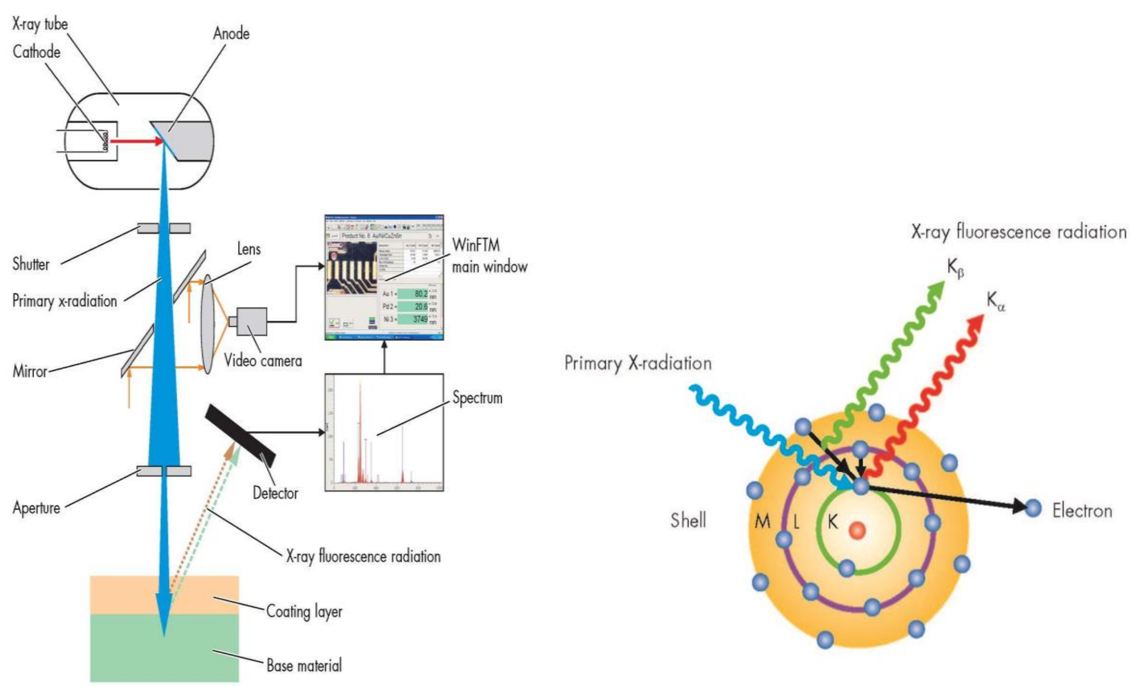


Fig.9: Components of XRF instrument (left) and principle of XRF (right).

Clay mineral phase analysis using X-ray Diffraction (XRD)

For the identification of mineral (phase) of a crystalline material or phases in a powder crystalline materials and information on unit cell dimension a rapid analytical technique i.e. X-ray powder diffraction is carried out. The method is now frequently used for mineral identification, atomic spacing, and crystal structure studies. The principle behind XRD is that the wavelength of X-ray is of the same order to that of crystal plane spacing, so it can interact, reflected or diffracted from the crystal plane which interfere when leaving the crystal. The X-ray on interacting with the sample produces constructive interference on diffraction which satisfy the condition of Bragg's law ($n\lambda=2d \sin \theta$) which relates wavelength of the electromagnetic radiation with the diffraction angle and crystals lattice spacing (d). The working principle is first the production of X-ray in a cathode ray tube the produced X-ray are filtered to produce monochromatic ray which is directed and focused at the sample and then the interaction of the sample with the ray producesdiffracted ray and interference as by the Bragg's law. The angle between diffracted and incident ray is very important. The diffracted rays are then collected, detected by detector, processed and counted by programme. The sample is scanned through a range of 2Ɵ values due to the random orientation of the powdered mineral all possible diffraction directions obtained.

At the Inter University Accelerator Center (IUAC), New Delhi XRD analysis of my powdered samples and clay XRD are done using PANalytical XRD instrument. Scanning is done through a range of 2Ɵ values from 2-80 degrees. 0.0080degrees was set as a step size with the scan time of 9.2550seconds. For generating the X-rays Cu-anode with Kα value 1.54060 was used with the power supply set at 40Ma current and 45KV voltage respectively.

The XRD data given by IUAC was analyzed with the help of X'Pert High Score program. The software helps us to identify the various mineral phases present in the sample and their semi-quantifications. With the help of reference minerals spectrum listed in the librarythe selected peaks were matched. By matching by the stick pattern various minerals were identified. The reference mineral having the highest matching score is given preference and then the minerals was selected manually. Using relative intensity ratio (RIR) of the selected reference minerals and score value semi-quantification (relative abundance) was calculated.

