A Hydrogeomorphic Analysis of Sinuosity Index of River Amran in the Vindhyan Region, India

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Abstract

In the present study, the river Amran having 50.89 km length, a tributary of river Satna flowing through the Bhander Plateau and Vindhyan plateau region is investigated by the Sinusoity index for evaluating the instability and erosion of banks related to stream power of the river. The Cartosat-1 DEM dataset has been used for generating the drainage network layer and measuring the differences in the sinuosity index in the ArcGIS environment. This is helpful for understanding and predicting future changes in river dynamics related to erosion, deposition, and flood, especially in the limestone lithological region of Nagod city, Satna district.

Key Words

DEM; Sinuosity Index; Vindhyan region; Amran River; erosion.

Introduction

A sinuosity index measures the deviated path of the river from the idealistic straight path of the river. Since, on the curved earth's surface, a straight path of the river could be observed only for a short distance where surface water flows along a very steep slope (*Schummm, 1963, Timar, 2003, Ghosh & Mistri, 2012*). While in the plain region where the slope gradient is very low a meandering path of the river is observed. The quantification of SI reveals the meandering path of the river. The SI is a linear hypso-morphometric parameter that is significant to study because a meandering path of the river is correlated with the erosion-deposition process along the bends or protection from erosion due to the straight path of the river (*Bridge et al, 1986*). In the whole thalweg of a river different aspects of SI could be observed at different watercourses (*Babar, 2005, Limaye et al, 2021*). The meandering or sinuous path of a river channel is the complex output of various factors viz., hydraulic, hydrologic, topographic, and geological conditions (*Boano et al, 2006, Petrovszki et al, 2012*). Nowadays, Cartosat-1 DEM, SRTM DEM, and ASTER DEM became major databases for assessing linear morphometric parameters as they provide reliable and authentic data at ground level.

Study Area

The ***Amran river basin*** is situated between 24°22'51.278"N to 24°38'32.186"N latitudes and 80°25'51.328"E to 80°40'3.232"E longitudes in the Southwestern part of the Satna river basin (1580.93 km^2) in the Madhya Pradesh state of India (figure 1). Physiographically, it belongs to the upper Vindhyan mountain system. River Amran is the largest tributary of the river Satna, it drains the northern foreland of Peninsular India.

