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RESEARCH ARTICLE

Active Tectonics Influence on the Evolution of Drainage & Landscape: Geomorphic Signatures in the Punad Gadhera Watershed of Alakhnanda Basin, Uttarakhand, India

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Abstract

Punad Gadhera is a small left bank tributary of river Alakhnanda converging near Rudrapryag town. The watershed is part of Lesser Himalayan region; predominate by Mesoproterozoic Garhwal Group of lithological formations located to the south of Alakhnanda Fault. The region is tectonically active due to ongoing Indian-Eurasian plate collision. This paper tries to contemplate the fluvial geomorphic signatures as evidences of ongoing structural movement in the Punad Gadhera region.Investigating geomorphic expressions of drainage pattern such as river meander, confluence angle, channel direction etc., provides an insight on understanding the complex interaction between internal and external forces of the Earth. It assists in understanding the dynamics of tectonic movements and temporal changes in Landscape evolution. The present study was conducted using, topographical maps, aerial photographs, satellite imageries, ground thruthing through field observations etc. Drainage basin anomalies in the region depict a strong structural control on the over lying Fluvial Landscape.

INTRODUCTION:-

The Himalayan orogeny Epitomizes one of most dramatic and visible creations of modern plate tectonic forces in the geological time scale. Stretching for about 2400 kms these ranges are product of prolonged continental-continental collision and incessant denudation that continues even today, at rates varying from 44 to 61 mm/year (Minster and Jordan, 1978). Fifty Million years after its first collision with the Eurasian plate, the Indian Plate is still on its relentless journey northwards, which make the whole region structurally fragile and susceptible to constant tectonic activity.Ongoing tectonic activity is well indicated by moderate to large magnitude earthquakes, as well as prominent tectonically controlled geomorphic indicators. Numerous studies in the Himalayan domain have recorded geomorphic expressions like displaced and warped late Pleistocene and Holocene surfaces along active faults in the frontal zone (Nakata, 1989; Valdiya et al., 1984; Valdiya, 1992; Yeats et al.,1992; Lave and Avouac, 2000; Kumar et al., 2001; Malik and Nakata, 2003).The influence of active tectonics and fault displacement in landscape evolution is indicated through the development of canyons/deep narrow gorges, entrenched channels and waterfalls along the zones of active faults, (Valdiya, 1996, 1999; Nakata, 1972).

Mountain Building is superlative which highlight a complex dynamism of Earth's structural forces i.e. network of highly scale-dependent interaction of climate, tectonics and surface processes. The existing relief is the consequence of imbricated crustal sheets (Schelling and Arita, 1991). Each mountain range correlates with a thrust sheet of the Main Central Thrust (MCT), the Main Boundary Thrust (MBT) and the Himalayan Frontal Thrust (HFT), which delineates the northern limit of the exposed Indian Plate. It is being observed that due to ongoing northward movement of Indian plate the zone of deformation has successively migrated southward from the MCT (Main Central Thrust) to the MBT (Main Boundary Thrust) and then the HFT (Himalayan Frontal Thrust) (Schelling and Arita, 1991; Delcaillau, 1992) resulting into intense faulting and folding along these zones. These tectonic features mark the major lithological as well as geomorphological boundaries in the area. However, understanding the geodynamics of mountain building and topographic evolution is quite challenging, although there are several geological and geomorphological evidences which indicate ongoing tectonic activity along the

MCT and MBT mainly in the lesser Himalayan region (Valdiya, 1980; Seeber and Gornitz). Many conceptual models indicate that understanding the process of landscape development, surface erosion, unfolds many mysteries of geological past (Riquelmea et al., 2003). The relationship between active faulting and the offset of recent alluvial surfaces or stream terraces has been successfully used to identifying active faults systems (Gaudemer *et al.* 1989, Jackson *et al.* 1996,Audin *et al.* 2003).The shape and the structure of the drainage constitute a response to the upliftment process, more or less modulated by lithological parameters (Jackson and Leeder (1994).

Therefore, investigating geomorphic expression of the drainage pattern in any mountain building provides plethora of facts which not only assist in detecting the spatial- temporal changes in landscape development but also help in monitoring, recognising the pattern of tectonic movements.The evidences of such active tectonics is preserved as distortions in normal course of drainage channels, like changes in confluence angle, course direction, formation of compressed meanders, hogback channel course etc.

STUDY AREA:-

Emanating from the Satopanth glacier, Alakhnanda is one of the most extensive river water systems in the country pertaining to its length and volume. There are numerous big and small streams which join Alakhnanda before it finally confluences with Bhagirathi at Devpryag to form the mighty Ganges. Punad Gadhera is one such, small left bank tributary of Alakhnanda River joining it from south, near Himalayan town of Rudrapryag in Uttarakhand. The V^{th} order subsequent stream originates from southern flank of the anticline and south eastern peak of Dob-2(2800 MSL). Flowing northward for about 15.43km it smoothly joins Alakhnanda River at 627 MSL. The total area of the watershed is about 39.13 sq. kms, located between $30^0 12'N – 30^0 18'$ N and $78^0 58'$ E – $79^0 3'30''$E with an average relative relief of 1750 m decreasing from south to North. (Figure - 1).

