Tectonic control on drainage network evolution and evidence of neotectonic activities in of the Wan River sub-basin, Central India

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Abstract. The study area lies in the Northeastern part of the Gavilgrah fault vicinity, which is one of the essential tectonic elements of the Son-Narmada-Tapti lineament, trending ENE-WSE direction. In this study field, data and satellite data observation are used for drainage characteristics of Wan river sub-basins. The course of Wan River is mostly controlled by the Gavilgrah fault and associated tectonic elements. The Wan River, which crosses the North's fault, exhibits two river terraces that rise and continue downstream, where the river flows on the down-thrown block. The drainage characteristics of the study area were investigated by using the LISS-III satellite data. The study of neotectonism is based on field evidence and drainage pattern. The nature of the drainage pattern in the study area shows dendritic, rectangular, and parallel together and shows evidence of neotectonic activity in the study area. The longitudinal river profile, the shape of the basin, gradient fluctuations, and valley incision, and their result also indicate neotectonic activities in the study area.

Keywords: Satellite Data, Wan River, Tectonically active, Neotectonic Activities

1. Introduction

Tectonism in any drainage basin area is well reflected by structural, fluvial, and morphotectonic parameters and plays a significant role in morphological evolution [1,2]. A multi-disciplinary approach using remote sensing aerial photos, geomorphological, structural, and neotectonism helps evaluate active tectonics in any drainage basins [3]. In most tectonic studies, using digital terrain models and shaded relief models combined with remotely sensed images and aerial photos can better understand the tectonism on a regional scale [4-8]. The presence of the parallel and rectangular drainage pattern altogether show the tectonic characteristics of the drainage. Several parameters, such as longitudinal profile, the shape of the basin, gradient fluctuations, and valley incision, have been derived from topographic maps and digital elevation models, also evident in tectonic activity [9]. The tectonic activity
in the drainage basins, which is influenced by geomorphological or tectonic factors, leads to new
landscape evolution in any basin [10]. The general image interpretation elements like tone, texture, size,
shape, association and pattern were used in rock type and geomorphic features discrimination. The IRS
LISS-III satellite data with 23.5.mt spatial resolution and SRTM DEM data along with Survey of India
toposheets of 1: 50,000 scale have been used for detailed study of drainage and its characteristics in the
area.

2. Study Area
The Wan River sub-basin is an important tributary of the Purna River, which is a major tributary of
Tapti River, is selected as study area having 480 km² area. It lies in the Survey of India toposheet no.
55G/3, 55G/4, 55D/9, 55D13, 55C/16, 55C/15 and 55C/12 at 1:50,000 scale. The Wan river sub-basin
rises from the Gavilgarh hill of eastern Satpura in Amravati District of Maharashtra (Figure 1).

3. Data used and Methodology

3.1. Satellite Data used
In the present study, Indian Remote Sensing Satellite IRS 1C Linear Imaging Self Scanner (LISS-III)
image with 23.5m spatial resolution and SRTM DEM (Digital Elevation Models) data of 90 m (Figure
2) were used generate the drainage and topographically defined structures.

3.2. Methodology
ERDAS Imagine remote sensing software has been used for Digital image processing techniques and to
identify and delineate drainage, topographical structure, and morphological parameters. LISS -III
satellite data 23.5m spatial resolution has been used rectified geometrically and registered with
toposheets on a 1:50000 scale using image processing software. Drainage was generated from the SRTM
90m digital elevation model (DEM) in the GIS environment. The Arc Hydro approach used for drainage
generation is more logical, time-saving, and consistent than a manual approach. For geomorphometry,
commonly used geomorphic indices of active tectonics such as stream length, elongation ratio, and Triangular facets for topographical structure.

Figure 2. SRTM DEM of 90 mt. Spatial resolution

4. Tectonic setting of the study area
The Wan River sub-basin lies in the vicinity of the Son Narmada Tapti Lineament (SONATA) zone and occupies its position SouthWest of the Tapti North fault and North West to South East of the Gavilgarh/Salbardi fault.

1. Son Narmada Tapti north fault (SNNF)
2. Gavilgarh Tan-Shear/Salbardi fault

4.1. Son Narmada North Fault (SNNF)
The tectonic set-up of this fault marks the southern margin of the Vindhyan Supergroup. This fault probably originated as an ENE-WSW trending trans-current ductile shear zone within the south part of Bundelkhand Craton, which was reactivated during the Paleoproterozoic as the normal fault and controlled the deposition of Mahakoshal Group [11]. The DSS profile of Kaliashows the SNNF as a
steep fault, dipping to North, displacing Moho[12]. There is no geological evidence for large scale Mesoproterozoic reactivation along the SNNF in CITZ. Apart from the Upper Gondwana sequence overlies the SNNF near Katni. The Neogene sequence of Katni formation also overlaps the SNNF in this area [13]. In the Hoshangabad area, Quaternary sediments overlie the SNNF. The present study area lies in the Eastern part of the SNNF, which plays an essential role in the minor fault reactivation.

