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Drainage characteristics of tectonically active areas in Wardha and Purna river basin, Central India using satellite data

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Abstract: The study area lies in the vicinity of north eastern part of the Salbardi fault which is one of the most important tectonic elements of the Son-Narmada-Tapti lineament trending in ENE-WSE direction. The drainage characteristics of the study area were investigated by using the IRS LISS III satellite data of 23.5 m spatial resolution and Shutlle Radar Topographic Mission (SRTM) Digital Elevation Models (DEMs). The course of Maru river is mostly controlled by the Salbardi fault and associated tectonic elements. The Maru river, which crosses the fault from north to south, exhibits two river terraces that rise and continue downstream, where the river flows on the downthrown block. The presence of dendritic to sub dendritic, rectangular and parallel drainage pattern in the study area shows the tectonic activity in the study area. Several parameters such as profile shape, gradient fluctuations and river grade and valley incision have been derived from longitudinal river profile.

Keywords: Tectonics; Remote sensing; topographical profile; morphotectonic indices

1. Introduction

Earth-observing satellites, airborne sensor systems, aerial and spatial data have almost the complete coverage of the Earth's surface that provides image data of different formats and various scales. This permits not only interpretation of landscape evolution, but rather offers the opportunity to integrate observation of a variety of processes over a large region. Geomorphic analysis from space has the advantage of allowing the use of quantitative methods for both data gathering and information extraction (Hayden, 1986). Thus, satellite images are becoming useful and necessary in geomorphology, especially in obtaining quantitative measurements and performing geomorphic analyses (Hayden, 1986; Ulrich et al., 2003). Conventional mapping of large thrusts extending for hundreds of kilometers is troublesome, slow and expensive. On the other hand, multi-sensor and multi-date remotely sensed data with ease of digital manipulation provide better synoptic view of the ground for mapping of recently developed features (Lillesaand and Kiffer, 1994).

Analysis of acquired information by means of photograph interpretation techniques, image image processing and interpretation which includes tone, texture, size, shape, association and pattern have been were used in rock type and geomorphic features discrimination (Sabins, 1987). Satellite imagery permits research at different scales, which is valuable in the investigation of lineaments and faults (Arlegui and Soriano, 1998). The integration of geographic information systems (GIS) and remotely sensed data could be more informative and results would be more applicable to image interpretation (Ehler 1992; Horsby and Harris 1992; Saraf and Choudhury, 1998). The IRS LISS III satellite data with 23.5m spatial resolution III and SRTM DEM data along with Survey of India toposheets have been used for detailed study of drainage and its characteristics the area. The recent advances in remote sensing technology have added new dimensions to the mapping of the geomorphological features from space (Bishop et al., 2012; Walsh et al., 1998). Information extracted from remote sensing data provide a synoptic view of terrain features and enable mapping of inaccessible terrain in a timely and cost efficient manner (Hengl and Reuter, 2009; Pike, 2000). Various researchers have used satellite data for the geomorphological mapping in India (Bhatt et al., 2007; Singh et al., 2007; Singh et al., 2013; Rashid et al., 2016).

Fluvial terraces are topographic platforms or benches in the river valley that usually represent former level of the valley floor or flood plain. Consideration of the internal composition of the terraces which cut in to valley contribute significantly to understand the evolutionary trends and origin of the terraces. Terrace reflects in two parameters, namely the base level and energy, which may change independently or together. Two fundamental categories of the fluvial terraces exist, namely erosional and depositional. The former are formed by the erosion of preexisting formation and later result directly from accumulation of stream deposits. According to McGee (1891), these are terraces of destruction and construction

2. Study area and river drainage network

The study area lies in the Survey of India toposheet No.55 k/2, 55 k/3, 55 G/14, 55 G/15 and bounded by latitude and longitude 21^0 20' to $21^0$35' N and 77^0 45' 78^0 10' E, respectively. The area for the present study is divided in to two parts: Part one falls in the state of Maharashtra while the other falls in the state of Madhya Pradesh (Fig. 1).