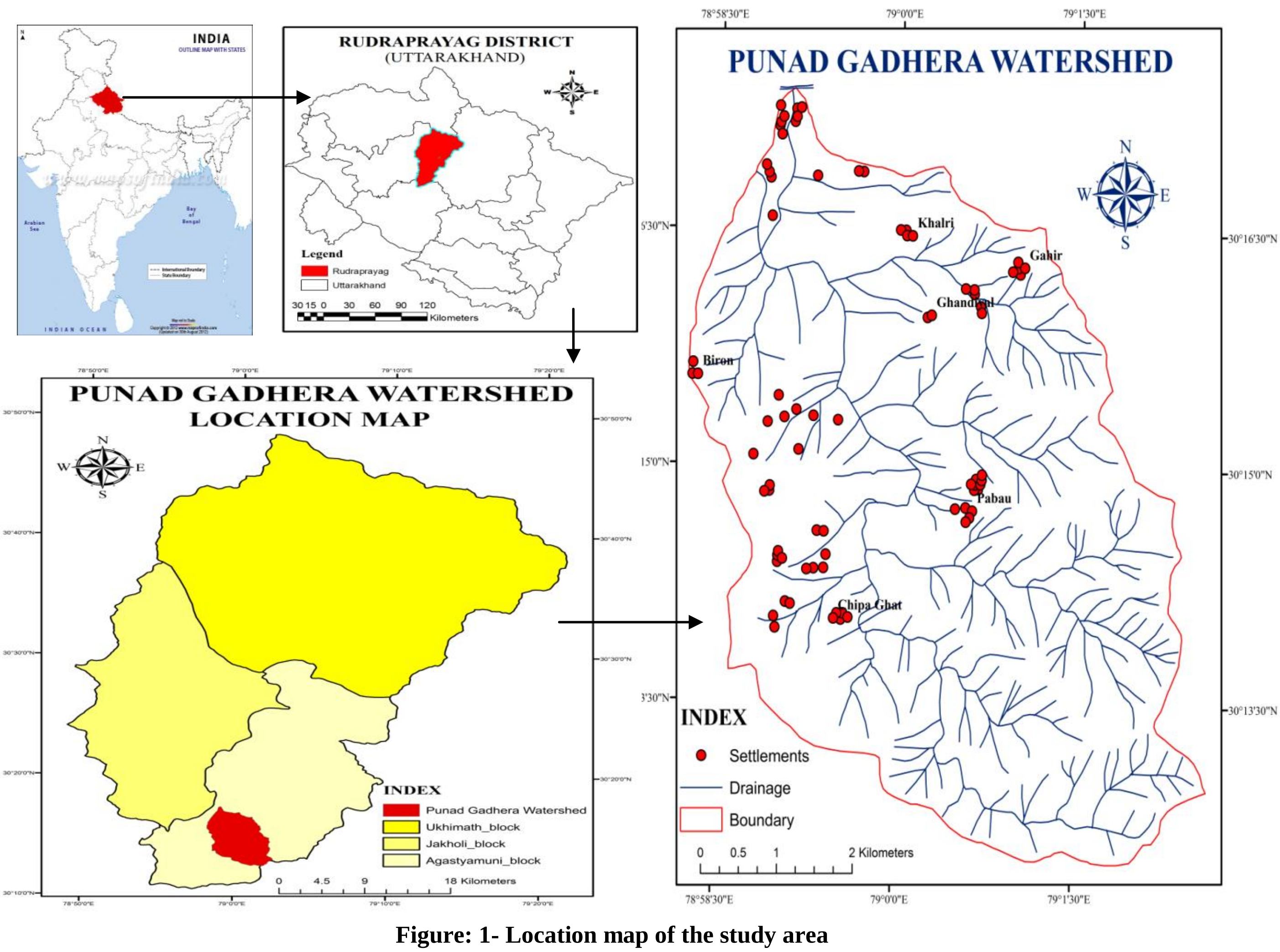

Figure: 1- Location map of the study area

MATERIAL AND METHOD:-

For several decades the geomorphological indicators have been used as one of the most powerful tools to delineate tectonically influenced landscapes, and these features have been extremely helpful in deciphering the role of tectonics in the evolution of the landscape. Prominent indicators are the development of a sharp morphology along active fronts, mountain front sinuosity, entrenched channels, or a high degree of incision along the channels flowing across active faults, the formation of linear valleys along fault traces, a sudden change in channel morphology, a sudden change in the base level of the channel floor – marked by pronounced knick-points in the river profiles etc (e.g. Bulland McFadden, 1977; Bull, 1984; Seeber and Gornitz,1983; Ouchi, 1985; Wells et al., 1988; Rhea, 1993; Schumm et al., 2002; Silva et al., 2003; Riquelmea et al., 2003; Bishop et al., 2003).The present study attempts to present the observed geomorphologic responses as tectonic changes in a small watershed of Lesser Himalaya.

To study the geomorphic responses in the highly stressed zone of the Lesser Himalaya, a small watershed known as Punad Gadhera was selected. The geomorphic and hydrographic features of Punad Gad were delineated using Survey of India (SoI) 1:50,000 topographic maps, along with remote sensing data of LANDSAT 5 satellite imagery with 30 metres resolution, and Google Earth web images. Field survey using portable handheld Garmin Montana 650 GPS has been conducted for ground thruthing. The spatial mappings of active faults and fluvial distortions (drainage patterns, changes in river course) have been done using Arcgis 9.1 software.

RESULT AND DISCUSSION:-

Punad Gadhera Watershed is located to the south of Alakhnanda Fault in Lesser Himalayan region of Rudrapryag district in Uttarakhand. The lithology is dominated by Garhwal Group of rocks mainly belonging to Mesoproterozoic geological Era. Garhwal group of rocks consists of Sandra, Deoban (upper, middle and lower) and Damta formations. The Garhwal group consists of ferruginous quartzite, phyllite, slate and dolomite limestone rocks. This sequence is characterized by extensive occurrence of meta-basic rocks. Arenaceous, carbonaceous and micaceous three types of phyllitic rocks are well exposed in the study area. Large number of folds, fractures, faults, lineaments and joints control the drainage landform pattern of the watershed. The major stream follows the synclinal axis of folds. The thrusts and faults have changed the course of the stream at numerous places, which has become and the sinuous in nature.