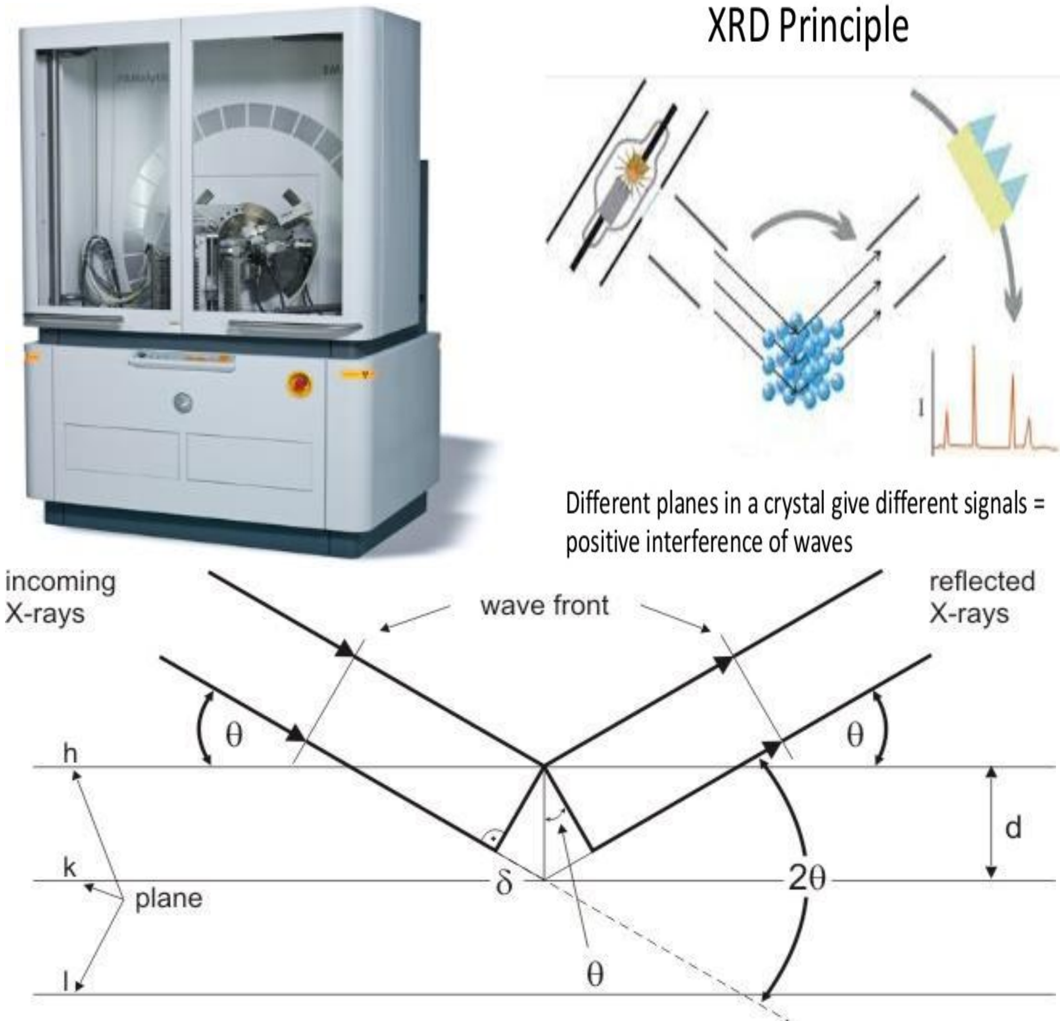


Fig.10: Photograph of PANalytical XRD instrument (left) and XRD principle (up right and below). (Source - http://www.panalytical.com)

Chapter 4

RESULTS AND DISCUSSION

4.1 Grain Size Analysis – Terrace sediments are poorly to moderately sorted (Priyanka, 2017) as these sediments are from upper reaches of the river basin are travelled lesser distance from the source. The highest mean grain size of the terrace sediments is of HP-1 (lower part of the Helipad section).In the helipad sections grain size decreases from the bottom layers to the top (Priyanka, 2017). The grain size in the KB section increases from bottom to top. The mean grain size of Saraswati river terrace deposit section is decrease from bottom to top and has lower mean grain size (Priyanka, 2017). Statistical analysis of grain size shows that the sediments were deposited in active environment. HP-1and HP-2 sediments are river deposits and rest sediment samples are between river and quite water shallow environments. The SR-BL show glacial origin and terrace sediments show mixed origin (Priyanka, 2017).

Table6: Clay Samples Weigh Calculation

s/no.	**Samples**	**Initial Weigh in mg**	**<2µm**	**2-4 µm**	**4-8 µm**	**8-16 µm**	**16-38 µm**	
			3 h 36 min in mg	54 min 2 sec in mg	27 min 1 sec in mg	6 min 45 sec in mg	Residue weigh in mg	Total in mg
1	KB-1	9471	9.39	21.47	105.07	334.57	9000.5	9471
2	KB-2	9395	7.59	16.07	47.17	323.87	9000.3	9395
3	SR-BL	9439	9.3	19.6	90.87	318.97	9000.26	9439

Table.7: Clay percentage of different setting time.

Samples	<2µm	2-4 µm	4-8 µm	8-16 µm	Residue%
KB-1	0.099144758	0.226692007	1.109386548	3.532573118	95.03220357
KB-2	0.080787653	0.17104843	0.502075572	3.44725918	95.79882916
SR-BL	0.098527386	0.207649115	0.962707914	3.379277466	95.35183812

The above data is the final distributed weights of different size of particles, getting after gravitative settling method. The clay percent for KB-1is 0.33%, KB-2 is 0.25% and SR-BL is 0.30% only. The major size fraction is belonging to the silt group from fine silt to medium. From the above tables it can be concluded that the <38 microns size of KB-1, KB-2, HP-3 and SR-1 are dominated by silt size grains however clay minerals analysis can be carried out from 0-2 μm size fraction extracted for this. The clay percentage in KB-1,KB-2 and SR-1 indicate chemical weathering in the catchment area is low.

4.3 XRD ANALYSIS OF DIFFERENT SIZE FRACTION

The XRD spectrum of different size fraction obtained by gravitative settling method of clay and silt separation was analyzed using X'pert Highscore program to identify the different mineral phases present and to find the relative proportions of different minerals present.

Table.8: Minerals present in 8-15.6μm (6min) fraction from the XRD analysis and semi-quantification**.**

S.No.	Sample name	Quartz	Plagioclase	K-feldspar	Muscovite	Clay	Others
1	KB-1	17	27	13	0	25	18
2	KB-2	14	36	15	0	19	16
3	SR-BL	14	27	15	19	24	1

Table.9: Minerals present in 4-8 μm (27min) fraction from the XRD analysis and semi-quantification.

S.no.	Sample name	Quartz	Plagioclase	K-feldspar	Muscovite	Clay	Others
1	KB-1	18	34	12		32	4
2	KB-2	17	18	20		40	5
3	SR-BL	17	25	10	20	26	1

Table.10: XRD analysis of 2-4 µm (54min) fraction and semi-quantification.

S.No.	Sample name	Quartz	Plagioclase	K-feldspar	Muscovite	Clay
1	KB-1	2		31		67
2	KB-2	27		29		44
3	SR-BL	1		27		71

