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Role of nalas in development of landforms and land use pattern with special reference to the Stakmo village, Leh valley

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ABSTRACT

In the Leh valley, apart from the river Indus, several nalas have a great significance on development of a number of villages and settlement areas. The present work is an effort to illustrate the pivotal role of the Stakmo nala in establishment of the Stakmo village. The study also seeks to emphasis the necessity of the nala basin management to sustain the natural resources for the existence of the villages. Various problems related with Leh city and its adjacent area have been studied by several scientists. However, most of the scientists hardly show interest in depicting the comprehensive roles of the different nalas for the construction of many settlement areas and their related issues in the Leh valley. Present authors have tried to unfold the role of nalas in development of landforms and land use pattern with special reference to Stakmo village, Leh valley. Along the Leh valley there are11 important nalas which have key role to supply necessary natural resources to develop a number of important villages and settlement areas. Undoubtedly, availability of natural resources of an area greatly influenced by the process of landform development and their characteristics, because landscape characteristics play a significant role in generation of local natural resources. Hence, in order to illustrate the significant role of the Stakmo nala in development of landforms and land use pattern in Stakmo village and its adjacent area, the authors analysed vivid geomorphic features of the Stakmo nala basin based on quantitative approach including morphometric techniques and field observation. Apart from morphometric analysis, field based data regarding nala sediment size, rock types, micro features, varied land use pattern of the Stakmo village including perception study of the local people have been tried to discuss in the work.

Introduction

Leh valley is situated in high altitude cold desert area under periglacial environment. Most of the part of Ladakh area is under barren land due to lack of water resource. Hence, existence of lives in this hard climatic region is very difficult. That is why development of settlement area in Ladakh area is mainly restricted in valleys where snow melt nalas are present. The current paper has tried to explain the role of the Stakmo nala in development of landforms and land use characteristics.Though, various problems regarding landforms and land use of Leh city and its adjoining areas of Ladakh area have been studied by several scientists.The rain shadow Ladakh area has been several times highlighted in many studies for its cloud burst induced flash flood vulnerability previously in different years specially in Leh valley (Ziegler *et al.,* 2016; Gupta *et al.,* 2012; Arya; 2011; Juyal, 2010).A number of scientists (Barrett,2014) have focused their studies on climate change and associated glacial retreat problems in the area. Searle (2011) had benchmark contribution in the study of geology in Ladakh and Karakoram ranges. Lal *et al.* (2018) has emphasised the tectonic influences on the

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landform development in Ladakh region. Many scientists (Sant *et al.,* 2011) have also emphasised on geomorphological classification of Leh valley emphasising on periglacial landforms. Koul *et al.* (2016) published report on glacier status over the past 50 years (1962-2013) on remotely-sensed volumetric changes of glaciers in Drass glacier basin, Ladakh Mountain, North-West Himalaya. Gupta *et al.* (2017) elaborated vividly the characteristics of the soils of Ladakh region. Mukhopadhyay (1980) had elaborated geomorphology of peri glacierised area of upper Tista basin.Sangode *et al.* (2017) have analysed the sedimentary and geomorphic signatures of 2010 cloudburst triggered flash flood in Leh valley. Mujtaba *et al.* (2017) identified the geomorphic imprints of the paleolakes, alluvial fans and other landforms around Leh. Many renowned scientists (Patel *et al.,* 2008 ; Raghuvanshi *et al.,* 2019) have contributed their valuable research works on agricultural land use patterns and associated problems in Leh and its adjoining areas. Dame *et al.* (2019) nicely elaborated the scenario of rapid urbanisation of the Leh town as well as the conversion of the barren land and agricultural land into built up area.

However, the earlier studies have hardly illustrated the role of nalas in development of different geomorphic features and land use pattern in different villages and settlement areas of the Leh valley. Hence, the present research has focused on quantitative analysis of the Stakmo nala basin emphasising the landform and land use relationship in a quantitative manner. The investigators have also vividly explained the characteristics of the landforms and their impacts on land use pattern in the Stakmo valley to study the local resource vulnerability.