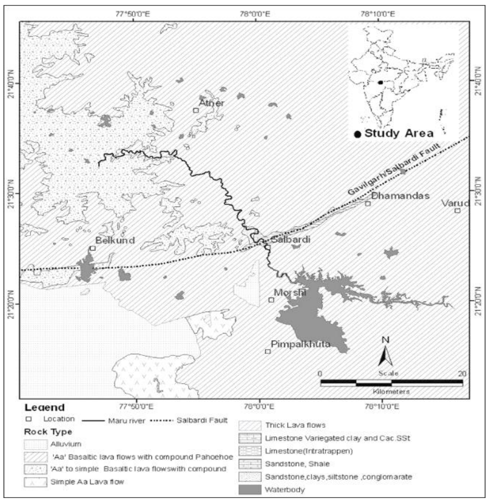

Figure 1: Geology and location map of the study area (GSI, 2001)

Salbardi and adjoining region comprise the four important rivers namely Wardha, Tapi, Purna and Maru. The study area covers the complete drainage network of the Maru river. The Maru river flows in the central part of the study area while some the tributaries of Tapi river drain the northern part. Similarly, the tributary of Purna river drains the south western part while the tributary of the Wardha river occupies the southern and south eastern part of the study area.

3. Geology and tectonic setup of the of the study area

Geologically, though the area is occupied mainly by Deccan trap, the rocks belonging to other ages also form an important part of the geological sequence. They vary right from base with litho units like granites, gneisses, quartzite and felspathic gneisses which followed by Upper Gondwanas and Lametas belonging to Upper Cretaceous period. This formation is unconformably overlain by Deccan trap which in turn is overlain by the alluvium of Quaternary period. The study area is located in north eastern part of the Gavilgarh / Salbardi fault which is tectonically active element of the Son-Narmada-Tapti (SONATA) lineament and Gavilgrah / Salbardi fault (Ravi Shankar, 1987; Saxena, 1994; Tiwari, 1985; Umak, 1992; Chattopadhyay et al., 2008; Manjare, 2013) which is straddling across the India shield in ENE-WSE direction (Fig. 2).

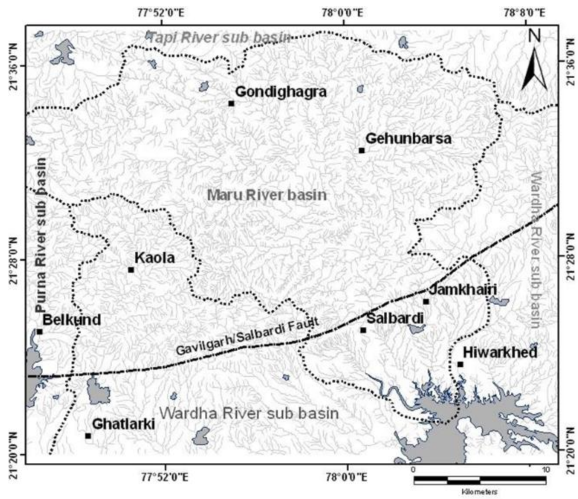

Figure 2: Drainage map of the study area

4. Methodology and data used

The present study is based on the remote sensing spatial data as well as the non-spatial data available from the various sources for different periods. The Indian Remote Sensing Satellite IRS 1C Linear Imaging Self Scanner (LISS-III) image with 23.5m spatial resolution was used (Fig. 3). The SRTM DEM (Digital Elevation Models) data of 90 m. (Fig. 4) resolutions with survey of India toposheets were used to trace the drainage and topographically defined structures.

For making the Maru river cross section the first stage is to measure the width and area where the rivers menders with different topography. The gathered data can then be plotted to create a scale diagram of the cross-section, or used to find the cross-sectional area and wetted perimeter of the river. The cross section diagram can be used to calculate the cross-sectional area or wetted perimeter of the river, which are needed to find discharge and channel efficiency.