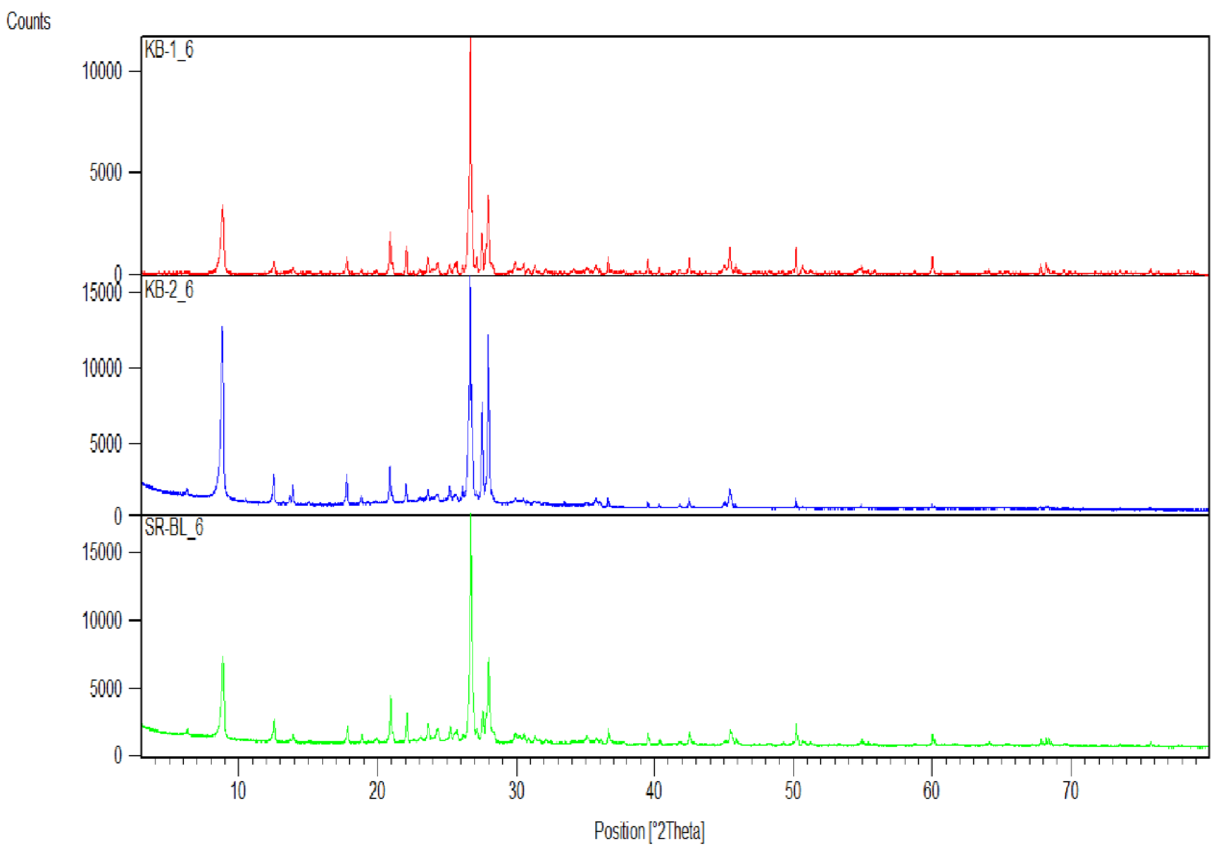


Figure 11: XRD spectrum of KB-1, KB-2 and SR-BL of 6min.samples.

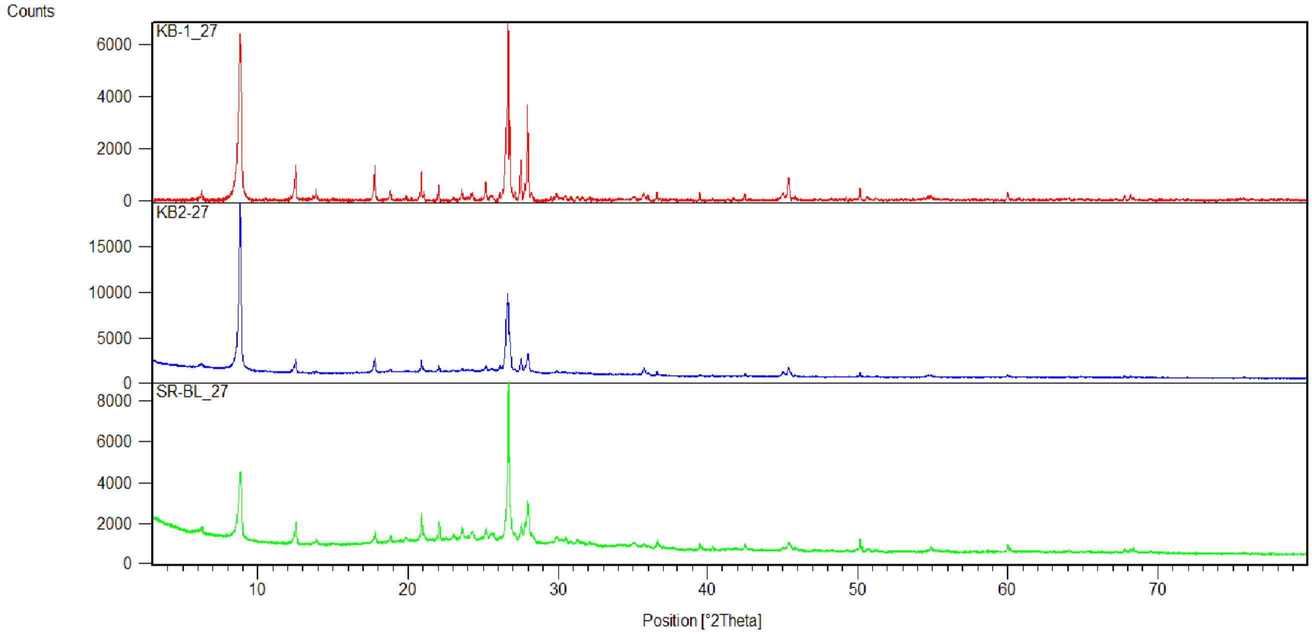
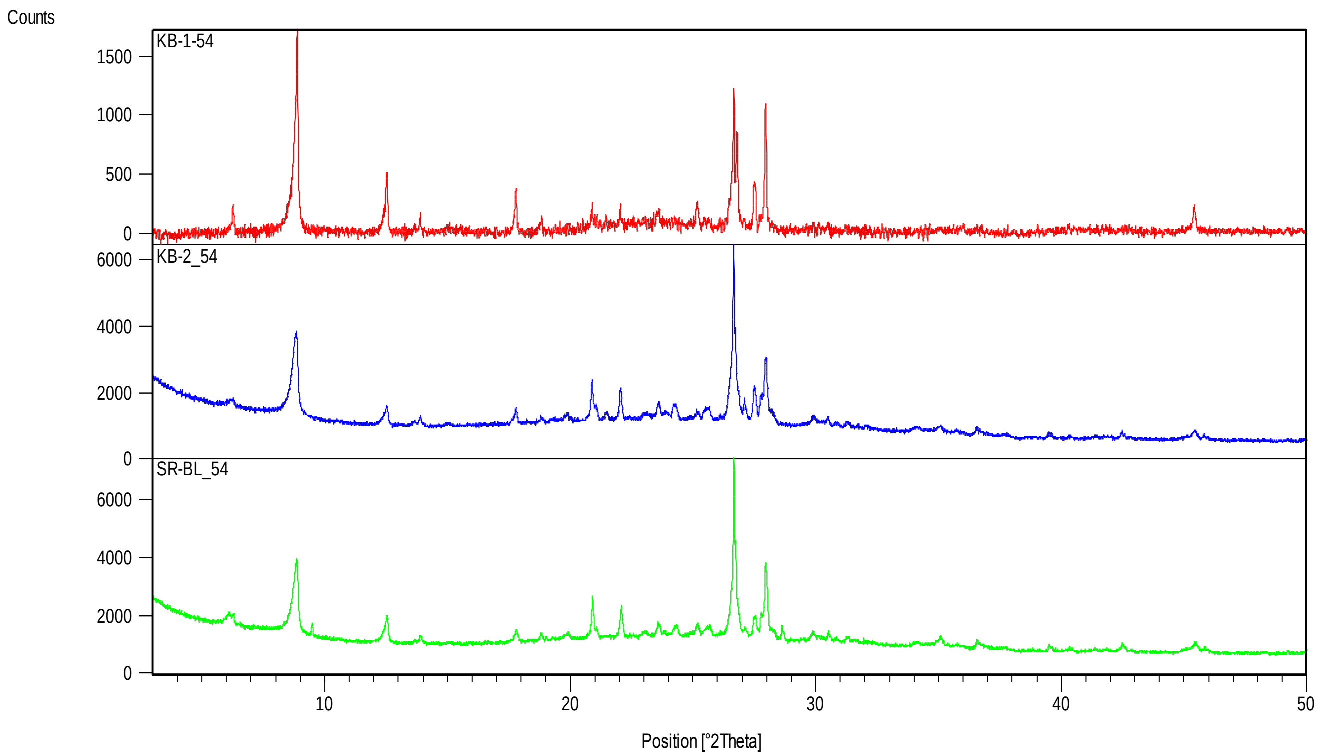


Figure 12: XRD spectrum of KB-1, KB-2 and SR-BL of 27min.samples.