Geology and Tectonics:-

In existing complex landscape, 4 groups of geological strata can be identified, i.e. Chandpur Formation, Deoband (Gangolihat) formations, Nagthat (Berinag) formations, Rautgara formation. Two thousand (2000) metres thick Chakrata formation is over layered by 2900 metres thick Rautgara formation which is mainly composed of Quartz-arenite, sublitherenite and purple shale with abundant mafic sills and dykes. The Rautgara Formation is well exposed along the Srinagar – Rudrapryag section in the Alakhnanda valley and present in north western and central region of the watershed (Figure 2) It is correlated to a sequence of massive cream coloured, purplish and brownish fine grained quartzite inter bedded with purple green mottled slate and calcareous phyllites exposed in Saryu valley of Pithoragarh district by Valdiya (1962).South Eastern region adjoining the Rautgara formation is Dominate by Deoband Group overlying Damantha series of rocks, presenting sharp change from siliclastic to carbonate facies (Tiwari & Sial, 2007).Usually in the Lesser Himalayan sequences, the areas dominated by Stromatolite bearing Shelf Facies, dolomite and dolomite limestone are called Deoband Gangolihat formations (Valdia,1980).

The Mesoproterozoic, thick Chandpur formations covers 26% area of the watershed towards the southern heights. It is 2000 metres thick sequence of Meta grey wake, meta siltstone, slate, phyllites and local carbonaceous grey phyllites.It is also composed of tourmaline biotite granite and is made up of hypidiomorphic granular aggregate of feldspars (microcline and plagioclase) and quartz with subordinate greenish biotite.It’s conformably overlain by Mid Proterozoic (850 ± 630ma) Nagthat formation covering 18% of highly rugged eastern topography of watershed. It is 1400 metre thick (Pant &Shukla1999) succession of quartzarenite associated with pene-contemporaneous mafic lava flows (Valdia, 1980; Ghosh, 1991).Presence of ortho-quartzite silicatic litho-facies with interlaying mafic sills has led many to correlate it with the Berinag Formations. The Depositional system of Nagthat is Interpreted as fluvio-deltaic (Rupke1974) and shallow marine (Valdiya,1980).These series are etched by east west running fault line in the region and Thrust line delineating it from Deoband Gangolihat series along the eastern part of the watershed which makes the eastern region more tectonically fragile. Evidence of faulting in the study area is marked by sagging of displaced beds, alignment of pebbles, shearing and formation of gauge.