Geographical location of the Stakmo village:

The Stakmo village is mainly located in the Leh valley.The longitudinally trending NW-SE Leh Valley extends from Karoo in SE (33°54′48″N, 77°44′14″E) to Pathhar Sahib in NW (34°11′31″N, 77°22′19″E). The Leh valley bordered by snow covered mountainous Ladakh and Zanskar hill ranges. Ladakh range lies between the Indus and Shyok river valleys, stretching to 230 miles (370 km). The entire eastern flank within Leh valley is marked by 11 major transverse streams arising from the Ladakh batholithic range and opening into the main Indus valley. Among the 11 nalas,Stakmo (figure 2)is one of the important nalas which has a great influence on the development of the Stakmo village (figure 1).The figure 3shows the upper course of the Stakmo nala flowing from the Ladakh range. The Stakmo village is situated over dry fan (fan apex,34° 7' N & 77° 42' 1" E) in the Leh valley. Along the fan surface, the Stakmo village (77° 42' 21.56" E, 34° 01' 36.90" N), has been developed which is under Leh block.

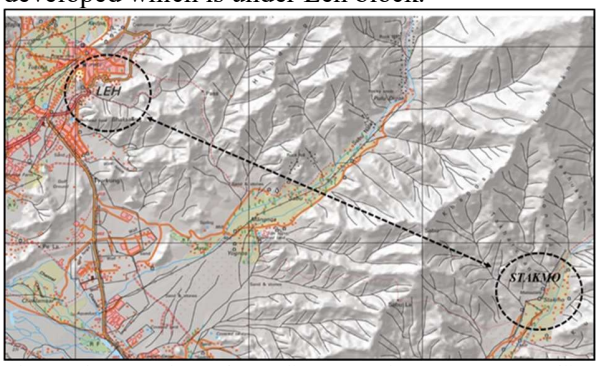

Figure 1: Location of the Stakmo Village and Leh City. (Source: Toposheet, S.O.I)

Figure 2: Location of Active Indus Channel and Stakmo Nala (study area) in Leh Valley, (source: Google Satellite Image, 2021)

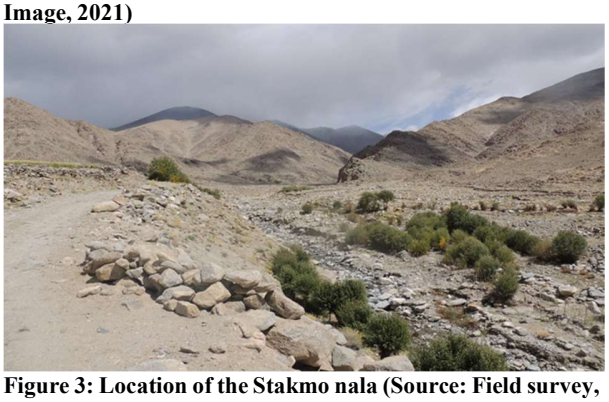

Figure 3: Location of the Stakmo nala (Source: Field survey, 2014)

Material and Methods

Stage-I: The paper is prepared on several secondary data and primary data including field observation. The secondary data includes toposheet (SOI), satellite images (google earth,2020),valuable literatures and the primary data consists of local people perception and field recorded data with photographic evidences. Based on several previous literature review specific research gap regarding *significance of nala* has been identified .

Stage-II: Field verification was done to gather different types of primary data of the Stakmo nala basin (landform study, nala morphology analysis, nala bed sediment study, observation of land use practices), photographic evidences including the people perception about the Stakmo village as well as the Stakmo nala .

Stage-III: Analysis of the secondary data was so import to delineate the Stakmo nala basin as well as fan area and establish the relationship among the different physical setup (physiography, ground water availability, climate, geology) .Morphometric interpretation of the basin has been done based on SRTM DEM. Visual interpretation of the satellite image (google earth,2021) was also very relevant for better understanding about the land use pattern of the basin.