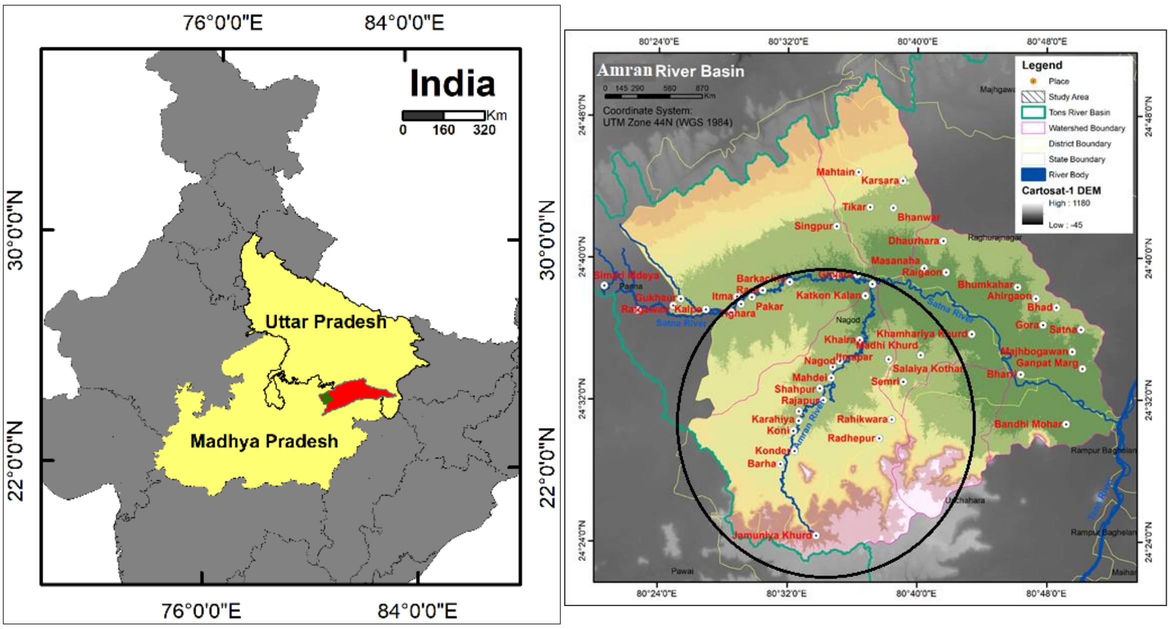

Figure 1. Location Map of Study Region

It extends for about 29.77 Km from north to south and 25.41 Km from east to west, covering an area of about 385.69 km^2, which occupies approximately 24.39 % geographical area of the Satna river basin (1580.93 km^2). The elevation ranges vary from 263 m to 565 m with a slope gradient of 46 degrees in the south-western part of the study region and 0-11 degrees in the rest part. The river Amran is the major tributary of river Satna having a 50.89 km total length, it originates from the extreme south-western part of the drainage basin over the Bhander plateau, near the Kotrahi Kalan village at an elevation of 436 m. It flows in the northeastern direction through the villages of Surdaha Kalan, Kodar, Rampura, Umri, Koni, Nagod, Tikuri of Nagod Tehsil and meets with river Satna at the geographic coordinate 24°38′31.40″ N and 80°37′13.79″E near the village of Katkon Kalan and Hinauta at an elevation of 317 m. Nagod is the only major city in the Satna district situated on the left bank of the river Amran.

Research Methods

In the present study, Cartosat-1 DEM data downloaded from the website of NRSC was the major database for extracting the sinuosity index for the year 2014. First, Cartosat-1 DEM data was pre-processed in the ArcGIS environment using the arc hydro and hydrology tool through the following certain steps; fill sink, flow direction, flow accumulation, and stream definition. Further, the river Amran, which was identified from the pre-processed DEM data, is overlaid on the georeferenced toposheet of the Survey of India, for clear demarcation and synchronization of the river channel. Lastly, the sinuosity index of the river channel is estimated by using two parameters, viz.; continuous point generation along with bending of the river and straight path generation along bending of the river (*Friend and Sinha, 1993*) through applying the equation SI was estimated;

$$Sinuosity\ Index,\ SI = \frac{Channel\ Length\ (m)}{Straight\ line\ Valley\ Length\ (m)}$$

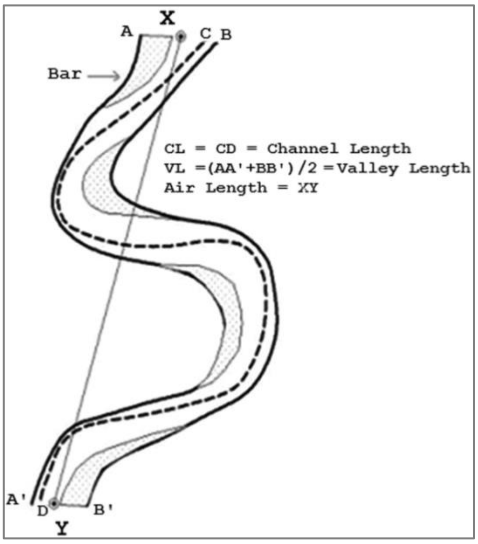

Figure 2. Pictorial Representation of SI Estimation (Muller's Sinuosity Index)

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SI Class	**SI Value**	**Length (in km)**
Straight	0 -1.100	52.794
Low Sinuous	1.101 - 1.260	193.384
Sinuous	1.261 - 1.580	46.586
Meandering	1.581 - 2.230	26.375
High Meandering	2.231 - 3.045	0.857

Therefore sinuosity index (SI) is the ratio of actual path length divided by the shortest path length. Since the actual path length is characterized by the curved channels while the shortest path length has a straight path (*Mueller, 1968; Haggett and Chorley, 1969; Prasad, 1982*). Therefore, in general, SI measures the degree of deviation from the idealistic straight path of the river (table 1). Also correlating SI with terrain and geology, it was superimposed on the elevation and geology map of the Amran river basin (figure 3, figure 4, and figure 5).