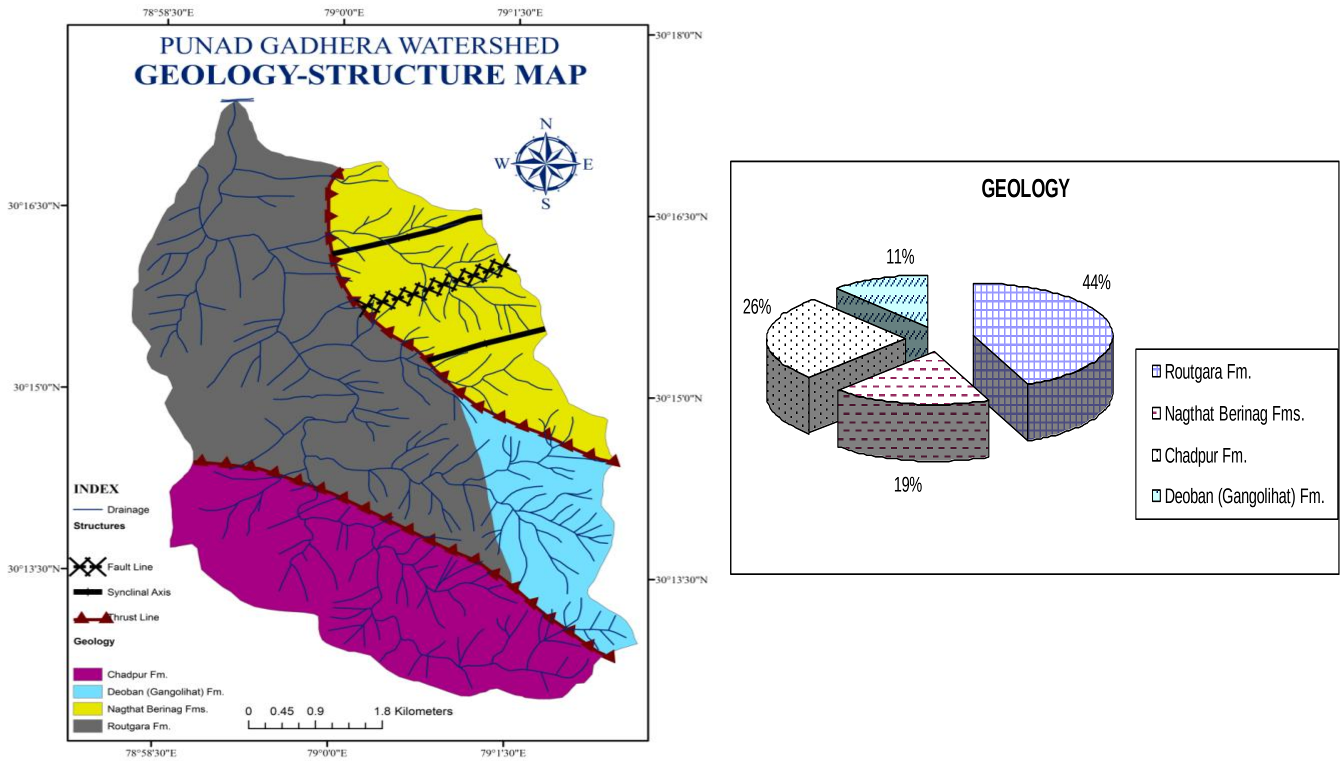

Figure: 2- Geo-structural map of the area

Engraved with such varied geological formations along with ongoing tectonic activity, Punad Gadhera stream channel creates unique geomorphic formations to identify the course of landscape development in the region. The origin of 5th order Punad gadhera subsequent stream itself highlights the structural unconformity of the region because it emerges from flank of the anticline and joins the master consequent stream (Alakhnanda) almost at right angle. Subsequent streams arise subsequently to the establishment of consequent streams starting as gullies on the sides of primary consequent valley, discover and explore the belts of structural weakness, due to multiple soft strata, faults, planes and shatter zones (Woolridge & Morgan, 1960, pp 173-74).These streams are not only indicative of the chronological sequence but define functional relationship between drainage on one hand and geology, structure and tectonics on the other (Ahemad 1985).

Longitudinal profile of the stream is concave with steep gradient of < 60 ° near the head and gentle gradient > 4° at the confluence zone. The gradient becomes gentle after 1500 meters, marked with structural terraces on both sides of the channel. The channel profile clearly reflects the geomorphological anomalies through presence of faulted stream course, change in course direction, length, and size of channel. The Drainage density is high along the Eastern slopes and decreases towards the western and southern Margins of the watershed, mainly due to high relative relief and very steep slope gradient in the western zone. (Figure-3) The major geomorphologic feature of the watershed is deep vertical gorges and "V" shaped valley throughout the channel course. The basic reason of such smooth profile curve is that the stream flows through quartzite resistant terrain for almost 2/3rd part of its entire course. Episodic folding and compressions is visible through formation of compressed meanders in the middle course of the profile. Presence of Thrust line along the South western and north eastern region of the watershed is marked by steep slope gradient and high relative relief in eastern and Western regions. The differential movements along existing faults and thrusts have produced tilting that triggered channel avulsion, creating numerous geomorphic anomalies.

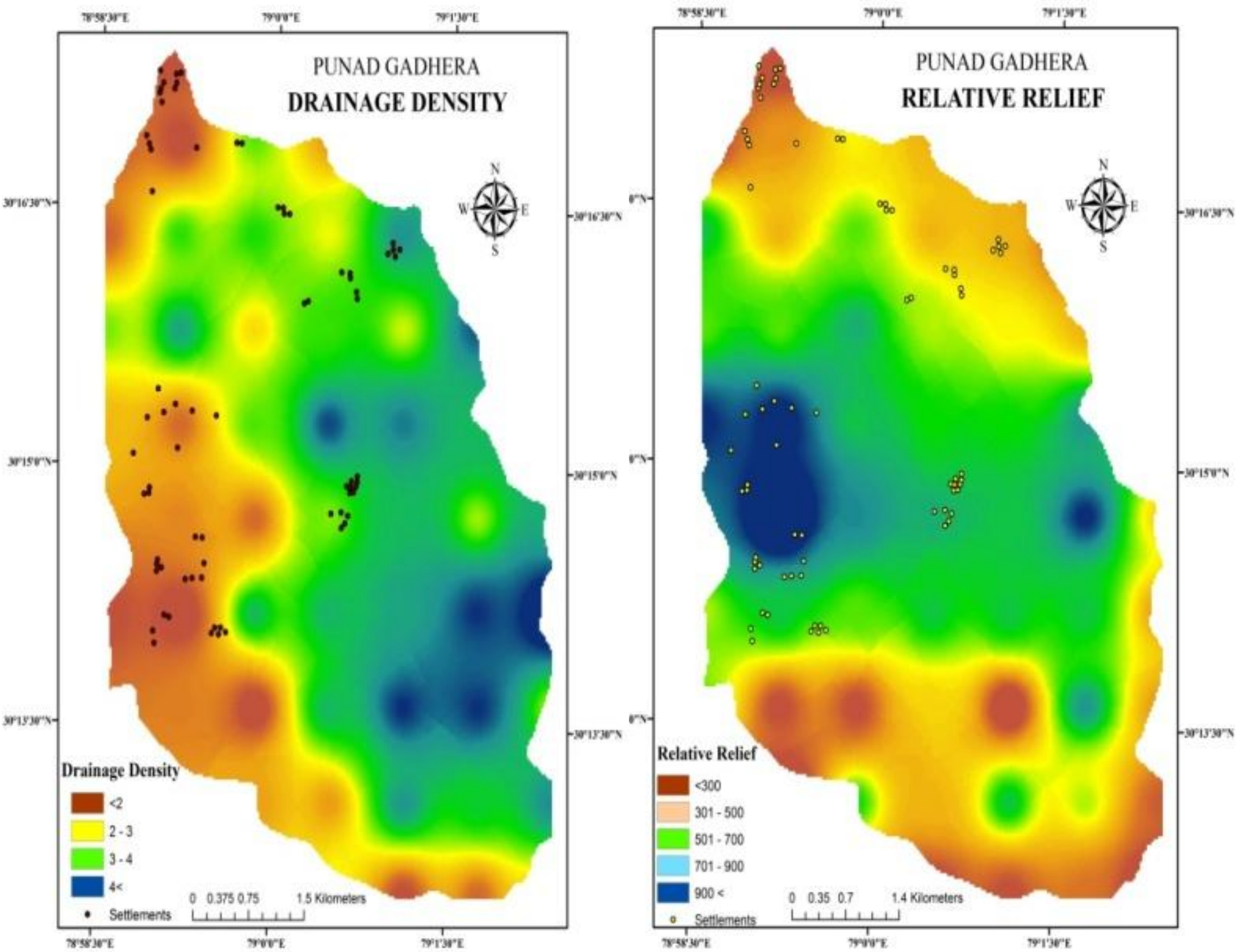

Figure: 3- Geo –structural map of the area.