Stage-IV: Depending on the analysis of the collected primary and secondary data role of the Stakmo nala in development of landform and land use has been evaluated and few effective measures have been concluded towards the sustainability of the natural resources of the Stakmo basin.

Objective: The main objective of the present paper is to illustrate the influence of the Stakmo nala on the development of landforms and landuse pattern in the Stakmo basin, Leh block.

Results and Discussion

Role of Physical setup for scarcity in ground water resources

The Leh city and its adjacent area are located in Leh valley which lies in the rain shadow zone because the Great Himalaya and the Karakoram range are located towards south and north respectively of the valley and the Tibatan plateau is situated towards east of the valley. As a result of the orographic barriers the area receives very little amount of rainfall. Annual average high and low temperature at Leh are 12.8 and -1.3 degree celcius respectively. The annual average rainfall at Leh is 105.5 mm (IMD, 2018). In the rain shadow region, due to lack of moisture a desert environment has been developed in Ladakh area. As a result of acute deficiency of soil moisture existences of trees and other vegetation are not found except the narrow valley portion. Extended parts of the area are under barren land. Apart from the climatic condition, geological setup of the area is also not favourable for the storage of ground water resources. The district is underlain by consolidated formation in maximum part. Ground water in these formations occur in fissures and fractures developed due to repeated tectonic activity. Large scale ground water development is not possible in consolidated formations but limited development of ground water resources can be taken up. As a result, ground water development in the study area is on moderate scale restricted only to the valley portion. At present, the development of ground water resources is very insufficient. According to the report by the Central Ground Water Board CGWB (2014), Leh district is about 81840 sq. km. and the total valley area is approx. 81 sq. km. The number of wells constructed by CGWB is only 25. In 1st phase(1973-2001) it was 16 and in 2nd phase(2005-2008) 9 wells were constructed. According to the Census report (2011) of India, total population of the Leh district is about 147104. The data is enough to establish the acute inadequacy in storage and supply of ground water resource in compare to total population resource in the are under study.

Broad drainage features including nalas: The Leh valley is mainly drained by the river Indus. Two main rivers flowing in this area Nobra and Shyok rivers. Nubra is a perennial river and is originated from Siachen Glacier and flows in North west to South east direction. Shyok river is also a perennial river and it originates from South Rimo Glacier and Central Rimo Glacier. Beside the main river Indus, in Leh valley there are so many nalas flowing from the north-eastern Ladakh Batholith Ridge. The Nalas are locally termed as Lungpa. Those nalas are mainly fed with glaciers and snowmelt water. The important nalas are such; Taru Nala, Phyang Nala, Khardung nala, Sabu Nala, Stakmo nala, Nang nala etc. Those nalas have great influence on the development of landforms and land use pattern in Leh valley. Along

the nalas, series of fans have been developed and depending on the fan topography as well as water resources of the nalas a number of settlement areas and villages have been developed (table 1& plate 1). All of the alluvial fans in the Leh valley area represent potentially important aquifers. On the other hand, during cloudburst triggered flash flood these nalas cause excessive water and sediment discharge as well as debris flow from the Ladakh Batholith Ridge into Leh valley causing severe damage of lives and properties. A study by Sangode *et al.* (2017) on 2010 flash flood event, reveals that the small stream drainage area produced extra stress on the pre-existing narrow channels, forcing the rapid lateral erosion and mass transfer. The field photograph also proves prominent Stakmo channel incision caused during 2010 flash flood (figure 6D).