5. Drainage pattern of the study area

Drainage system is highly sensitive indicator of active tectonics (Jackson and Leeder, 1993). Tectonic deformation causes change in channel slope, inducing variations in channel morphology, fluvial processes

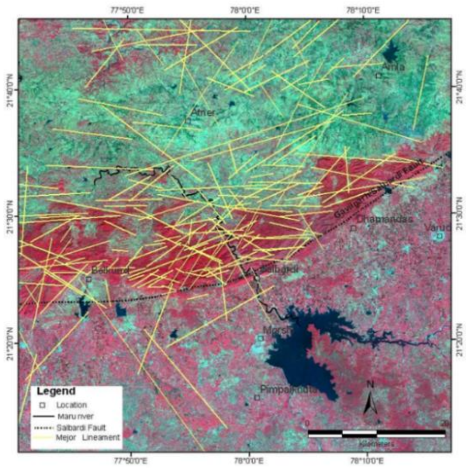

Figure 3: Representation of the Salbardi fault and study area on the IRS LISS III FCC

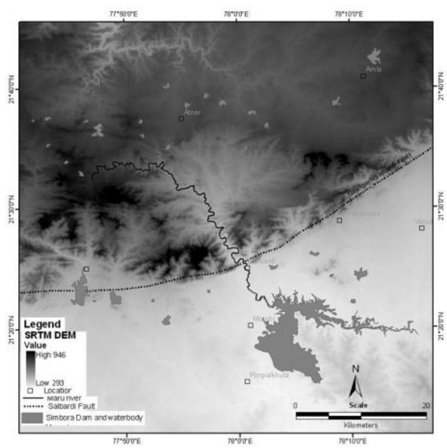

Figure 4: SRTM DEM (90 m) of the study area (Elevation value in meters)

and hydrological characteristics of a river system. Rivers in the foreland basin have responded and adjusted to slow and subtle active tectonic movements (Jain and Sinha, 2005). The evolution of landscape andtectonically produced slopes are further modified by the external forces through the process of erosion and deposition with the development of new deformational structures (Singh and Singh, 1992). Drainage system became accustomed to any small amends of surface morphology and witness in order about any structural deformations (Jackson and Leeder, 1993; Raj, 2007; Kale and Shejwalkar, 2008; Pati et al., 2008; Singh 2014; Prakash et al., 2016).

Maru river

The Maru river in its complete journey passes through highly dissected terrain with high slopes of Deccan trap formation. The course of the Maru river on the satellite image is very meandering (Fig. 5 A). The Maru river is in its youth stage and many geomorphic features are observed that are formed by the running action of water (Fig. 5 B). Further journey of Maru river flows southeasterly across the Salbardi fault and finally joins the Wardha at east of Morshi near Thana and Thuni village near Salbardi village. At the Salbardi and the river flows at the base of the morphological scarp produced by the Salbardi fault but a little upstream a sinister offset of the River course is clearly discernible. Downstream of Salbardi, the Maru river shows NE-SE trending straight reaches which are controlled by weak plain in Deccan trap basalt that floor the river. The river passes through the all Deccan basalt and reaches the southern boundary of Salbardi scarp (Manjare, 2013).

Figure 5: (A) Maru river meandering seen at Salbardi village; and (B) Erosional action seen on the bank of Maru river near Salbardi village

Dendritic to Subdendritic in the study area
Dendritic to subdendritic drainage pattern is the most common pattern formed by all four important drainage networks in the study area. It is characterized by a tree like branching system in which tributaries join the gently curving main stream at acute angles (Fig. 6).