Tectonic influence on evolution of landscape and drainage anomalies:-

Based on the study the following anomalies can be recognized in the study area.

Compressed meander:-

The Rivers responds to upliftment by increasing its sinuosity, thus producing array of compressed meanders. The type of anomalous occurrence of compressed meanders in other wise normally flowing drainage system have been demonstrated to be indicative of active tectonics in zone of active in zones of structural compression(Valdiya 1989,Barooah and Bhattacharya 2001). Northward flowing stream is suddenly deflected into a semicircular loop bending towards north east and then North West. Compressed meanders can be observed between Chin Gwar and Ranigarh village along the stream course (Figure-4). There are 3 major faults and 5 minor faults disturbing the river course within 2 kilometers, embedded by the numerous lineaments. All these faults are in South-East to North-West direction. These major and minor faults have compressed the river in the region.

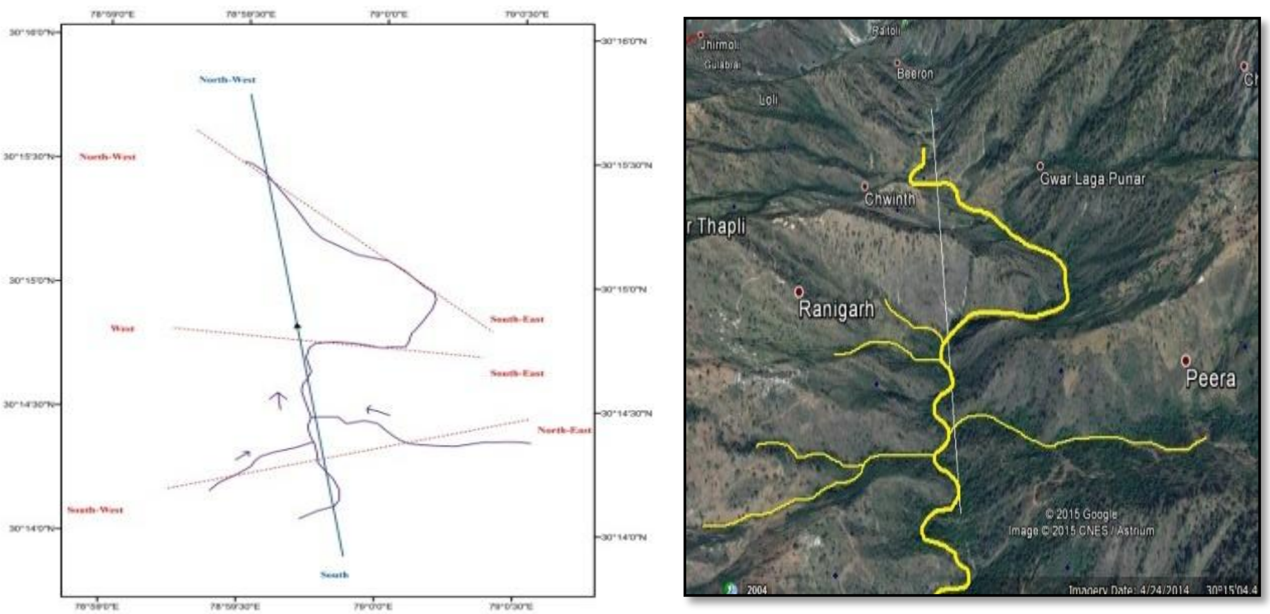

Figure: 4- Compressed meanders

Faulted Course:-

This is the simple pattern of the river course, which is found easily in the mountainous river system. The stratified rock structure and underlying faults create a complex lithological landscape which is reflected through drainage anomalies, resulting into increased sinuosity and curved path. Faulted course of the stream is clearly depicted along the faulted lineaments and exposed rock fractures. The general south- north course of stream following the dip of the anticline is disturbed by south-west to north east Fault line which turns the river from south west to north east as shown in (Figure-5)