Table 1: Important settlement areas developed along the nalas in Leh valley

Name of the important nalas	Settlement situated along the nala
Taru	Taru village
Phyang	Phyang village
Khardung	Leh city
Sabu	Sabu village
Stakmo	Stakmo village
Thikse	Thikse Monastery and adjacent settlement
Nang	Nang Village
(Based on Sangode *et al.,* 2017 & Google earth Image,2020)	

Effective character of the nalas in development of settlement areas:

Under the adverse environmental conditions nalas and springs have enormous roles to enrich the soil moisture and natural vegetation resources along the different valleys. The settlement pattern of people in this district are mainly concentrated in the river and nala valleys. The ground water development in these areas is of utmost importance. All the major irrigation and drinking water supplies depend on natural springs, rivers and nalas. Sangode *et al.* (2017) have clearly identified eleven important nalas in Leh valley, originating from the Ladakh Batholith Ridge Crest.

Broad geomorphological characteristics of the Leh valley:

Geomorphology of the Leh valley has a great influence on the development of ground and surface water availability in some parts of Leh valley. The present authors think that there are three important geomorphic zones where development of settlement area including land use patterns have been possible; (1) Indus floodplain (2) Amphitheatre valley with nalas (3) dry alluvial fans.In broad valley, snow fed surface and ground water is an important natural resource to sustain the lives. The broad glaciated valleys are mainly filled with glacio-fluvial alluvium, moraines, weathered materials including stone lag deposits, sand dunes etc. The unconsolidated formations like alluvium, scree and talus deposits present along the river valleys which plays a vital role in terms of occurrence and movement of ground water. The moraine formations consist of boulders and clastics in a matrix of gravel, sand, silt and clay which from the aquifer. Depth in water level in moraine formations is very deep which varies from 60 m bgl to 75 m bgl (CGWB ,2014). The Stakmo village is located along the Stakmo nala valley. The upper part bears prominent characteristics of amphitheatre valley and the lower part the Stakmo nala has developed an elongated dry fan over which the Stakmo village has been developed.

Morphometric analysis of the Stakmo nala basin:

The Stakmo nala basin is extended from 34°0'north to 34°12' north and 77° 30' east to 77° 47'east. The river is mainly snowfed originated from the Ladakh range. It is 4th order nala (figure 5). The nala has developed an elongated dry fan which has been demarked in the basin map. A relative relief map of the entire basin has been prepared based on SRTM DEM. The apex of the fan (fan apex ,34° 7' N & 77° 42' 1" E) is shown in the map. Above the apex of the fan prominent amphitheatre valley is located. Excessive terminal moraines are observed over the floor of the amphitheatre valley. The moraines are heavily weathered under periglacial environment. Heaps of weathered moraines are the source of sediment of the Stakmo fan. According to the villagers during 2010 cloudburst induced flash flood debris flow from the upper course of the basin or from amphitheatre valley caused devastation in downstream settlement area over the Stakmo fan and the campus of the Druk a Lotus school.

Plate 1: Important settlement areas including Leh city and several villages developed along different nalas (Source: Google earth image, 2021)

On the other hand, the average slope map shows maximum slope 41°-69°in the upper part of the basin where mass wasting process is very active. Over the fan surface the average slope is 0 – 12 ° where the Stakmo village is located. The Stakmo nala is flowing over this fan area with its characteristic channel form. In the upper part of the basin maximum intensity of dissection (0.113-0.156) is observed (figure 4). Mainly glacial erosional process is responsible for this higher intensity of dissection index. The absolute relief map of the Stakmo basin clearly indicates fan surface with gradual decline of the elevation. The elevation of the upper fan is 3780 – 4222m. On the other hand ,lower fan is located at the elevation of 3290-3780m (figure 4).

Major periglacial landforms in Stakmo Nala basin:

The landforms of the Stakmo basin indicate clear evidences of periglacial features.Several geomorphic processes are working over the entire landscape that are characterised with glacial, periglacial, glacio-fluvial, aeolian, lacustrine and tectonic processes.The landforms prominently observed by the authors during the field survey are;amphitheater valleys (Glacial erosional), moraines (Glacial depositional), sand dunes and sand sheet (aeolian depositional), alluvialfans (fluvial depositional), glacial outwash (glacio-fluvial), palaeo lake sediments (lacustrine process), flood plain(fluvial depositional) etc. Beside these, stone lag deposits, tor, dells are the observable periglacial features. The researchers have observed the important features during field visit.