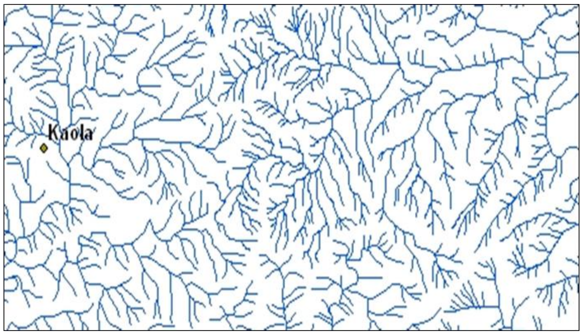

Figure 6: Dendritic to subdendritic drainage pattern observed near Kaola village

Parallel drainage pattern in the study area
Tributary streams tend to stretch out in a parallel-like fashion following the slope of the surface. A parallel pattern sometimes indicates the presence of a major fault that cuts across an area of steeply folded bedrock. In the study area, these type is present near to the Ghatarki which is near to the Salbardi fault (Fig. 7).

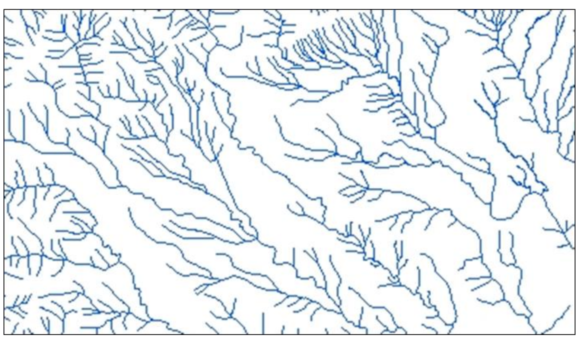

Figure 7: Parallel to subparallel drainage pattern observed near Salbardi village

Rectangular drainage pattern in the study area
This type of drainage also develops in regions that have undergone faulting. Streams follow the path of least resistance and thus are concentrated in places were exposed rock is the weakest. Movement of the surface is due to faulting off-sets the direction of the stream. As a result, the tributary streams make shape bends and enter the main stream at high angles and suggesting that the area is structurally controlled (Thombury, 1969). In the study area it is observed near Gheunbersa village (Fig. 8).

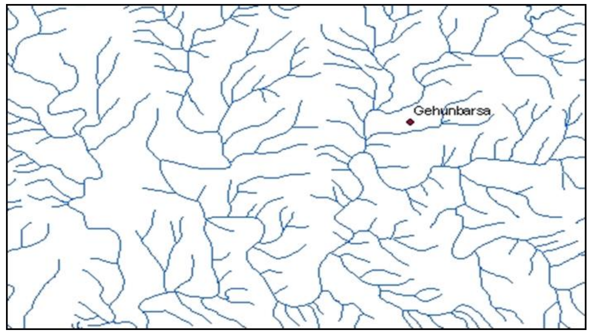

Figure 8: Rectangular drainage pattern observed around Gehunbarsa village (Modified after Manjare, 2013)

Longitudinal river profile
The semi-log plot of an equilibrium long profile is a straight line on the axis if the River is flowing across uniform bedrock (Hack, 1973). Overstepped reaches that cannot be explained by resistant lithology in the stream bed reflect disequilibrium conditions, and a common cause of such disequilibrium is tectonic disruption of the bed (Bishop and Bousquet, 1989). The utility of this parameter is based on the fact that irregularities in channel slope might reflect disequilibrium conditions, suggesting uplift along active faults. Upwardly concave profiles may suggest prolonged basin and channel degradation associated with longer periods of time since basement lowering. More upwardly convex profiles suggest fewer channels down cutting, continued base-level lowering or less time since base-level fall (Wells et al., 1988). Longitudinal stream profiles are plotted at 10 times vertical exaggeration in order to highlight any irregularities in channel slope. Long profiles were plotted for those streams that reach the drainage divide and transversely cross the main fault systems.