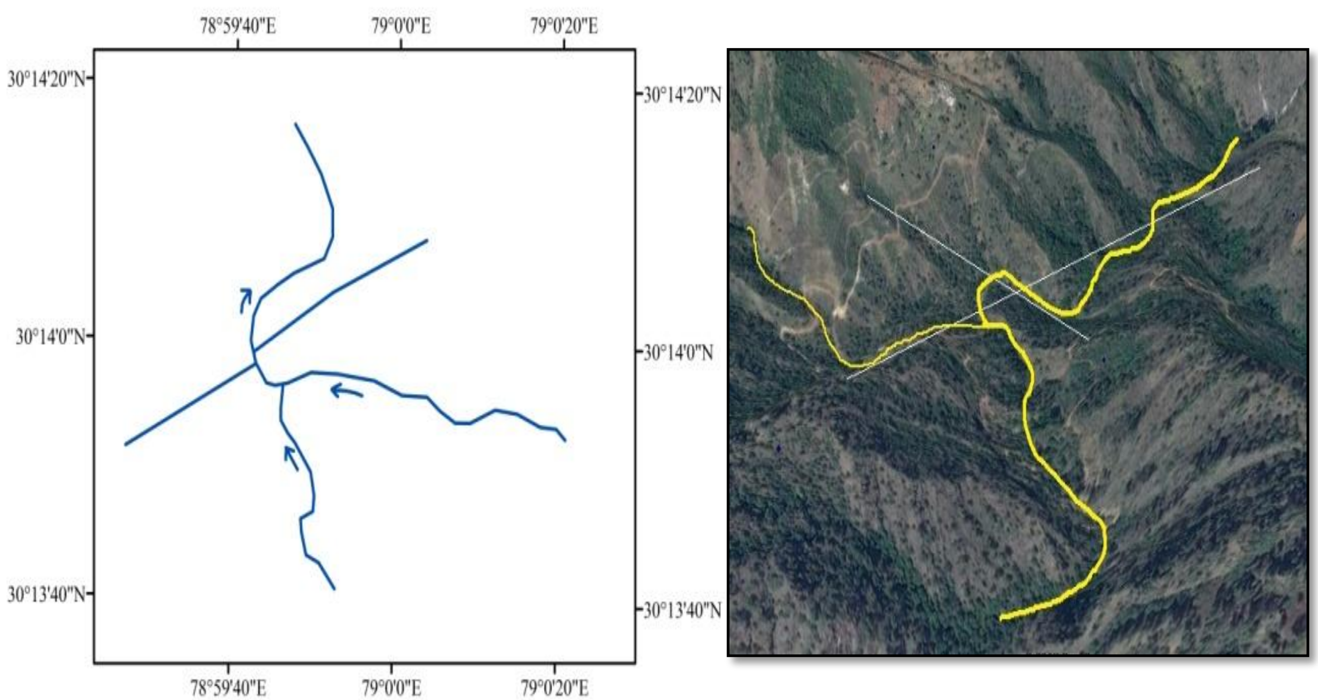

Figure: 5-Faulted course.

Pinching Course:-

This course is the product of complex geological set up dominated by numerous major and minor faults, fractures, which disturbs normal course of the drainage system. When the faults direction is found from many direction, there the river represent a muddled pattern modifying itself into consequent, subsequent, consequent and resequent patterns, All these sequential drainage types are at times simultaneous to each other at one place. This condition is found near Chwinth and *Gwar Laga Punad* villages in the area. Here 6 major and other small faults lie from North-East to South-West direction within one kilometre distances, creating the sequent drainage system in the particular area. (Figure-6)

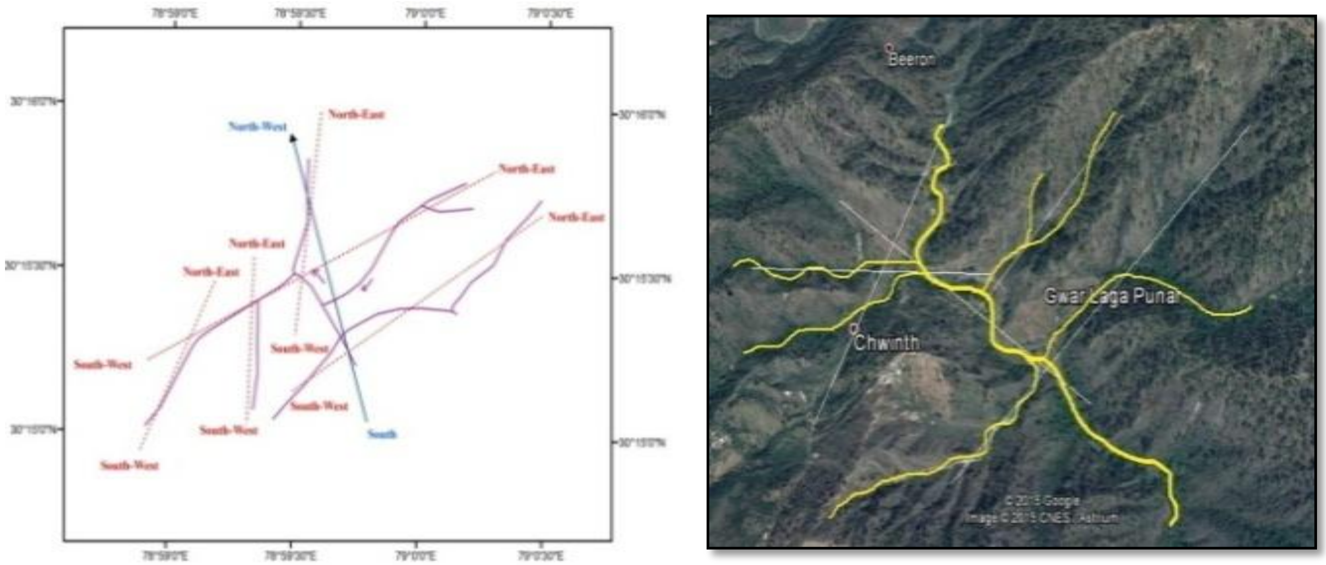

Figure: 6-Pinching course

Hogback course:-

Hogback pattern is like the elbow shape of the drainage pattern. This pattern is generally found in subsequent stream originating from Sharp ridge with steeply sloping sides in the Himalayan regions.When the tributary of stream merges in a right angle (90°) making elbow shape in steep sided slopes then this pattern becomes Hogback course. This condition is found in South-Eastern part of the watershed near *Khairpani* village below Dob-2 peak (Figure-7)