Fiure 13: XRD spectrum of KB-1, KB-2 and SR-BL of 54min.samples.

Result shows that the samples with decreasing size or increasing settling time the clay percent increases significantly. In the clay minerals illite have more percent than kaolinite. The percentage of other major minerals getting decrease with reduced grain size. Quartz and other mineral percentages are decreasing in smaller size fractions as the sediments are not travelled too far from the provenance their size are coarser and being resistant they are incorporated in big grains sediments. Also there is more physical weathering in the provenance as it consists of steep hills, colder climate and monsoon dominated region.

The presence of clay minerals gives an idea about the chemical weathering in the catchment area and it is evident from the sediments found in the SR-BL, KB-1 and KB-2. The bulk mineralogy also gives the evidence of clay minerals. The rocks in the catchment area are gneisses, granite, cal-silicates. Resistant mineral are found in the sediments in more percentage and the non-resistant minerals which weathered quickly. From the presence of Ca-plagioclase, pyroxene and minor amount clay minerals suggest that in the catchment area lower degree of chemical weathering. As the catchment area is having steep slopes and glaciated so it promotes physical weathering over chemical weathering. Physical weathering facilitates reduction in grain size rather chemical alterations. The difference in clay contents and mineral composition suggest that the climate during deposition was different than the present day.

4.4 Clay Mineral Identification And Quantification

The clay percentage is calculated manually from the formula –

$$I(7A°)/2.5 + I(10A°) + I(14A°)/2 = 100\%$$

Where I = intensity of peak for specific d-spacing corresponding to clay minerals.

The presence of clay minerals such as illite/clay mica, kaolinite, vermiculite and clinochlore indicate that some extent of chemical weathering was happened in the past from SR-BL and in present from KB-1 &KB-2. From the XRD spectrum given in figure numbers 7A°, 10A° and 14A° peaks are significant. The identification involves not only single spectrum but also Ca-saturated and K-saturated spectrum at 110, 330 and 550 degree centigrade. Here the 110, 300 and 550 degree centigrade test is only done for K saturated samples.

From the three spectrums it can be observed that the most prominent peaks is at 10A° which indicate two clay minerals illite and hydrated hyallosite. The hydrated hyallosite dehydrates at 100 degree centigrade and shift to a spacing of 7.2 to 7.4A. At 100degree centigrade there is no such change. Further the 110, 300, 500 degree test confirms the presence of illite as the peaks become more sharp.

The 7A° peak identified as of kaolinite as it disappear at 500degree centigrade. The 14A° peak confirms clinochlore for KB-1, vermiculite for KB-2 and SR-BL.

Table 11: Semi-quantification of clay minerals in KB-1, KB-2 and SR-BL.

SAMPLE	ILLITE	KAOLINITE	VERMICULLITE/CLINOCHLORE	TOTAL
KB-1	90.2	5.5	4.22	99.92
KB-2	89.6	4.20	6.2	100
SR-BL	84	10	5.00	99

From the quantification it can be inferred that the dominant clay mineral in the three samples is illite>80% than the other clays. Second thing observed is the percentage increases from bedload SR-BL to KB terrace deposits which indicate that cooler and drier climate prevails when these sediments deposited. This is also indicated by the kaolinite percent which shows higher value in SR-BL as it present day bed load. This indicate KB-1 and KB-2 were deposited in colder climate. The study area must have climatic variations in past.

Kaolinite formed from the chemical weathering of feldspar rocks in hot, moist climates. Illite occurs as an altered product of muscovite and feldspar in weathering environment during glaciation and kaolinite may be during warmer period. Vermiculite is formed by weathering of biotite or phlogopite. Clinochlore exist in range of temperature –pressure conditions within low to medium metamorphic rocks and igneous rocks of hydrothermal rocks. From different amount of illite and kaolinite in SR-BL and KB- 1, 2 indicate different climatic conditions for both the deposited sediment.SR-BL deposited recently so it has more kaolinite than KB1, 2 and less illite.KB-1,2 deposited back many thousand years ago indicated by more illite and less kaolinite. Indicating cooler climate than today.

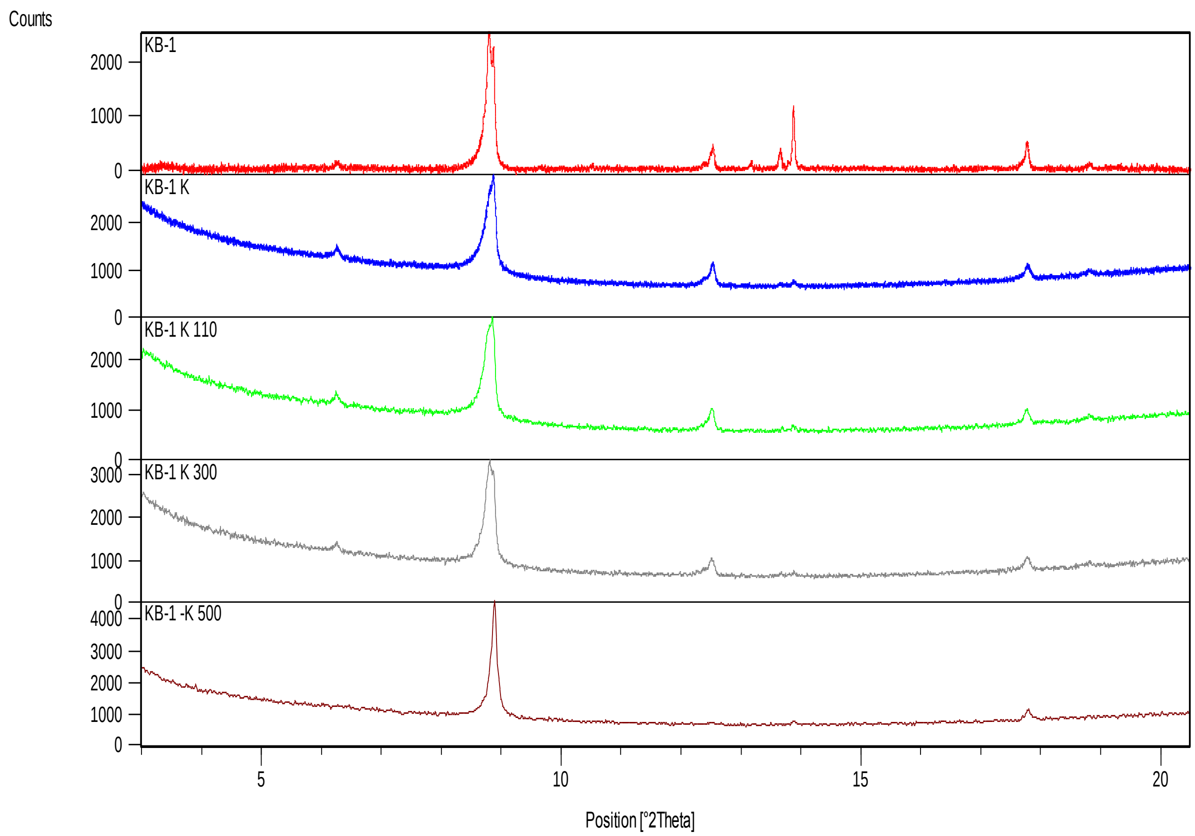


Figure 14: XRD spectrum of KB-1 for clay identification and quantification.