4.2. Gavilgarh -Tan –Shear (GTS)
Tectonic Setup of the Gavilgarh -Tan-Shear extends for more than 400 km from Gavilgarh to East of Amarkantak. Further, in the West, it was described as the Satpura foothill fault [14]. In the eastern part, the GTS marks the northern boundary of the Sausar Mobile Belt. Ductile shearing during Mesoproterozoic marks the earliest phase of the GST [15,16]. There is a widespread indication of subsequent brittle reactivation during Lower Permian, leading to the Gondwana basin's development. The northern contact of a Proterozoic rock with Upper Gondwana and Deccan trap from which Upper Gondwana formation is faulted and trending ENE-WSW, a fault is called as Salbardi fault [17-20].

4.3. Salbardi fault
The Salbardi fault has rejuvenated repeatedly from Precambrian through Paleozoic to the Quaternary period. Much of these tectonic activity described from the fault zone pertains to the post Deccan trap period [21]. Gavilgarh/Salbardi fault lies in the South direction of the study area (Figure 3).

5. Geology of the study area
The study area is comprised of the lava flow and alluvium and a very small patch of sandstone. The lava flows are well exposed in the Wan River basin's upper part, surrounded by a high and low-level plateau. The lava flows belong to various geological formations, namely Indore and Kalsindhi formation, and the lava flows are of two types ‘‘aa” and pahoehoe’’. The alluvium in the lower part i.e. southern part of the Wan River basin (Figure. 3 & Table 1).

5.1. Upper Gondwana group
The sandstone which occurs near Sheba village belonging to the upper Gondwana subdivision comprises of Mahadeva group, Pachmarihi formation of Lower Triassic to Cretaceous age. A small patch of Gondwana formation consisting of sandstone is exposed in the region where the Wan River enters from the hilly region to the plain area (Figure 3 & Table 1).

5.2. Satpura group (Deccan Trap)
The Deccan traps are widely exposed in the northern part of the study area, composed of different types of lava flows. Satpura group comprises of five formations viz. Kalsindhi, Kankariya-Pirukheri, Indore, Bargonda, and Golai formation. In the Wan River basin, Kalsindhi and Indore formation is well exposed, comprising of Group of ‘‘aa” and ’pahoehoe” lava flows (Figure 3 & Table 1).

5.3. Purna alluvium
The lower part of the Wan River basin is composed of alluvium of Quaternary in age and deposited a lithological unit. The study area’s alluvium is geologically very young and occurs in villages, namely Sonala, Kated, Wadgaon, Wankhed village (Figure 3 & Table 1).
Figure 3. Geological map of the study area (modified after GSI, 2001)

Table 1. Lithology and Stratigraphical succession of study area

| Age                     | Group                        | Formation              | Lithological characters                                                                 |
|-------------------------|------------------------------|------------------------|-----------------------------------------------------------------------------------------|
| Cenozoic                | Quaternary                   | ---                    | Alluvium                                                                                 |
| Upper Cretaceous        | Satpura group (Deccan Basalt)| Indore formation       | Group of “aa” and “pahoehoe” lava flows (16 to 22 lava flows, 300 to 400 m thick)         |
| to Paleogene            |                              |                        | Kalsindhi formation                                                                      |
|                         |                              |                        | Group of “aa” and “pahoehoe” lava flows with one mega horizon (11 lava flows 440 m thick) |
| Lower Triassic to Cretaceous | Upper Gondwana group | Pachmari formation     | Sandstone                                                                                |
6. **Drainage and drainage patterns**

The Wan River is a tributary of River Purna originating from village Dhargad, the journey passes through highly dissected terrain with high slopes of Deccan trap formation. The river passes through the Deccan basalt and alluvium reaches the southern side near Wankhed village and meet to Purna river. Wan River cuts and meanders at Salbardi/ Gavilgrah fault near Wari village (Figure 4 and figure 8).

![Figure 4. Drainage map of the study area](image)

Wan basin is active drainage basins with dendritic, parallel, and rectangular types that are highly sensitive indicators of active tectonics in the deformed area [22]. Tectonic deformation results in a change in channel slope, channel morphology, fluvial processes, and a river basin's hydrological characteristics. Rivers in the foreland basin are slow and exhibit slightly active tectonic movements, and it refers to the orderly spatial arrangement of geologic and topographic features [23]. The river drainage pattern is an essential element in interpreting geological features on aerial photos and satellite images.