Longitudinal profile of Maru river
In the study area the Maru river originates from the village Mathudhana with its length is 56 km. The main and tributary stream is the result of different geomorphic processes with varying intensity. These profiles indicate the various stages and characteristics of the valley forms. Fluvial, lithological and tectonic processes dominate the existing valley forms. The longitudinal profile is an erosional curve, which can interpret the surface history and different stage of valley development from source to mouth (Tiwari, 1985). These methods assume that landscape is in steady-state or dynamic equilibrium such that erosion and river incision are equal to rock uplift. Such

longitudinal profile of Maru river shows accordant junction with the Wardha river at point *F* (Thuni village). Gradient of the Maru river from *b-k* is almost constant with insignificants knick points at *m-l* and *0* produced by appearance by bedrocks across the profile. *k- i* is the most prominent knick points followed by the *m-l* and *l-0*. Rejuvenation of the Salbardi fault is reflected in *k-i*, *m-l* and *l- 0* knick points are related to the earlier rejuvenation which has receded quite upstream. The *K-I* knick points are located in easily erodible Gondwana sandstone and not in more resistant rocks like Precambrian granite gneiss, basic dyke and Deccan trap exposed immediately downstream, also tectonic significance of the *K-I* knick points (Fig. 9).

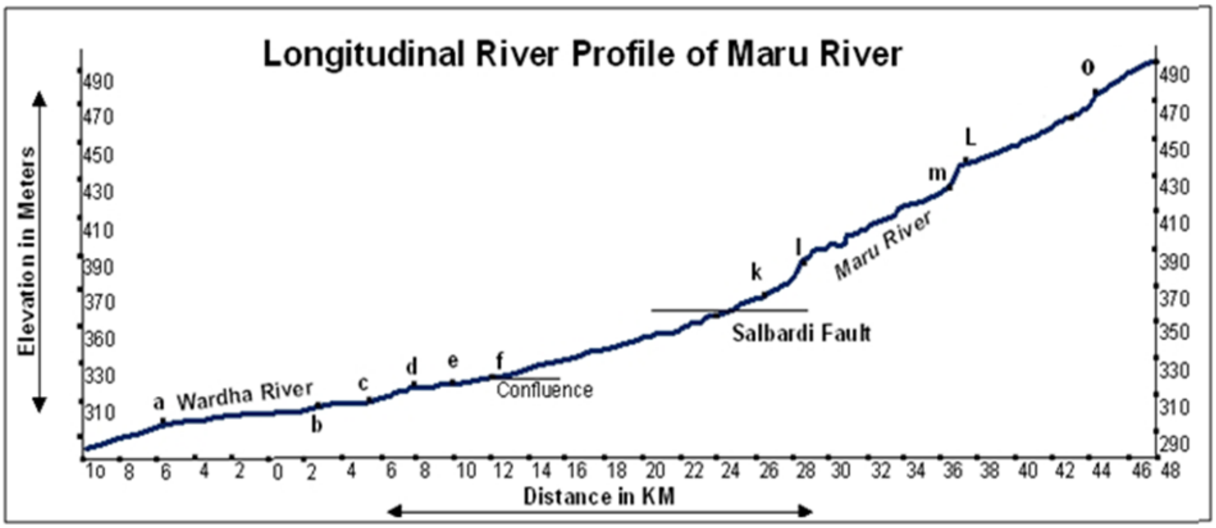

Figure 9: Longitudinal river profiles of Maru river (Fault cuts the Maru river near Salbardi village)

Maru river cross section

In the study area the section has been taken at two places i.e. section A-B and C-D (Fig.10 & 11) where the area is topographically different. The cross section along the A-B has been taken on the hilly tact of Deccan tarp which is lies north to the Salbardi fault. And C-D cross section on the Morshi surface which is plain surface present to south to the Salbardi fault. From the section A-B the river flowing the existing slope on one side while hilly topography on other. In section the C-D the river flows the slope on the both the side.