Glaciated amphitheatre valley: Many scientists (Sant *et al.* 2011) have identified amphitheatre valleys characterised with triangular funnel shaped deglaciated valley bounded by steep rocky slopes on three sides within Ladakh hill range comprising glacial out wash and lag deposits all along the valley floor. At the upper part of the Stakmo river a prominent amphitheatre valley has been surveyed (figure 6B) by the authors. The Stakmo amphitheatre valley is characterised with steep rocky slopes on three sides with lag deposits all along the valley floor.

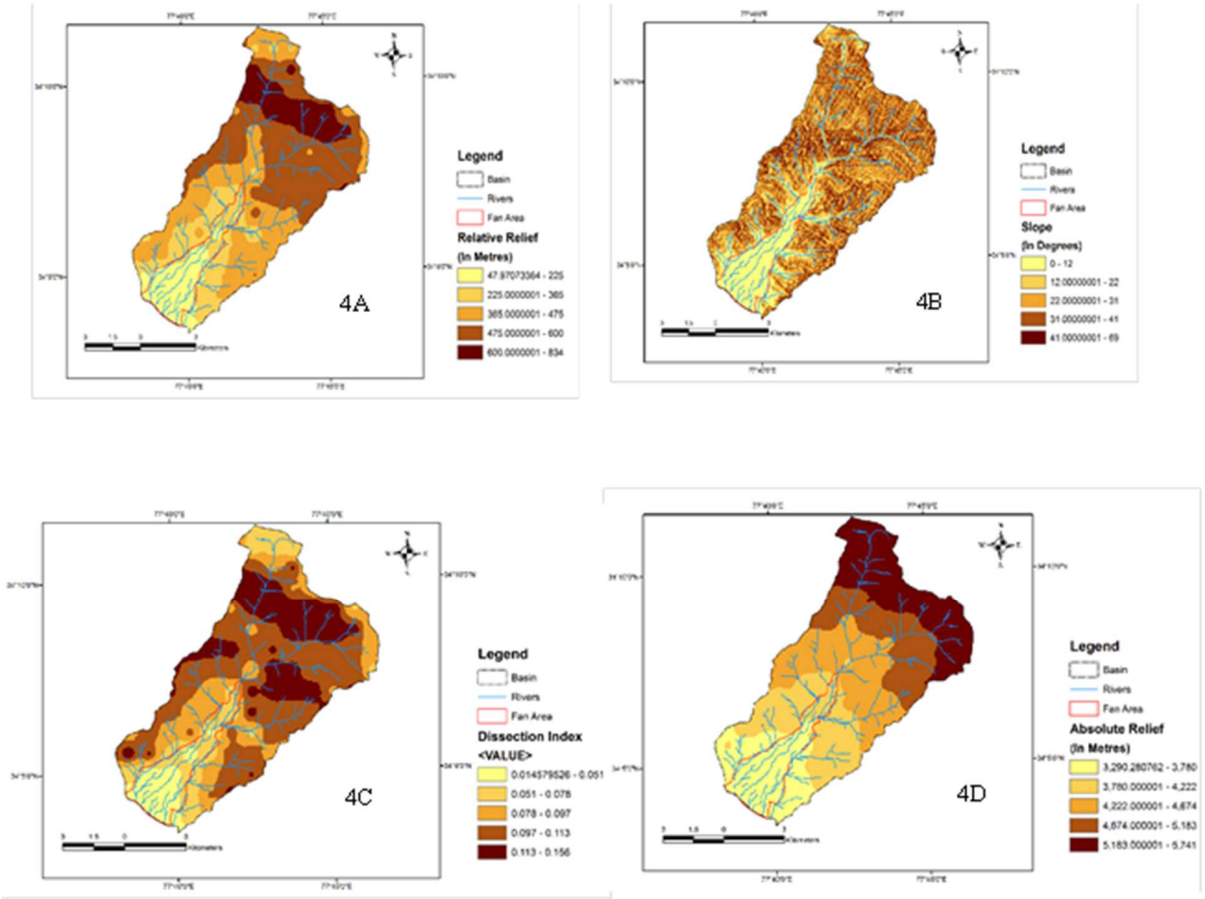

Figure 4: Morphometric Analysis of Stakmo Nala Basin (4A:Relative Relief, 4B: Slope, 4C: Dissection Index, 4D: Absolute Relief (Source: SRTM, DEM)

According to the Stakmo villagers the debris flow originated from the upper part of the amphitheatre valley during flash flood 2010. Towards the lower part of the Stakmo valley a dry alluvial fan has been developed . Heavily weathered rocks and debris of the amphitheatre valley are the major source of sediments for development of the Stakmo alluvial fan in downstream.