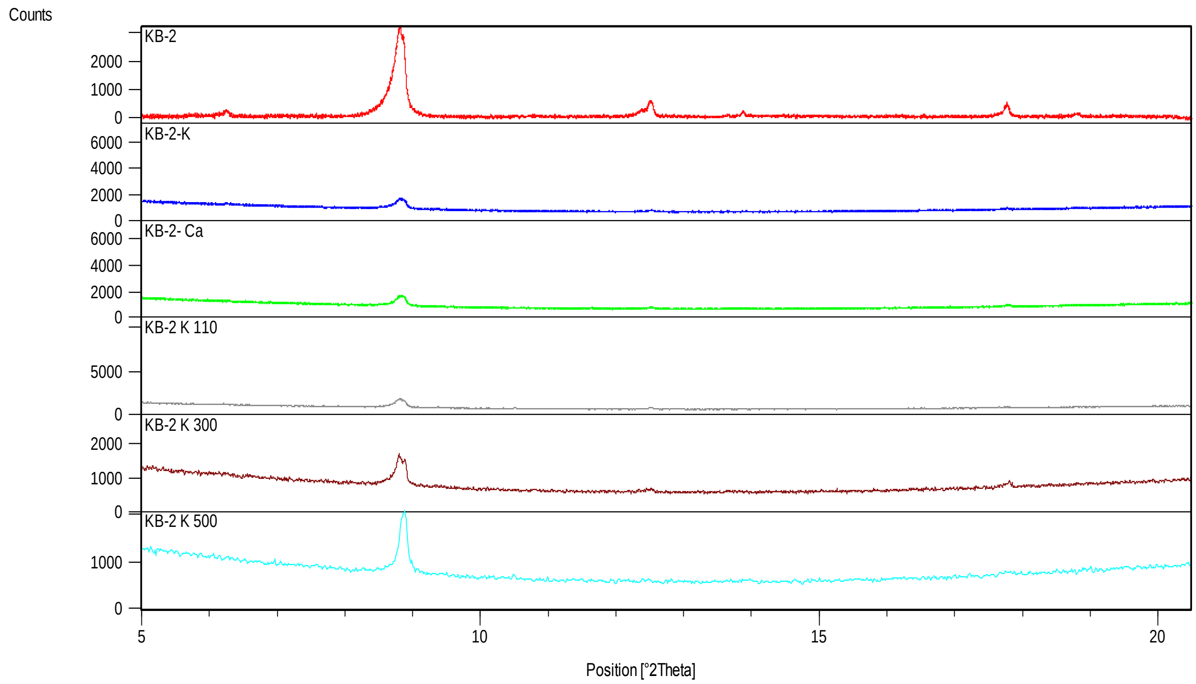


Figure15:XRD spectrum of KB-2 for clay identification and quantification

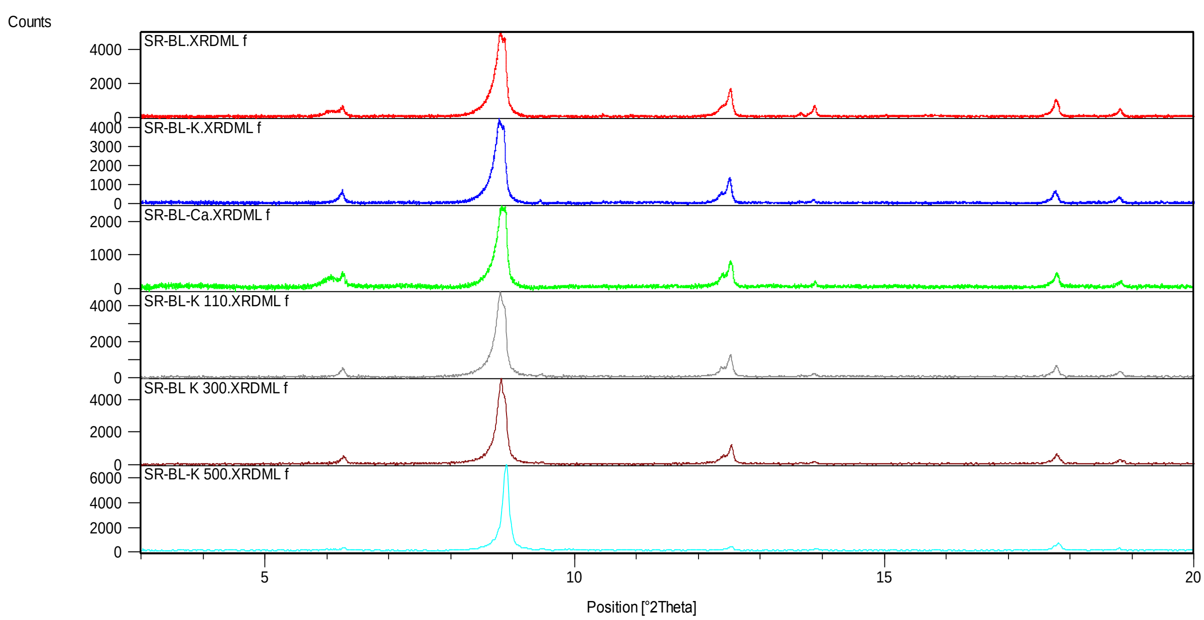


Figure 16: XRD spectrum of SR-BL for clay identification and quantification.

4.5 Geochemical Analysis Of The Terrace Sediment

The geochemical analysis of five terrace samples and one bedload SR-BL sample was carried out. The data is incomplete as no loss on ignition, wt%of P_2O_5,FeO andTiO_2 data is not calculated and that's why total weight percent is not 100%.

Table 12:Major elemental composition in wt% of the terrace sediments are given below .