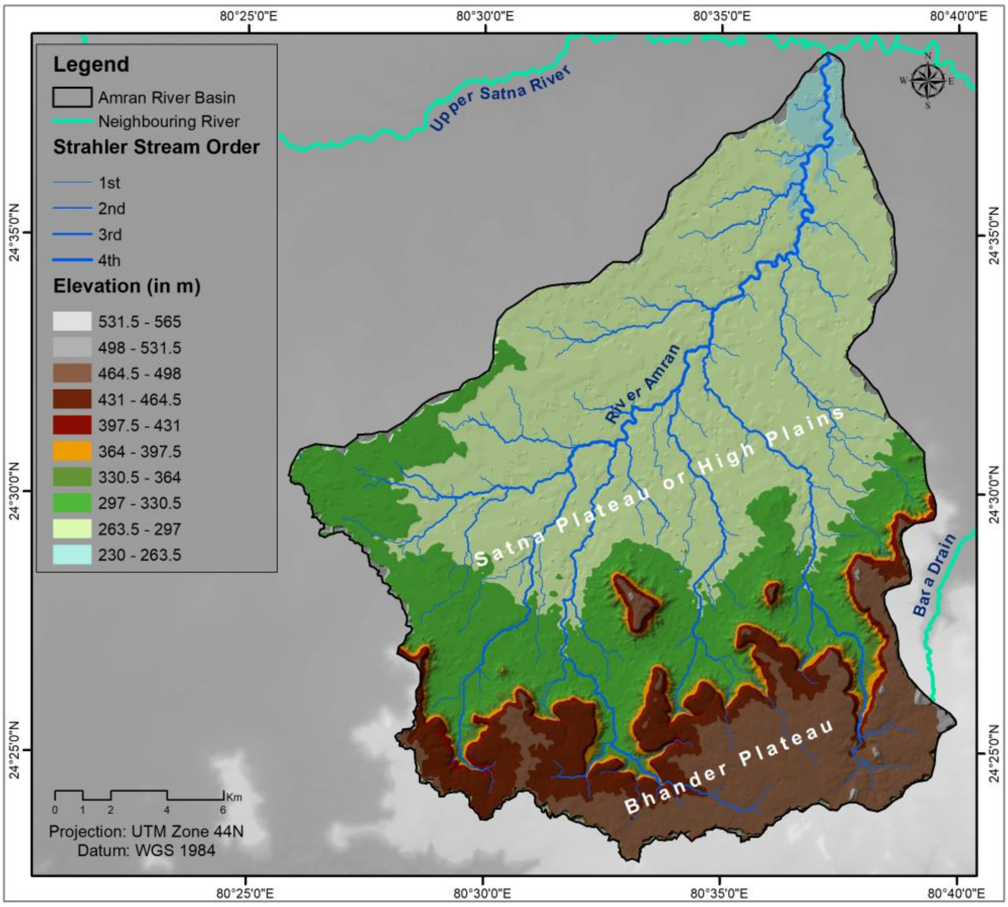

Figure 3. Showing Spatial Distribution of Stream Order over Terrain Relief in the Study Region