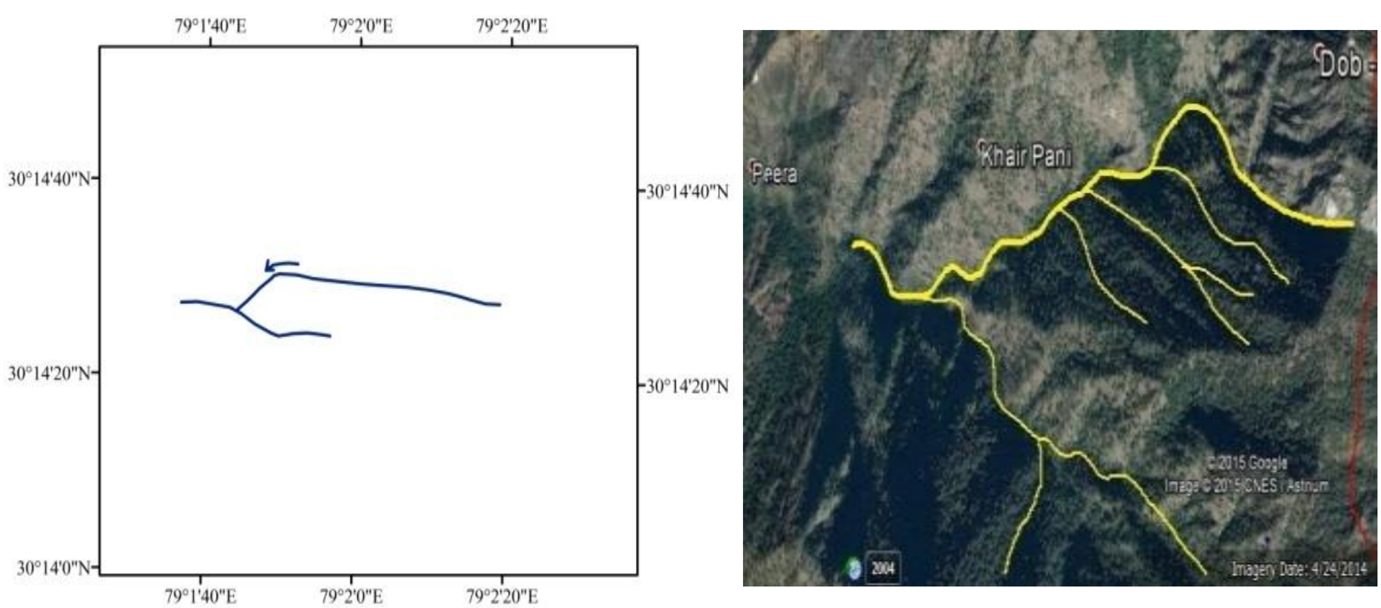

Figure: 7-Hogback course

Change in channel course:

It is the case of intense folding when the river channel abruptly changes its course, mainly because of the movement in under lying rock structure. Stream capturing during alternative deformation stage is evidence of active tectonics in the Himalaya.

Channel course direction:-

Generally, the tributary streams join in the main stream either from right angle or in the acute angle. But one of the typical examples of course direction is seen downstream of *Peera* Village wherein 3rd order stream originating from eastern peak merges with the main stream at an Obtuse angle (120°) reflecting that stream flows through some fracture lineament. Similar Faulted river course can also be identified in 2nd order streams near *Sri Kot Lagga Durg Village*.(Figure-8)

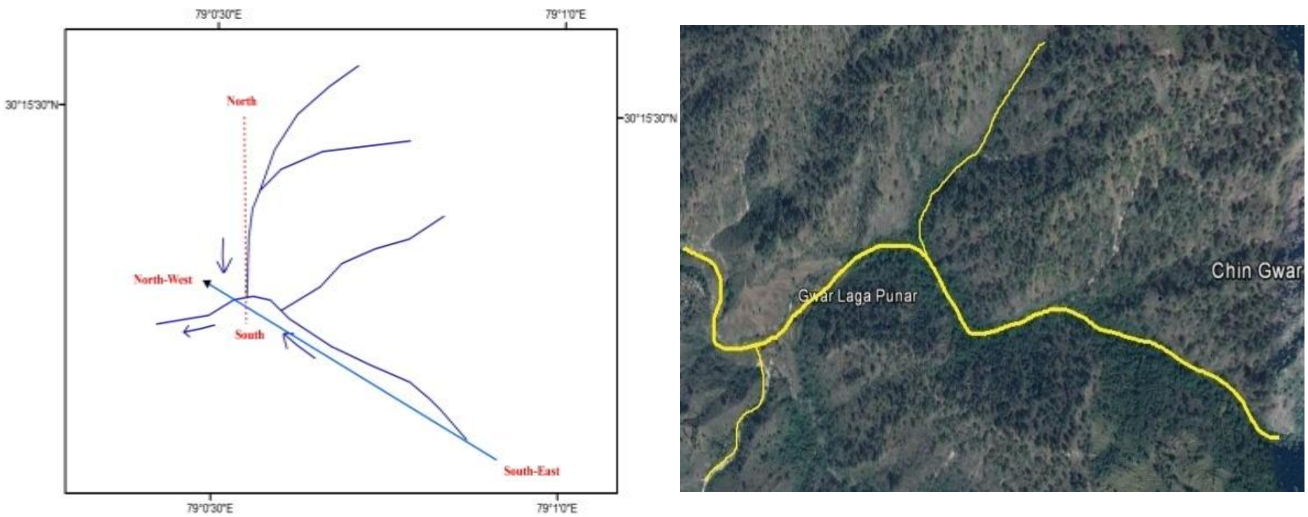

Figure: 8-Channel course direction.