Dendritic to Sub-Dendritic drainage pattern (Figure 5) is seen in the study area. Some part of the study area also shows the parallel (Figure 6) and rectangular drainage pattern (Figure 7). The drainage is very dense and thick, interpreting the hard rock geology of the study area. The drainage order ranges from I to VI order. The total number of streams is 2256 with first-order (1746), second-order (392), third-order (92), fourth-order (20), fifth-order (5), and sixth-order (1) [24]. In the study area, a dendritic drainage pattern is observed near the villages, namely Bori, Dhargaon village of the Wan River sub-basin. The parallel and rectangular drainage patterns are seen near PingalliJhangir village in the study area. In contrast, the rectangular drainage pattern is seen near Shebha and Nirghar village in the study area (Figure 4).
Figures 5-8. Observations of various drainage patterns and meandering in the study area.

7. Geomorphometric indices
For the geomorphometry aspect, several geomorphometric indices of neotectonic activities have been described. These indices help evaluate the relationship between tectonic and morphology.
7.1. Sub-basin elongation ratio (Re)
Bull and Mc Fadden have proposed the sub-basin elongation ratio (Re), which is one of the proxy indicators of recent tectonic activity [25]. Schumm stated that the basin elongation ratio is the diameter of a circle of the same area as the sub-basin to the maximum sub-basin length [26]. Drainage sub-basins in arid and semi-arid climates show Re values of less than 0.50, between 0.50-0.75, and more than 0.75 for tectonically active, slightly active, and inactive settings, respectively (Table 2). The sub-basin elongation ratio (Re) values in the study were calculated for ten selected sub-watersheds with well-developed drainage, ranging between 0.25 and 0.75 (Table 2). Out of twelve sub-watersheds, four sub-watersheds (WANWR5, WANWR7, WANWL3, WANWL4) sub-basin elongation ratio (Re) value is less than 0.50, indicates a tectonically active setting. In contrast, in six, it is greater than 0.50, and less than 0.75 shows a slightly active setting and WANWR5, WANWL2 sub-watersheds, inactive (Figure 9 and Table 2).

Figure 9. Basin elongation map and tectonic intensity in the Wan River sub-basin
Table 2. Basin elongation values and tectonic intensity in the Wan River sub-basin.

| Sr.No. | Sub Watershed | Basin Area (Km²) | Basin length L(Km) | Elongation Ratio (Re) | Inference                  |
|--------|---------------|------------------|--------------------|-----------------------|----------------------------|
| 1      | WANWR1        | 248.33           | 12.25              | 0.62                  | Slightly active            |
| 2      | WANWR2        | 21.88            | 8.30               | 0.63                  | Tectonically active        |
| 3      | WANWR3        | 21.44            | 7.79               | 0.67                  | Tectonically active        |
| 4      | WANWR4        | 47.59            | 12.70              | 0.61                  | Inactive                   |
| 5      | WANWR5        | 48.75            | 22.30              | 0.35                  | Slightly active            |
| 6      | WANWR6        | 63.34            | 11.83              | 0.75                  | Tectonically active        |
| 7      | WANWR7        | 42.84            | 13.79              | 0.53                  | Inactive                   |
| 8      | WANWR8        | 33.64            | 13.56              | 0.35                  | Tectonically active        |
| 9      | WANWL1        | 47.46            | 12.08              | 0.64                  | Slightly active            |
| 10     | WANWL2        | 19.46            | 6.62               | 0.75                  | Tectonically active        |
| 11     | WANWL3        | 49.21            | 19.07              | 0.41                  | Inactive                   |
| 12     | WANWL4        | 23.80            | 21.39              | 0.25                  | Tectonically active        |

7.2. *Longitudinal river profile*

The longitudinal profile is an erosional curve that understands the surface topography and different valley maturity stages from the source to the mouth. The morphology of small to medium-sized channels that cross the mountain fronts may reflect the impact of local base-level changes due to relative uplift along active structures resulting in frontal escarpments [03]. The semi-log plot of an equilibrium river long profile is a straight line on the axes if the River is flowing across uniform bedrock[27]. The longitudinal river profile study can be done on the channel slope, which shows the irregularities and reflects disequilibrium conditions, suggesting uplift along active faults. Upwardly concave profiles suggest prolonged sub-basin channel degradation associated with longer periods of basement lowering.