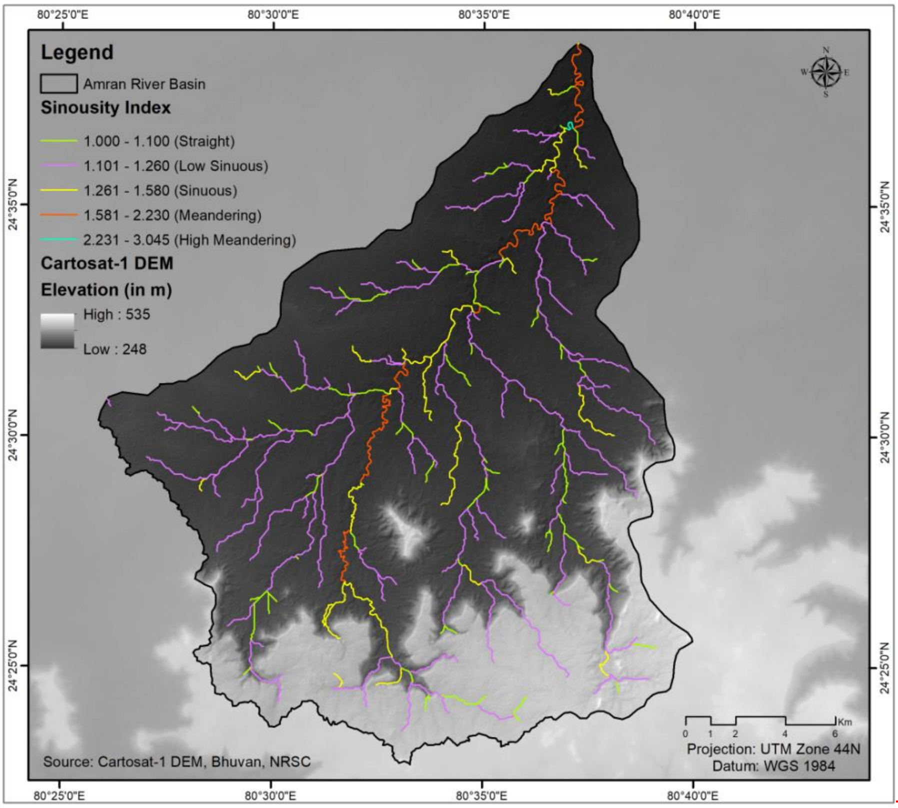

Figure 4. Showing Spatial Distribution of Sinuosity Index over Terrain Relief in the Study Region

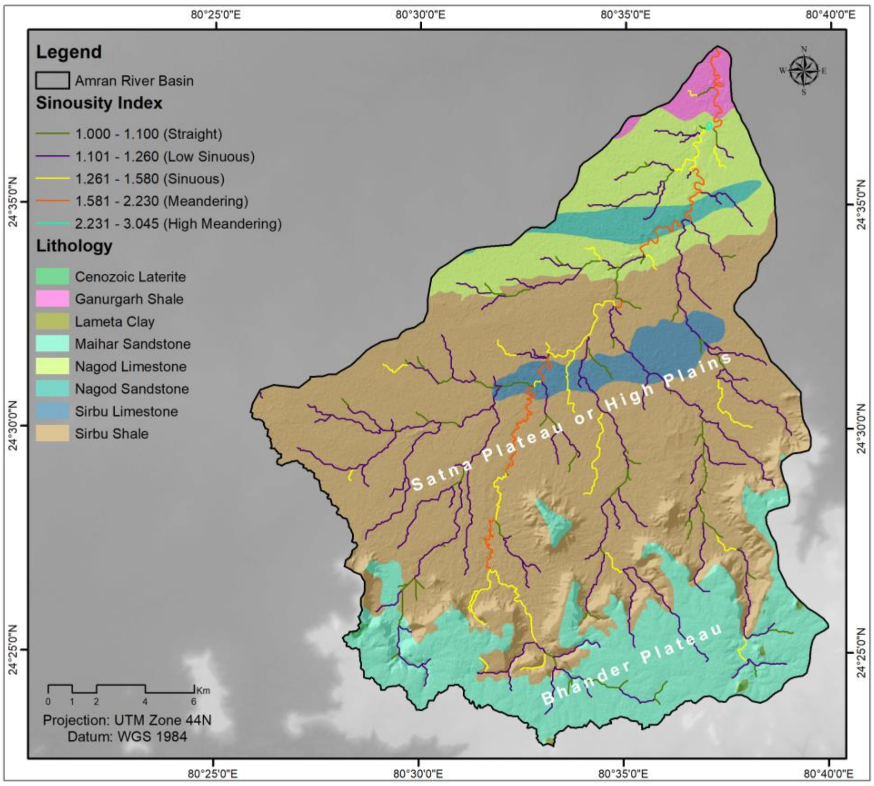

Figure 5. Showing Spatial Distribution of Sinuosity Index over the Lithological Unit in the Study Region