OXIDE (Wt%)	SR-BL	SR-1	SR-2	HP-1	HP-2	HP-3
SiO2 (%)	69.858	64.38	67.307	68.779	69.844	62.072
Al2O3 (%)	10.672	12.926	12.276	11.404	11.644	14.384
Fe2O3 (%)	2.309	2.716	2.546	2.57	2.744	4.455
CaO (%)	0.891	0.819	0.887	0.934	1.018	1.3
Na2O (%)	2.836	2.626	2.794	2.454	2.47	1.928
K2O (%)	2.817	3.806	3.492	3.505	3.432	3.941
MgO (%)	0.339	0.84	0.503	0.168	0.221	1.389
MnO (%)	0.02	0.02	0.01	0.01	0.02	0.04
TOTAL	89.742	88.133	89.815	89.824	91.393	89.509

Table13:The major elemental composition in mole% of the terrace sediments with the corresponding CIA values are given below-

Oxides (Mole)	SR-BL	SR-1	SR-2	HP-1	HP-2	HP-3
SiO2	1.16275	1.071571	1.12029	1.14479	1.162517	1.033156
Al2O3	0.104668	0.126775	0.1204	0.111848	0.114202	0.141075
Fe2O3 (%)	0.014459	0.017008	0.015943	0.016094	0.017183	0.027898
CaO	0.015889	0.014605	0.015817	0.016656	0.018153	0.023182
Na2O	0.045758	0.04237	0.045081	0.039595	0.039853	0.031108
K2O	0.029904	0.040403	0.03707	0.037208	0.036433	0.041837
MgO	0.008411	0.020841	0.01248	0.004168	0.005483	0.034463
MnO	0.000282	0.000282	0.000141	0.000141	0.000282	0.000564
CIA	53.34245	56.55737	55.13632	54.47855	54.73593	59.47472

The major element has minor compositional variation of Al2O3, Fe2O3, MgO, MnO and this is due to the variations in concentration of SiO2 which show higher concentration range between 62-70 %. The sediment samples show limited range in composition.

CIA value is calculated by the formula –

$$CIA = \frac{100*Al2O3}{Al2O3+CaO+Na2O+K2O}$$

CIA is chemical index of alteration a parameter which quantitatively give the degree of weathering of the sample. According to Nesbitt and Young, 1984 the relationship among the alkali and alkaline earth major elements (Na2O, K2O and Ca) and Al2O3 in silicate phase can give the weathering history, intensity and duration in the source area. The CIA value are in range between 53.34 to 59.47 indicating low to nearly moderate chemical weathering and being derieved mainly by the physical breakdown of source rocks.

A-CN-K and A-CNK-FM plot (Nesbitt and Young, 1982, 1984,1989) helps to understand the extent of chemical weathering and type of sorce rock for the sediment. It consist not only the CIA but also other informations required to answer the problems. Various researcher draw these plots and get reliable result. .

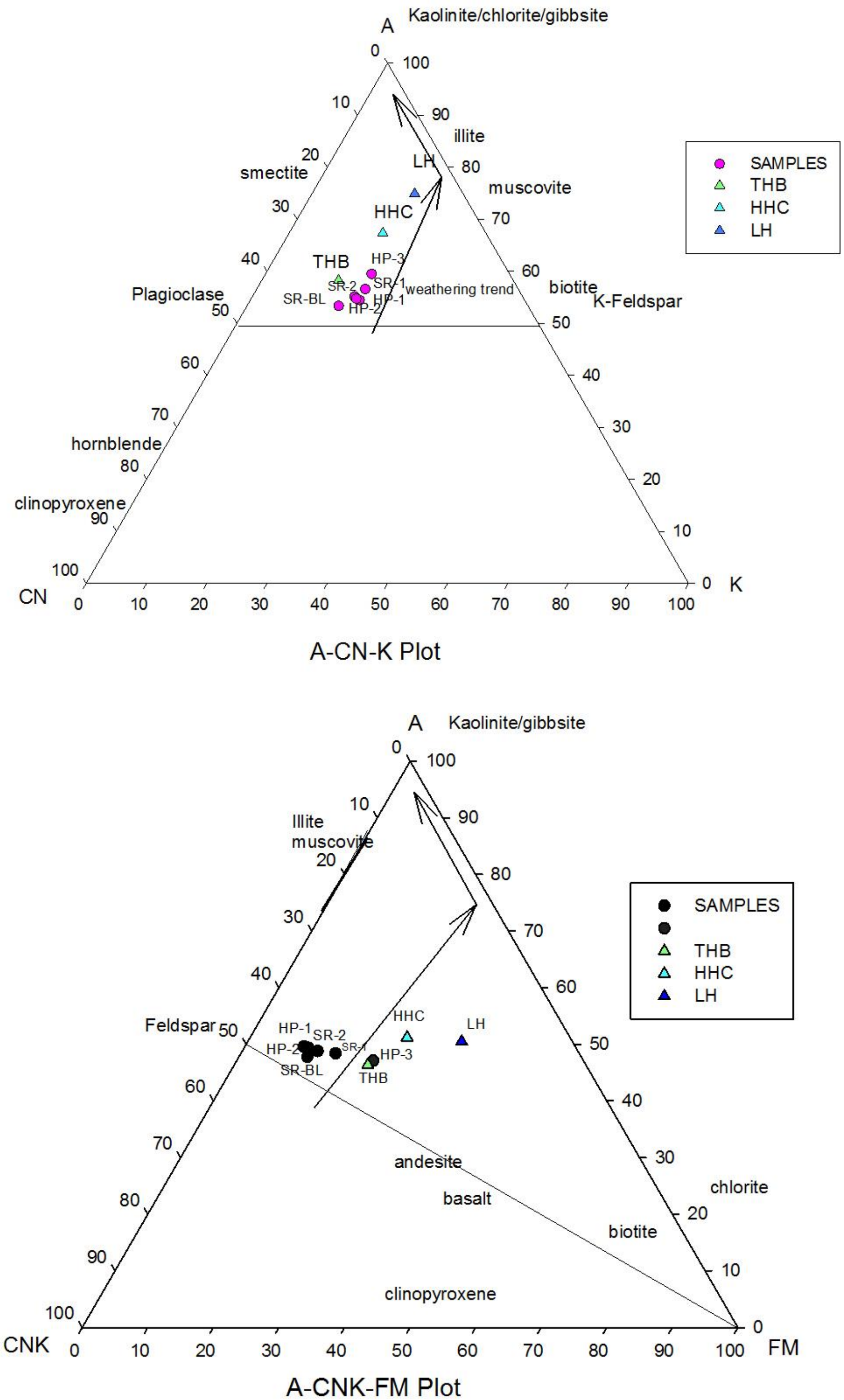


Figure.17: Plot of all the samples in the A-CN-K and A-CNK-FM diagrams. HHCS and LHS are also plotted for comparison.