Dry periglacial fan: Periglacial dry fans are formed during deglaciation and their development is dependent upon the temporary abundance of glacial debris. In the present study the authors have given a special emphasis on dry fans which are noticeable periglacial feature of the area. The authors have observed that these dry periglacial fans (figure 6c) have great impacts on the development of city and other settlement areas along the Leh Valley. The present investigators think that the series of dry alluvial fans observed in the north-east part of the Leh valley are developed depending on the pre existing foothill topography and important nalas (Taru , Phyang , Khardung , Sabu, Stakmo , Nang nala etc) which are fed by snow, glaciers and sometimes rain water as well as heterogeneous sediments which are the important factors in sculpturing the surface of the fan topography.

Sand sheet: Existence of sand sheets Kumar *et al.* (2016) in the Stakmo basin has been observed by the authors. The authors have identified a palaeo lake covered with sand sheet on the way from Shey to Stakmo village.

Role of the Stakmo nala in development of the Stakmo village: The Stakmo valley (elevation about 3800 m.) is situated at a distance of 26 km from Leh city. It is believed that the name of the village is derived from the village's shape which resembles as a Tiger or 'Stak' in Ladakhi language.

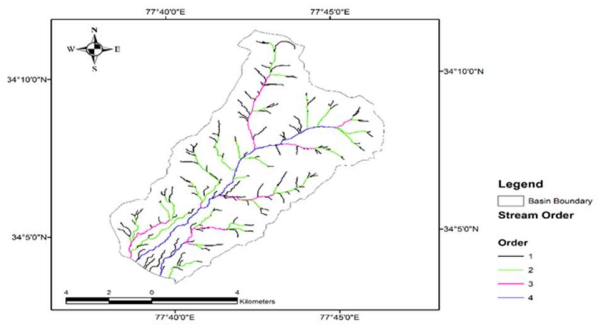

Figure 5: Stream Ordering of Stakmo Nala Basin (Source: SRTM, DEM)