Result and Discussion

Figures 3 & 5 show the spatial distribution of SI, it reveals that river Amran which belongs to 4th order in the Strahler hierarchical system has the highest sinuosity throughout the basin. It ranges from 1.581 to 3.045 that comprise approximately a 27.23 km length of the stream in the basin. While, the rest three order stream (1st, 2nd, and 3rd) have SI ranges from 1.100 to 1.580 which comprises a 292.76 km length of the stream in the basin. This pattern of sinuosity of river or stream is so obvious in the fluvial geomorphology since it is a general presumption that as the river left its` origin area and reaches to mouth, its velocity and stream power decrease due to a decrease in slope gradient and sinuosity of river/stream increases, that is characterized by the meandering path of the river. However, in the present study, the SI shows a unique characteristic if superimposed with the geological structure and when a cross-section profile is generated by superimposing SI over terrain surfaces.

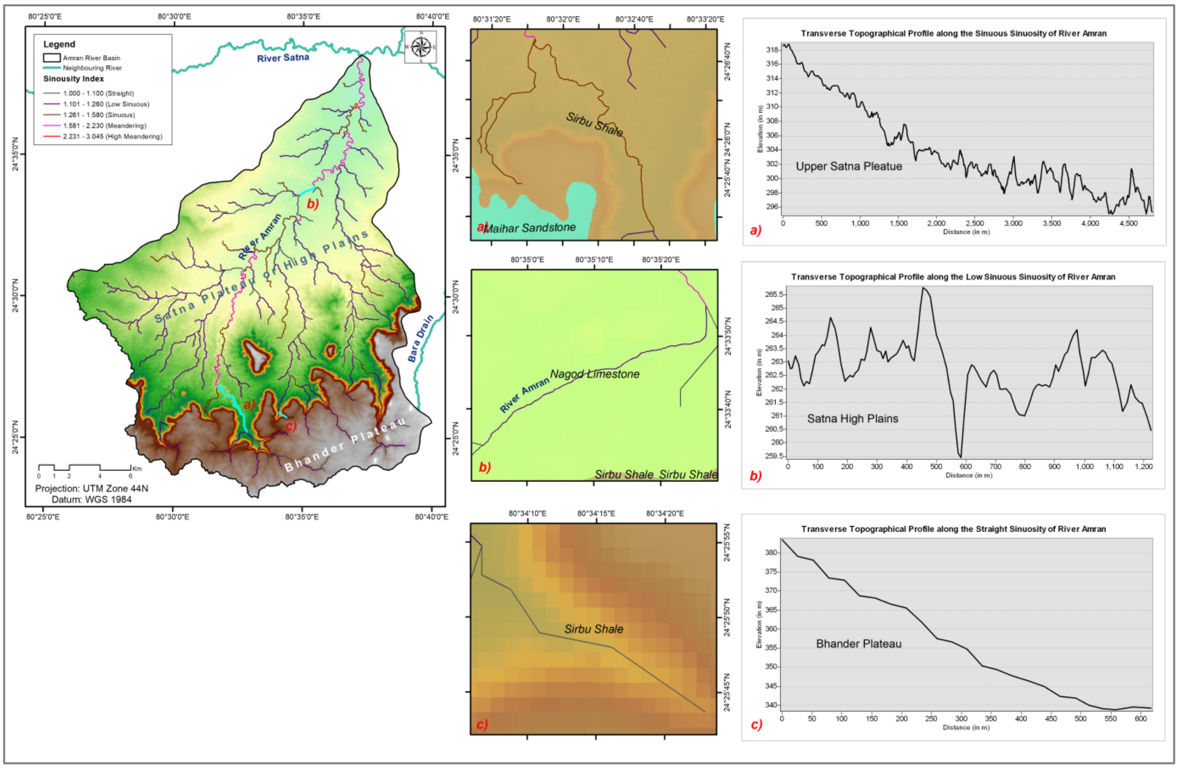

Figure 6. Cross-Section Profile of Sinuous SI of River Amran

Figure 6 depicts a transverse topographic profile along the sinuous SI of river Amran. An approximately straight path of the river was observed for the sinuous SI (1.101 -1.580) section of river Amran. The low sinuous and sinuous path of the river dominates throughout the basin where the slope gradient is low. Although if this path of the river passes through a high slope gradient (figure 6,c) then the bottom of the valley has a less vertical erosive surface than flowing through the same geological unit of hard rock terrain (Sibru shale) in the less sloppy