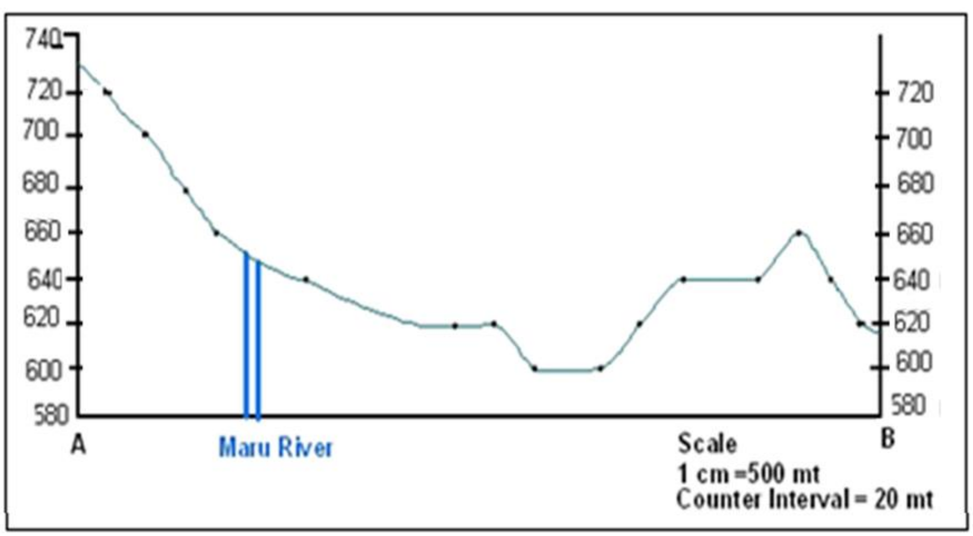

Figure 10: Cross section of Maru river along reference line A-B (Modified after Manjare)

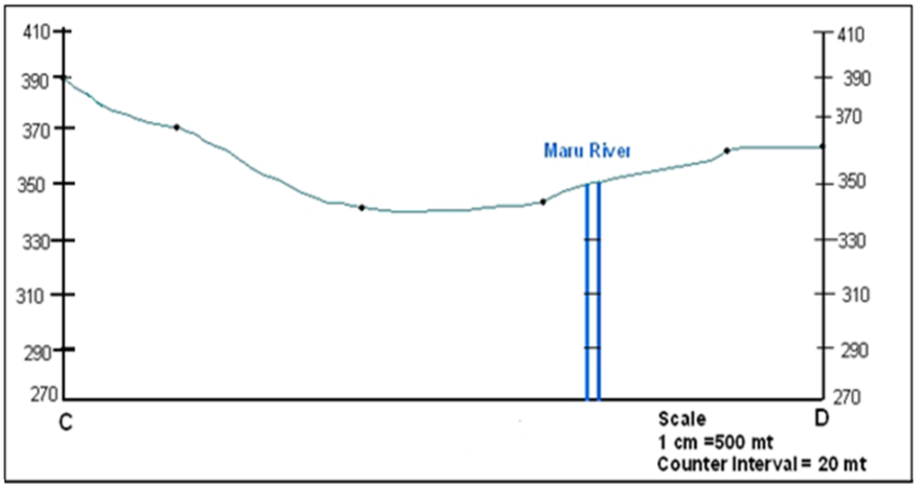

Figure 11: Cross section of Maru river along reference line C-D (Modified after Manjare)

Alluvial terraces

In the present study area the alluvial terrace of erosional type demarcated along the Maru river. These terraces situated on the right hand side of river channel, exhibits an unpaired nature. The terraces have been noticed at more or less constant heights above the present flood plain. The terraces T0 and T1 have been located along the Maru river near Salbardi village and Ghodev village (Fig.12 A).

Alluvial fans

Alluvial fans are formed when the sudden drop of energy and stream dropped the sediments and deposits as fans. In the study area, these landforms are observed towards south west, north east part of Salbardi village and also in small patches along the Salbardi scarp in north east and northwest direction (Fig. 12 B).