The present investigators have studied the dry fan over which the village of Stakmo is located though according to the studies of several scientists (Sant *et al.* 2011) the Stakmo valley(upper part) is actually falls under amphitheatre valleys characterised with different types of moraines. The Stakmo valley is situated about 7 km. far towards the north- east direction of the Shey Fort as well as the famous Druk Padma Karpo school. Depending on the field verification the authors have identified varied micro landforms and land use features over the fan (figure 6 &7) specially along the Stakmo nala. A prominent trenching of more than 6 metres height was observed along the Stakmo nallah(upper course), which is very significant evidences regarding the supply of sediments from source area . The dry fans are trenched because of the relatively rapid depletion of the erodible glacial debris and the subsequent reduction of sediment loads from the drainage basin Eckis (1928).The fan is comparatively steeper and the upper part is covered with the soils shallow to very shallow in depth, generally yellowish brown, coarse textured loamy sand with common occurrence of gravels and pebbles. Depending on the water resource and shallow soil resource of the Stakmo fan, a large portion of the area is utilized for cultivation of barley and also different type of vegetables and simultaneously used for orchard .The Stakmo nala provides the water to the whole Stakmo village. More than fifty families live in the village. There is a large stretch of barren land which is being converted into agricultural and built-up area. Though different literatures (Patel *et al.,* 2008; Dame *et al.,* 2019)also have described the rapid conversion of barren land into built-up area in the entire Leh valley. The present researchers have evidently observed the geomorphic signature of the 2010 flash flood along the Stakmo nala (figure 6C&D) in its upper reaches where the cloud burst resulted into significant vertical and lateral cutting increasing the channel width along with a sharp axial incision of Stakmo bed. The feeder nala (Stakmo nala) has actively eroded its bank in the form of toe erosion. The feeder channel is filled with granitic gravels in heterogeneric size (figure 6C) that studied by the authors during field survey. The flash flood events have brought lots of fresh gravels and boulders in the channel of Stakmo. Prominent breaks in longitudinal profile of the nalla has been observed from the field survey .According to the local source, at the upper reach of the dry fan ,mainly extensive part of the left bank was totally washed away in form of debris flow by the devastating 2010 flash flood. Distinct altitudinal variation in between the both sides fan surface of the river clearly indicates that (figure 3). Plantation of Willow trees are seen in different parts of the village. There is an extended part of barren land covered with lag stone and deep weathered (figure 6F) rocks mainly in the upper part of the fan area. Organised irrigation network of earthen channels (called 'yuras') are constructed to properly distribute (figure 7A) of Stakmo river water into agricultural fields.Stakmo river water is the only source of irrigation water. Prominent agro-based livelihood of the villagers has been observed during field survey in September, 2014 by the authors (figure 7C&D). Apart from the agriculture they depend on animal husbandry. Along the elongated dry fan (figure 8) different types land utilisation patterns are observed. In order to understand the capacity of the Stakmo nala at its maximum flow analysis of sediment size in terms of bed load was done in random sampling approach. About fifteen samples of bed loads along the nala about 969m. reach from the fan apex were studied. In this reach , maximum intermediate axis of bedload was found 2.1m.(granite) and minimum was recorded 0.3 m(granite).About 86.66 percent of bed loads are granite and 6.66 percent of bed load are basalt and dolerite respectively .About 53.33 percent of surveyed samples were elongated in shape. Apart from it, platy (13.33%) , rectangular (13.33%) and

Figure 6: Different landform features in Stakmo nala basin; (A) dells or small dry valley (B) Stakmo amphitheatre valley (C) Stakmo channel characterised with heterogeneous size of sediments over the upper part of Stakmo fan (D) Prominent channel incision due to cloudburst,2010. (E)Moraines. (F) Deep weathered upper part of the basin. (Source: Field observation, 2014)

Figure 7: Important land use pattern along Stakmo nala;(A) Man-made irrigation channel and barren land used for plantation (B) Way to Stakmo Gompa. (C) House type and fencing with boulders as land divide in Stakmo village.(D) Agricultural field observed in Stakmo village.(E) Location of the Stakmo primary school and village road in Stakmo valley. (F) Human induced check dam to store Stakmo nala water for drinking and irrigation purpose. (Source: field survey,2014)