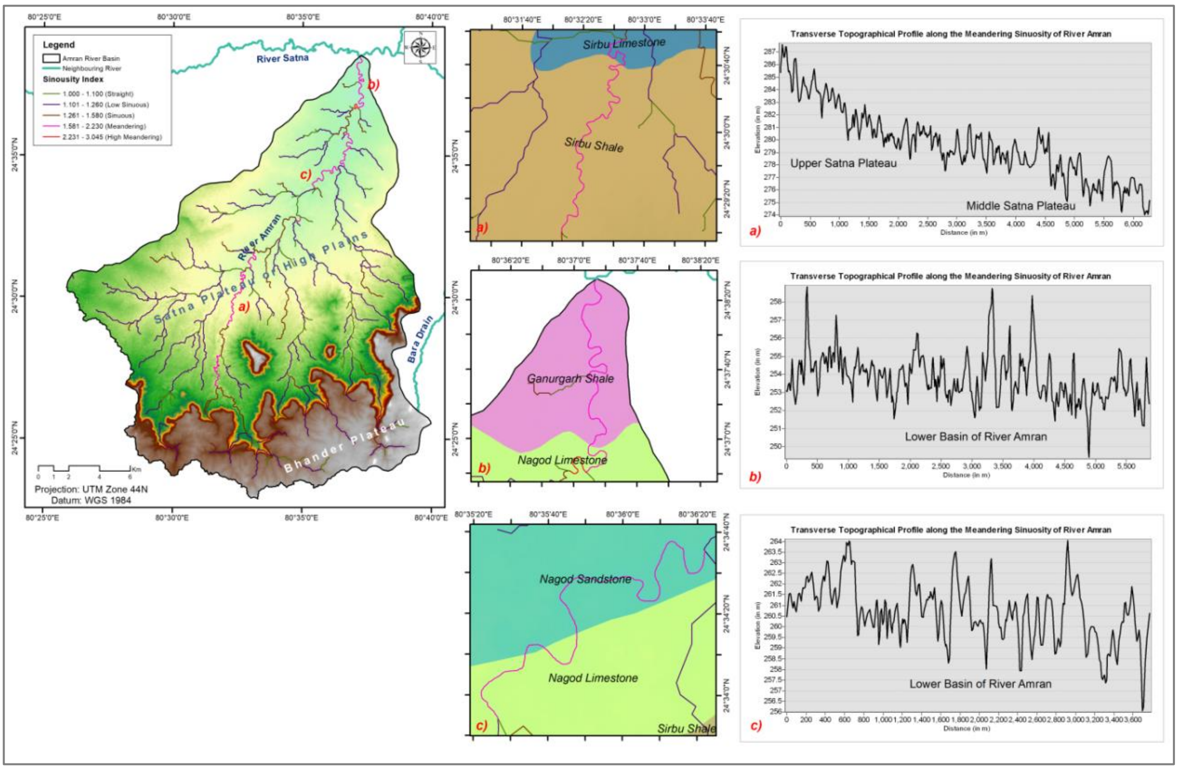

Figure 7. Cross-Section Profile of Meandering SI of River Amran

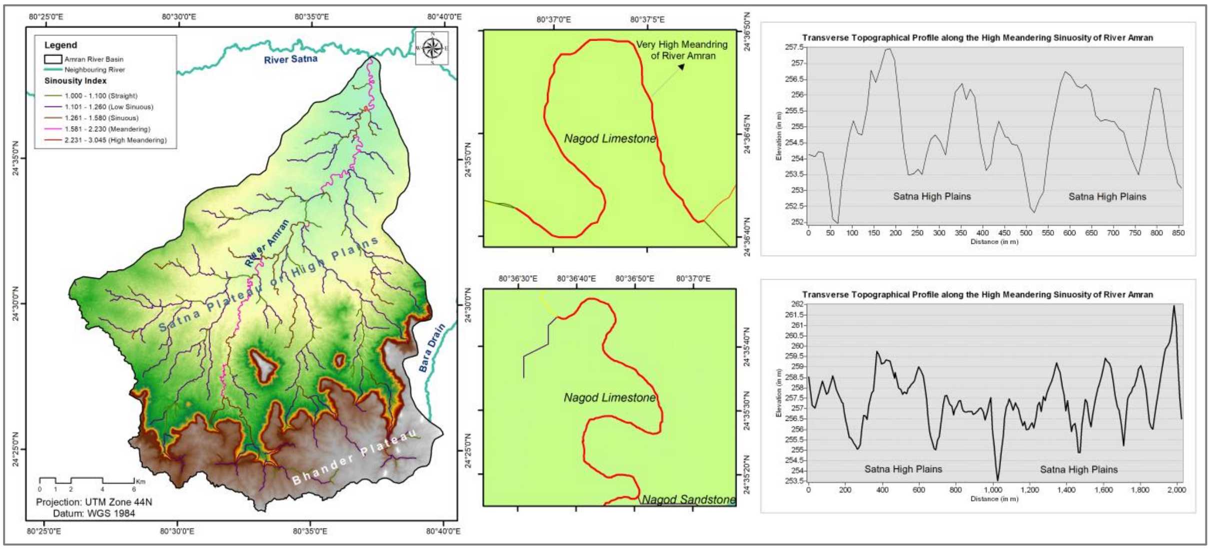

Figure 8. Cross-Section profile of High Meandering SI of River Amran

region (figure 6, a), where highly rugged bottom relief observed along the sinuous SI section of river Amran.

Figure 7 explains the transverse topographic profile along with the meandering SI (1.581 – 2.230) of river Amran. This section of the river comprises 26.375 km of the river basin, 2nd lowest length in the basin among all five classes of SI. This pattern of river dominates over the

Ganurgarh shale, Sirbu shale, and Nagod limestone lithology. While the meandering SI river flows through the less or high sloppy region it has a rugged valley bottom in the whole section.

Figure 8 shows a transverse topographic profile along the very high to high meandering SI (2.231 – 3.045) of river Amran. It indicates that Satna high plains endowed with Nagod limestone lithology have high to very high SI of river Amran. The limestone lithology and lesser slope gradient facilitate the meandering path of the river, in which erosion is prominent along the outside concave bank where stream velocity and stream power increases due to convergence of flow. In contrast to this, the inside convex bank is characterized by the divergence of flow, least stream power, and least stream velocity, hence, deposition of debris is dominated in this region. Although, due to limestone rock structure, development of meandering path and valley deepening (5-10 m range) are maximum in the basin along this section of river where SI is very high to high.