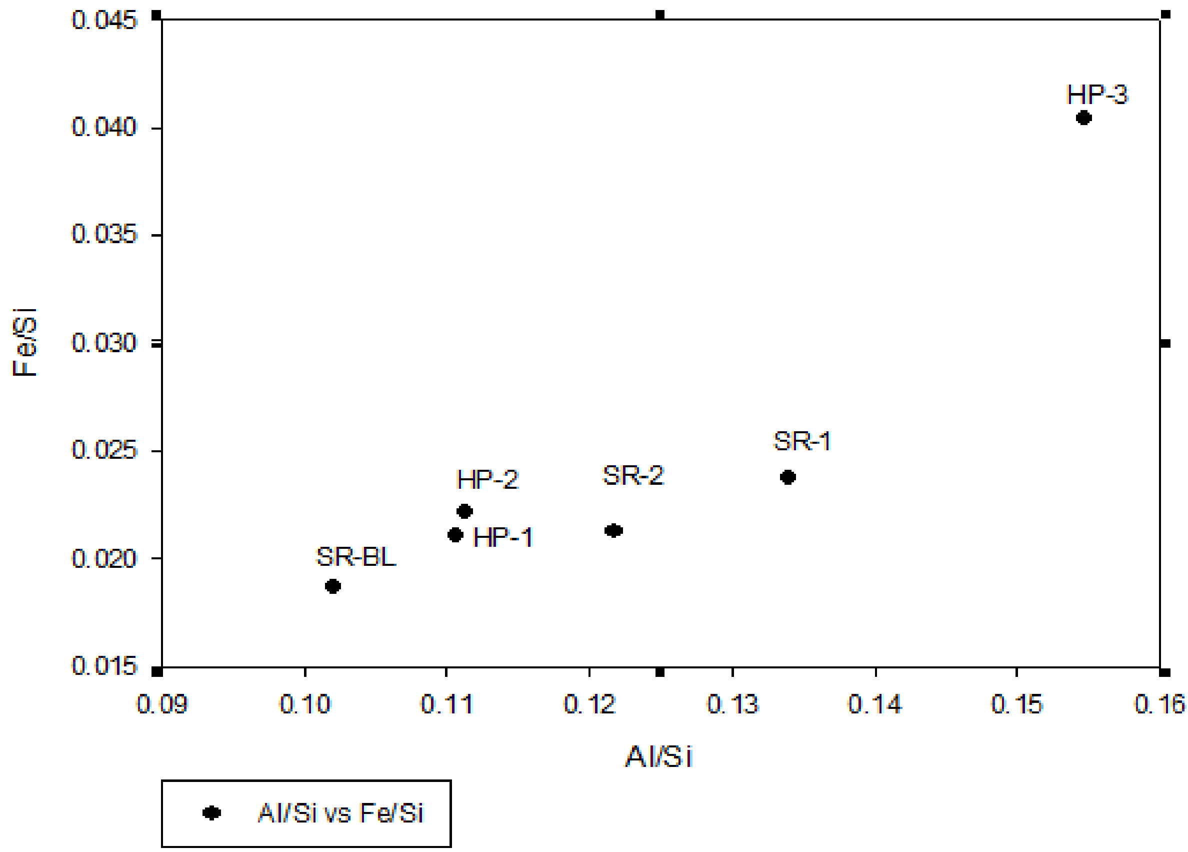


Figure 18: Plot Al/Si vs Fe/Si indicating fields of fine clay, biotite, muscovite near HP-3 and coarse quartz sediments near clustering of most of the samples.

From the plots of A-CN-K and A-CNK-FM by Nesbitt and Young, 1984, 1989 the samples were plotted clustering near the feldspar line and closely in the field of the source rock lithologies HHC and TH of Himalaya which indicate that Ca and Na is not mobilized yet indicating low extent of chemical weathering and the sediments were derieved mainly by the physical weathering. Also the clustering of the sediments closed to the provenance rocks indicate the felsic nature of source rocks that is most probably Higher Himalayan Crystalline (HHC). In the plot A-CN-K the line indicate the removal of Ca and Na which trend towards A-K line and finally towards the A apex by the removal of K. The trends indicate the increasing intensity of weathering which is also depicted in the A-CNK-FM.

The plot in fig. between Fe/Si vs Al/Si shows that the samples plots at the coarse quartz end away from the clay end, plotted near source rocks which indiacte low content of Fe and Al but high $SiO2$ in the sediments means low clay contents. Also indicate source rock chemistry and low chemical weathering as they have low Fe/Si and Al/Si ratio. The plot also shows that the sediment is derived by physical weathering mainly and travelled less distance.

Chapter 5

CONCLUSIONS

- The sediment samples are poorly to moderately sorted negatively skewed which indicate mixed sediment sizes.
- From the < 38µm grain size gravitative setling analysis it can be inferred that silt fraction is nearly 95% which suggest that the sediments are not travel too far from the source and the chemical weathering is low to moderate in the area with dominating physical weathering.
- The value of CIA for the samples are between 53.34 to 59.47 indicating low to nearly moderate chemical weathering at the time of deposition of terrace sediments.
- Clay minerals which are present indicate different paleoclimatic conditions. Illite is the dominating clay mineral in all the three samples indicating colder dier climate i.e. glaciation period during the deposition of the terrace Presence of Kaolinite indicate warm and humid climate.
- CIA , A-CN-K, A-CNK-FM and Fe/Si vs Al/Si plots indicate low to nearly moderate intensity of chemical weathering during the depositon of terraces and close resemblence of the chemistry with the source rock lithology .
- From the Fe/Si vs Al/Si plot it is concluded that the sediments are derieved from the near provenace travelled lesser distance.

REFERENCES

Arya, P. (2017), ‘Mineralogical and grain size distribution of river terrace deposits of upper Alaknanda basin’(Unpublished Master’s thesis). Central University of Punjab, Bathinda, Punjab, India.

Bali, R., Ali, S. N., Agarwal, K., Rastogi, S. K., Krishna, K., & Srivastava, P. (2013). Chronology of late Quaternary glaciation in the Pindar valley, Alaknanda basin, Central Himalaya (India). *Journal of Asian Earth Sciences*, **66**, 224-233.

Barnard, P. L., Owen, L. A., Sharma, M. C., & Finkel, R. C. (2004). Late Quaternary (Holocene) landscape evolution of a monsoon-influenced high Himalayan valley, Gori Ganga, Nanda Devi, NE Garhwal. Geomorphology, **61(1)**, 91-110.

Benn, D. I., & Owen, L. A. (1998). The role of the Indian summer monsoon and the mid-latitude westerlies in Himalayan glaciation: review and speculative discussion. *Journal of the Geological Society*, **155(2)**, 353-363.

Bhambri, R., Bolch, T., Chaujar, R. K., & Kulshreshtha, S. C. (2011). Glacier changes in the Garhwal Himalaya, India, from 1968 to 2006 based on remote sensing. *Journal of Glaciology*, **57(203)**, 543-556.

Bookhagen, B., Thiede, R. C., & Strecker, M. R. (2005). Late Quaternary intensified monsoon phases control landscape evolution in the northwest Himalaya. Geology, **33(2)**, 149-152.

Chakrapani, G., Saini, R., & Yadav, S. (2009). Chemical weathering rates in the Alaknanda–Bhagirathi river basins in Himalayas, India. *Journal of Asian Earth Sciences,***34(3)**, 347-362.

Crone, A. J., Machette, M. N., and Bowman, J. R. (1997).Episodic nature of earthquake activity in stable continental regions revealed by palaeoseismicity studies of Australian and North American Quaternary faults. *Australian Journal of Earth Sciences,***44(2)**, 203-214.

Cohen, K. M., Finney, S. C., Gibbard, P. L., and Fan, J. X. (2013).The ICS international chronostratigraphic chart. Episodes, **36(3)**, 199-204.