Change in confluence angle:-

In this type of distortion the main stream is forced to join the straight flowing tributary due to structural displacement along the original course of the stream channel. The course of the tributary remains straight and undisturbed where as the main stream is shifted, curved to join its tributary at right angle. Such drainage anomaly is associated with upliftment of the underlying structure and can be observed down the slope of the *Loli* village along the middle course of the stream. (Figure-9) Out of these some other examples of confluence angle are also recognized in 3rd order and 2nd order streams of many locations where the later subsequent streams are forced to join the main stream due to lineament shift.

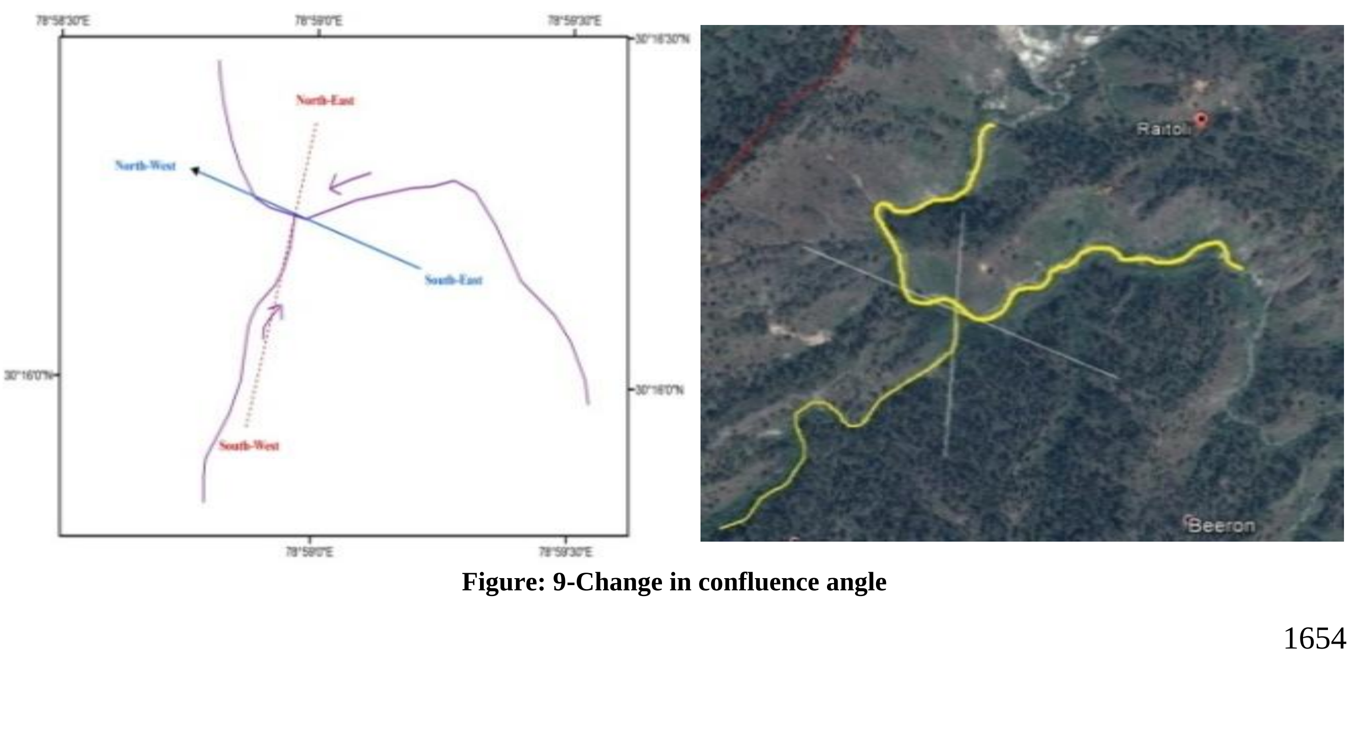

Figure: 9-Change in confluence angle

Change in length, order and area:-

The main stream have longer course, large areal expansion and rises from highest elevation, but this criteria cannot be applied in case of Punad Gadhera streams. The main stream originates from the southern heights of 2735 metres, upstream *Bansu* Village, while the tributary stream originates from much higher eastern DOB -2 Peak (2830metres). Intense compression and faulting near Ranigarh village has forced the stream to alter its original course lengthening its stream channel. Stream lengthening can also be created due to development of Hogback structure in the upper heights of the anticline resulting from folding. Changed order of stream can be witnessed between Punad Gadhera and its primary tributary. Here the tributary stream is of higher order (5th) while the master stream of the area is of immediate lower order (4^{th}) in certain places. It is also a typical drainage anomaly in the study area.

CONCLUSIONS:-

The purpose of this work was to highlight the geomorphic markers along the tectonically active zones in the lesser Himalaya. The region does not accommodate very high tectonic displacement, but surely preserves episodic structural compressions, movements in terms of geomorphic anomalies, showing a strong control of the former on the later. The fluvial terrain in the study area have responded and adjusted to slow and subtle active tectonic movements. A typical response to upliftment includes development of compressed meanders, convexity in longitudinal profile, pinching of streams, anti-flow direction, stream piracy, and frequent channel avulsions. It is affected by a high spatial variability of folding and sensitivity of the fluvial system to active tectonic processes, which are outlined by anomalies of streams channels and high asymmetry in drainage basins. Geomorphometry suggests drainage basins development in response to ascent and lateral migration of folding. Considering the existing geomorphic parameters, we demonstrate morphological data and drainage networks in an active frontal zone.

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