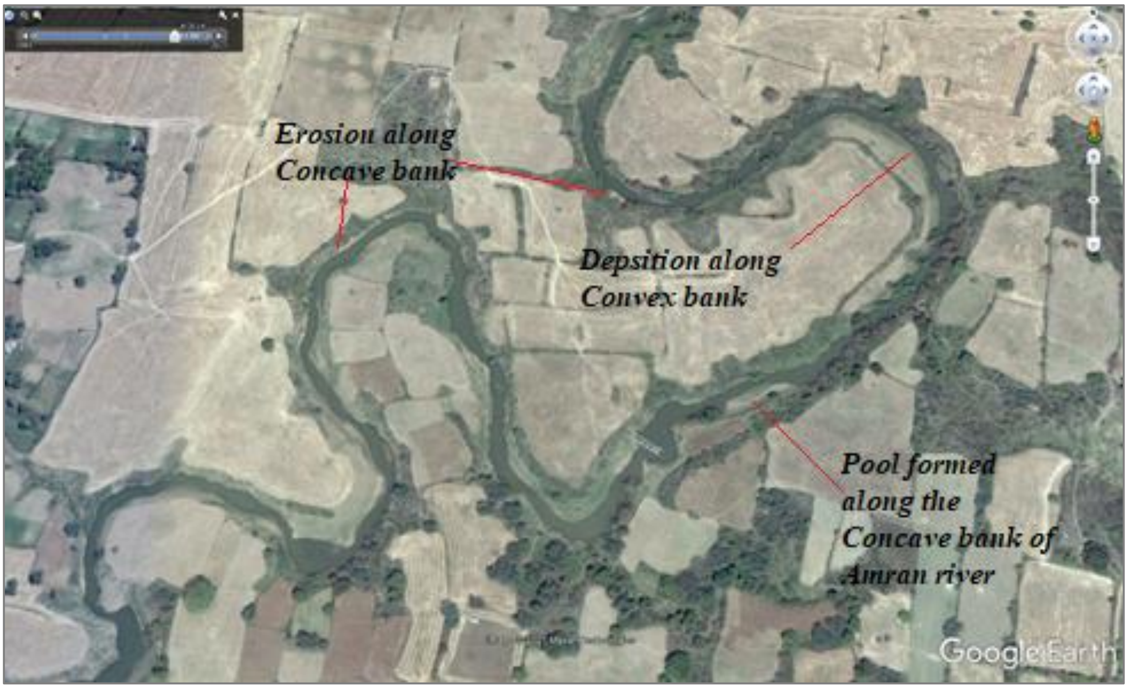

Figure 9. Google earth imagery showing geomorphic process related to high meandering SI of River Amran near Nagod City Area

Therefore, it could be concluded from this study that for all the above SI of river Amran the curved path of the river varies from 0 to 3.045 and the vertical bottom of the valley for all sections of SI could be represented by a cross-section topographic profile in ArcGIS environment that reveals about the bottom ruggedness of river Amran as well. Along the thalweg of river Amran different typesof geomorphic features could be seen (figure 9) in the one section at different sideways. The erosion is more effective on the outside concave bank that is the downstream side of a meander characterized by the maximum velocity and high slope. While, depositions are more prominent, along the convex bank, which is characterized by the minimum velocity of the river. The meandering path of the river is also characterized by the pool, riffle, paleo-channel, an ox-bow lake. In the study region pool, paleo-channel and riffle are more prominent than an ox-bow lake (figure 9).

Conclusion

In the present study, the SI of river Amran has been derived from Cartosat-1 DEM data and further correlated with the geology, elevation, and slope profile of the river basin. In the result, it was found that river Amran which belongs to the 4th order in the Strahler hierarchical system has the highest sinuosity throughout the basin. It ranges from 1.581 to 3.045 that comprise approximately a 27.23 km length of the stream in the basin. While, the rest three order stream (1st, 2nd, and 3rd) have SI ranges from 1.100 to 1.580 which comprises a 292.76 km length of the stream in the basin. Moreover, the flow pattern of river Amran along with its lateral erosion and vertical erosion are investigated by the topographical profile. It reveals that vertical erosion dominates in the valley either river Amran has a low or sinuous channel, although the meandering curve is slightly high near the lower part of the basin. The vertical erosion became insignificant along the Bhander escarpland, where the slope is almost freeface to rectilinear.

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