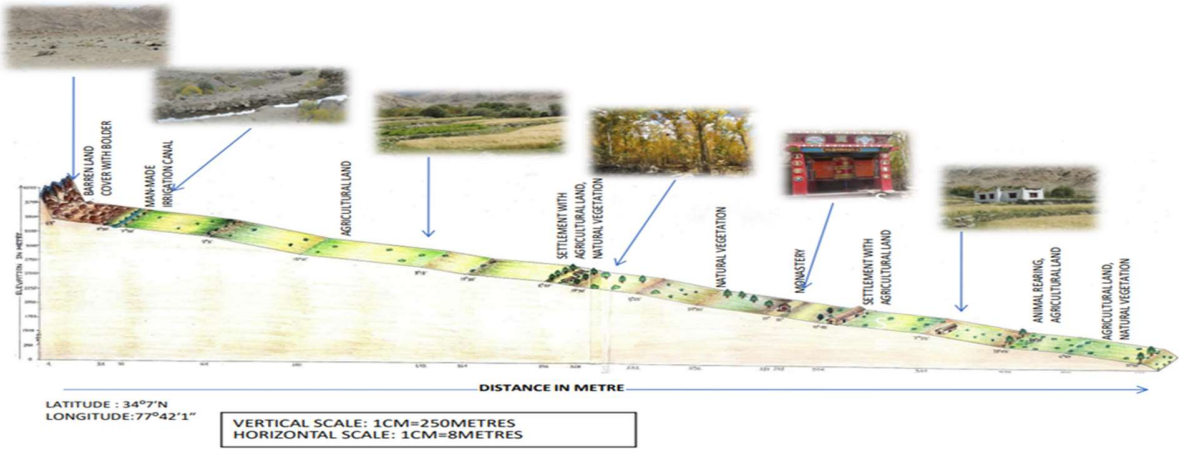

Figure 8: Diagrammatic illustration of the Stakmo dry fan showing land cover land use types (source: field survey, 2014)

circular (13.33%) shaped samples were also observed respectively (table:3). Based on field data analysis and observation of nala bed sediment sizes it can be understood that the main source of nala bed sediments are glaciated moraines and those heavy loads are mainly transported by mass wasting process specially by flash flood events.Though, according to the views of the local people, as a result of glacial melting and lesser trend of snowfall, the amount of water flow in the nala is gradually decreasing compare to earlier condition.

Major findings:

Based on the above study some important findings have been observed. Those are;(1)Naturally, in the high altitude cold desert environment there is an acute scarcity of surface as well as ground water resource. Hence, extensive area is under barren land. (2) Presence of the Stakmo nala is the only reason to develop the village and its different land use pattern. The snow melt water of the nala is the main source of drinking and irrigation. (3) The result of the morphometric techniques of the Stakmo basin clearly suggest the fan topography which is influenced by mainly glacio-fluvial processes. (4) Apart from the river Indus, there are many nalas (Taru, Phyang, Khardung, Sabu, Stakmo, Nang etc) that play significant role to develop elongated and slopy dry fans over which many settlement areas have been developed depending on its water and sediment resources.(5) Based on secondary sources and field observation the authors have identified dry Stakmo fan and its vivid geomorphic features. The upper portion of the fan clearly indicates a prominent amphitheatre valley and the downstream area an elongated dry fan has been developed, which is topographically and hydrologically favourable for the development of Stakmo village. (6) Considering the wide ranging role of the Stakmo nala on the physical and cultural environment of the village scientific nala basin management can be introduced to minimise the intensity of hazards like soil erosion and cloudburst induced flash flood etc.

Conclusion

It is true that the Stakmo nala is not so significant like river Indus in the entire Leh valley but undoubtedly, the nala has pivotal role for providing sustainable resources like; favourable fan topography, surface and ground water resources, riverine alluvium, natural vegetation etc. Depending on those natural resources the entire Stakmo village and the livelihood of the villagers have been established. Water of the Stakmo nala is the key issue behind the socio-economic activities of the villagers like; agriculture, plantation, animal husbandry etc. Like Stakmo nala other nalas have also significant role in establishment of many other villages and settlement area in the entire Leh valley. In near future there is a possibility in decline of the amount of the nala water due to deglaciation or the demand of water by the local people may exceed the

level of availability. In this possible adverse situation the existence of the village may be under threat. So, the local people, planners and researchers have great challenge to develop the alternative sources of water resource availability in the Stakmo and other villages of the Leh valley for the sustainability. In this regard proper management of the nala basin including snow resource management can be an effective planning for the sustainability of the nalas.

Conflict of interest

The authors declare that they have no conflict of interest.

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