Easterbrook, D. J. (1999). Surface processes and landforms. Pearson College Division.

Fairbridge, R. W. (1968). The encyclopedia of geomorphology.

Gribbin, J. (1983). Future weather: Carbon dioxide, climate and the greenhouse effect. PENGUIN, HARMONDSWORTH(UK). 1983.

Gradstein, F. M., Ogg, J. G., Smith, A. G., Bleeker, W., and Lourens, L. J. (2004).A new geologic time scale, with special reference to Precambrian and Neogene. Episodes, **27(2)**, 83-100.

J.J. Lowe et.al, (2007) introduction, understanding Quaternary climate change. (encyclopedia of quaternary science)

Juyal, N., Sundriyal, Y. P., Rana, N., Chaudhary, S., and Singhvi, A. K. (2010).Late Quaternary fluvial aggradation and incision in the monsoon-dominated Alaknanda valley, Central Himalaya, Uttrakhand, India*. Journal of Quaternary Science,***25(9999)**, 1-13.

Juyal, N., Pant, R., Basavaiah, N., Bhushan, R., Jain, M., Saini, N., . . . Singhvi, A. (2009). Reconstruction of Last Glacial to early Holocene monsoon variability from relict lake sediments of the Higher Central Himalaya, Uttrakhand, India. *Journal of Asian Earth Sciences,***34(3)**, 437-449.

Juyal, N., Sundriyal, Y., Rana, N., Chaudhary, S., & Singhvi, A. K. (2010). Late Quaternary fluvial aggradation and incision in the monsoon-dominated Alaknanda valley, Central Himalaya, Uttrakhand, India. *Journal of Quaternary Science,***25(9999)**, 1-13.

Komal, Joon R., (2016). Watersheds in the Alaknanda Basin of Uttrakhand. International *Journal of Advanced Research in Computer and Communication Engineering,Vol. 5*

Lowe, J. J., and Walker, M. J. (1984). Reconstructing Quaternary Environments. London.

Ladakh, NW Indian Himalaya—a study based on field observations. Geomorphology **65**, 241–256.

Lowe, J. J., Walker, M. J. C., and Porter, S. C. (2007). Understanding Quaternary Climatic Change. Encyclopedia of Quaternary Science, 28, 39..

Lupker, M., France-Lanord, C., Galy, V., Lavé, J., & Kudrass, H. (2013). Increasing chemical weathering in the Himalayan system since the Last Glacial Maximum. Earth and Planetary Science Letters, 365, 243-252.

Nayak, K. (2015). Geochemical characterization and provenance study of glacial lake deposits of the Badrinath valley (Unpublished master's thesis). Indian Institute of Science Education and Research Kolkata, Kolkata, India.

Negi, S. S. (1995). Uttarakhand: Land and people. MD Publications Pvt. Ltd..

NavinJuyalet.al, (2010), Late quaternary fluvial aggradation and Incision in the monsoon-dominated Alaknanda Valley Central Himalaya, Uttrakhand, India. *Journal of quaternary science.*

Nainwal, H., Chaudhary, M., Rana, N., Negi, B., Negi, R., Juyal, N., & Singhvi, A. (2007). Chronology of the Late Quaternary glaciation around Badrinath (Upper Alaknanda Basin): Preliminary observations. Current Science (00113891), 93(1).

Nainwal, H., Negi, B., Chaudhary, M., Sajwan, K., & Gaurav, A. (2008). Temporal changes in rate of recession: Evidences from Satopanth and Bhagirath Kharak glaciers, Uttarakhand, using Total Station Survey. Curr. Sci, **94(5)**, 653-660.

Owen, L. A., Derbyshire, E., & Fort, M. (1998). The Quaternary glacial history of the Himalaya. *Journal of Quaternary Science,* **13(6)**, 91-120.

Owen, L. A., Finkel, R. C., & Caffee, M. W. (2002). A note on the extent of glaciation throughout the Himalaya during the global Last Glacial Maximum. Quaternary Science Reviews, **21(1)**, 147-157.

Oven L.A., Derbyshire E., Fort M., (1998). The quaternary glacial history of the Himalaya. *Journal of Quaternary Science***13**, 91 – 120

Pramod Singh, (2010), Geochemistry and provenance of stream sediments of the Ganga River and its major tributaries in the Himalayan region, India.220-236.

Phartiyal B., Sharma A., Srivastava P., Ray Y., (2009). Chronology of relict lake deposits in the Spiti River, NW Trans-Himalaya: Implications to Late Pleistocene–Holocene climate-tectonic perturbations. Geomorphology **108**, 264 – 272.

Punia M. and Dhanker V., (2014). Mapping of snow spectral properties and regional climatic variability in Alaknanda Basin, Uttarakhand, India. No. 356/ISRS Proceedings/ISPRSTC 16Mid-Symposium, Hyderabad, India.

Phartiyal, B., Sharma, A., Srivastava, P., & Ray, Y. (2009). Chronology of relict lake deposits in the Spiti River, NW Trans Himalaya: Implications to Late Pleistocene–Holocene climate-tectonic perturbations. Geomorphology, **108(3)**, 264-272.

Phartiyal, B., Sharma, A., Upadhyay, R., & Sinha, A. K. (2005). Quaternary geology, tectonics and distribution of palaeo-and present fluvio/glacio lacustrine deposits in Ladakh, NW Indian Himalaya—a study based on field observations. Geomorphology, **65(3)**, 241-256.

Pramod Singh, (2009), major, trace and REE Geochemistry of the Ganga river sediments: influences of the provenance and sedimentary processes, 251-264.

Phartiyal B., Sharma A., Upadhyay R., Ram-Awatar, Sinha A.K., (2005). Quaternary geology, tectonics and distribution of paleo- and present fluvial/glaciolacustrine deposits in.

Sundriyal, Y., Tripathi, J. K., Sati, S., Rawat, G., & Srivastava, P. (2007). Landslide-dammed lakes in the Alaknanda Basin, Lesser Himalaya: Causes and implications. CURRENT SCIENCE-BANGALORE-, **93(4)**, 568.

Sundriyal, Y. (2010). Late Quaternary fluvial aggradation and incision in themonsoon-dominated Alaknanda valley, Central Himalaya, Uttrakhand, India.*Journal of Quaternary Science*, **25(8)**, 1293-1304.

Singh, P. (2010). Geochemistry and provenance of stream sediments of the Ganga River and its major tributaries in the Himalayan region, India. Chemical Geology, **269(3)**, 220-236.

Sener certain, (2007), new chemical weathering indicates for estimating the properties of rocks: A case study from the Kurt Granodiorite, NE Turkey, Turkish *Journal of Earth science*.

Wang, P., Chen, J., Dai, F., Long, W., Xu, C., Sun, J., & Cui, Z. (2014). Chronology of relict lake deposits around the Suwalong paleolandslide in the upper Jinsha River, SE Tibetan Plateau: Implications to Holocene tectonic perturbations. Geomorphology, **217**, 193-203.