![Figure 10](image-url). Longitudinal profile of the Wan River sub-basin near Shebha and Nirghar village

The upwardly convex profiles suggest the smaller number of channels down cutting and less time as base-level fall [03]. The longitudinal river profile indicates the various stages of fluvial, lithological, and tectonic processes and their characteristics. The longitudinal profile of Wan River and the section
were taken near Shebha, and Nirghar village is highly concave upward, which suggests that the headwater area is tectonically active. There is a sudden change in the gradient between 600 – 280 m after this, the profile is less undulating (Figure 10).

The topographic profiles and longitudinal river profiles were carried out by using QGIS 3.2 software (Figure 11) while slope aspects were extracted by using ArcGIS. The longitudinal river profile shows steep gradients in the upland reaches, which contrasts with the graded, but steeper profiles in other parts of the reach. The longitudinal profile shows good correspondence with the weaker incision in the segment, and longitudinal profiles show distinct convex-up morphology in the study area.

Figure 11. Longitudinal profiles of the Wan River sub-basin using QGIS software.

7.3. Topographical Structure

7.3.1. Triangular facets. Triangular facets can be significantly seen on satellite images which are generally formed by the erosion of fault-bounded small isolated hilly ranges. Triangular facets are the most prominent geomorphic features frequently observed on active normal fault scarps and fault-line scarp and also observed in regions of active extension such as the sub-basin and range[28,29]. Balogunsuggested that triangular facet development and their size and slope exhibit a strong linear dependency on fault slip rate [30].

Figure 11. (a) Observation of cross-cutting of Salbarid fault to Wan river near Wari village .(b) Cross-cutting of triangular facets near Wari village
Triangular facets in the study area have been observed near WankhedPantond and Wari village. This might be due to the Wan River sub-basin lying in the vicinity of the Son Narmada Tapti Lineament (SONATA) zone and occupying its position SW of the Tapti North fault and North West South East of the Gavilgarh/Salbard fault (Figure 11 and Figure 12).

7.3.2. River terraces. A river terrace is a step like geomorphic landform and mainly consists of a flat or gently sloping geomorphic surface which is bounded one side steeper ascending slope. The size, shape and age of terraces are the geologic processes and can understand tectonic uplift and climate change and are viewed as dominant mechanisms for their formation. River terraces may be influenced by tectonics, climate, and erosion; therefore, they can be used to study variation and how these processes interact [31,32]. River terrace in the study area has been observed near the village Wadgaon and Kated (Figure 13).

7.3.3. Alluvial fans. An alluvial fan consists of stream deposits that form a cone segment that radiates downslope from the point where the stream emerges from the mountain area [33].

Figure 12. Triangular facets on the satellite image in the study area

Figure 13. Observation of River terraces near village (a) Wadgaon (b) Kated
If the alluvial fan gets thicker and the grains become coarser heading up the fan and indicates the sub-basin margin is tectonically active if the alluvial fan gets thinner and the grains become more fine heading up the fan, this indicates that the sub-basin margin has no tectonic activity or the tectonic activity. Tectonic uplift is a driving factor in determining the development, shape, structure, size, location, and thickness of alluvial fans and influencing segmented fault [25]. Alluvial fans in the study area can be observed near the village (a) Wankhed (b) Kated village (Figure 14).

![Figure 14. Observation of alluvial fans near the village (a) Wankhed (b) Kated village](image)

8. Conclusion
Field investigation and observation of different geomorphic features on the Wan river sub basin's satellite data shows alluvial fans, escarpments in the northeastern part of the study area, and V-shaped valleys elongated ridges in the central part of the study area gives evidence of tectonic activity. The drainage in the study area is mainly controlled by the Gavilghar fault/Salabardi fault, which passes through the basin's middle. The parallel to sub-parallel drainage and rectangular drainage pattern shows the tectonic activity in the study area. Alluvial fans near Wankhedpalthond village indicates active tectonics in this area. The river terraces may respond to changes in river base level in the study area due to the Gavilgrah fault/Salbardi fault. The geomorphic feature on the satellite image indicates that the study area's landforms are structurally controlled and mainly covered by linear and parallel strike ridges and valleys. These valleys show the sign of stream rejuvenation and the occasional presence of ravines. The elevation can measure longitudinal river profiles of the Wan River. The distance along rivers and the Wan river basin profile indicate the presence of several post-tectonic activities in the study area. Based on the basin elongation ratio study, out of 12 sub-basins, six sub-basins show Slightly active, four sub-basins show the tectonically active nature, and three sub-basins show inactive setting. An abrupt change in the river course near Wari village indicates structurally controlled drainage in the study area.

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