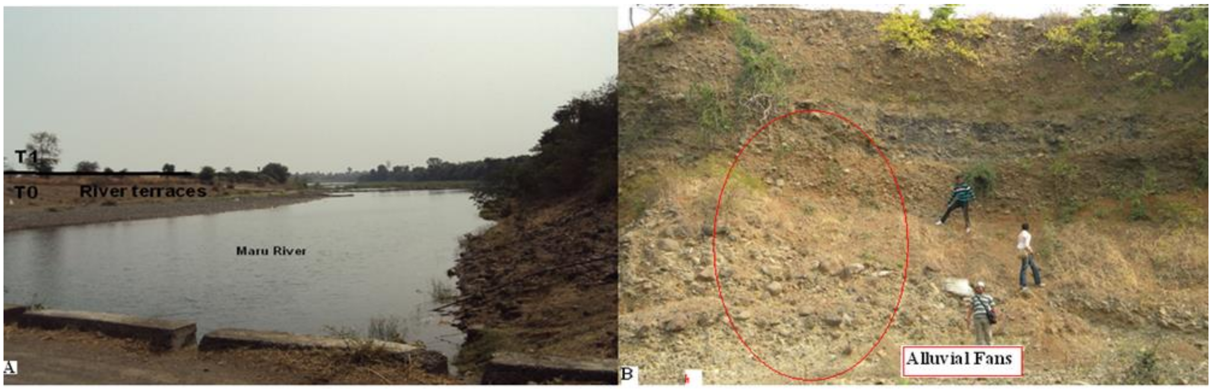

Figure 12: (A) Alluvial terraces seen near Salbardi village; and (B) Alluvial fans exposed near Salbardi village

River meandering

The meandering river, demarcated with the visual interpretation on the satellite image The important location of the of the meandering are near to the Salbardi, Pachmuri, Palaspani village (Fig. 13). In the study entrenched meanders is seen near Salbardi village. Rejuvenation occurs when the river's base level falls. The effect on rivers is to produce features called 'knick points' (which can be seen as waterfalls and rapids), river terraces and incised meanders (Fig. 13).

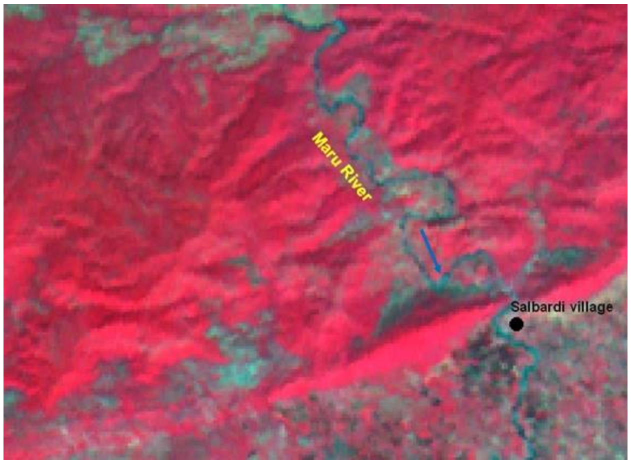

Figure 13: River meandering observed along Maru river on IRS- LISS -3 satellite image

Conclusion

The drainage of the study area is mainly controlled by the Salbardi fault which passing through the middle of the basin. The presence of the dendritic, parallel to subparallel drainage rectangular drainage pattern all together show the tectonic characteristics of the drainage. Alluvial fans at the base of the footwall of the mountain front are still receiving sediments at the fanhead and this indicates active tectonics in this area. The Maru river exhibits two river terraces that rise and continue downstream, where the river flows on the downthrown block. The origin of these terraces might be the response to changes in river base level due to Salbardi fault. The satellite data interpretation indicates that the landforms of the study area are structurally controlled and mainly covered by linear and parallel strike ridges and valleys all over the study area. These valleys indicate signs of stream rejuvenation and occasional presence of ravines. The profile parameters of the part of Maru river basin indicate the presence of several neotectonically activities in the study area. Abrupt change in the river course near Ghorpend and Salbardi village indicates structural control drainage in the study area.

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