Quantitative Morph Tectonic Evaluation of Dhasan River Basin through DEM-derived Drainage Parameters

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Abstract : The geomorphic studies so far have established that the geodynamic processes considerably influence the drainage systems. Therefore, quantitative evaluation of drainage basin can provide the signatures of geodynamic changes either due to natural geomorphic cycle or due to tectonic controls. This paper presents the results of morphotectonic interpretation of drainage characteristics and various basin parameters of Dhasan River Basin. DhasanRiver flows in a part of so called rigid plate but in close vicinity of major tectonic zone of central India. Hence, morphotectonic evaluation of Dhasan River Basin is carried out to understand the effects of regional tectonic forces in the basin. The drainage morhometry and basin parameters derived through topographic analysis in this paper gives detail insight towards understanding the probable morphotectonic signatures and shows strong correlation with values of structurally controlled and tectonically active basins.

***Keywords* – Geomorphic, tectonic, morpho, basin.**

I. Introduction

The tectonic studies carried out so far have proven that the younger tectonic events affect river morphology widely and expressed in terms of changes in channel slope, channel width, channel braiding patterns, grain size distribution trends and in other many more ways(NagS. K. & Chakraborty Surajit, 2003). The structural characteristics and the degree of jointing/fractures also affect the extent to which the materials can be detached by fluvial processes (Derbyshire et al., 1981). Therefore, it can be hypothecated that river morphology carries measurable signature of tectonic activities and detailed morphotectonic investigations of river basins may further lead to detect ongoing tectonic activities as well as reactivation of past tectonic events, which are not yet significantly manifested in the topography and landscape. Thus the role of rock types and geologic structure in the development of stream networks can be better understood by studying the nature and type of drainage pattern and by a quantitative morphometric analysis, information about geomorphology, hydrology, geology and land cover can be obtained by studying reliable information of the drainage pattern and texture (Astras and Soulankellis, 1992).Morphometric analysis of river basins have been carried out by Horton, 1945; Smith, 1950; Strahler, 1957 et.al. using conventional methods.Many geoscientists like Krishnamurthy and Srinivas, 1995; Srivastava and Mitra, 1995; Agarwal, 1998; Biswas et al., 1999; Narendra and Nageswara Rao, 2006 haveused remote sensing and GIS tools to compute morphometric parameters.Hack (1960) convincingly demonstrated that geomorphic processes operating today are sufficient to explain modern landforms. Devdariani (1967) mathematically discussed the Davisian cycle of erosion and explained landform changes and tectonics. This concept was further followed by W.B. Bull, 1970, 1973, 1975; Bull and McFadden, 1977 and various workers have contributed later on from different parts of the world. Similar concept has been reworkedto study tectonic changes of various parts of central India (CRUMANSONATA, 1995; Sinha Roy, 2001; Chamyal et. al. 2002; Reddy, 2003; Rajawat et. al. 2003; etc.). All the efforts made so far in this direction are of regional nature, detailed and systematic investigations are yet to be furnished (Verma, 1998). A systematic study of various sinuosity parameters for individual basins is expected for vital information over the active tectonics in the area (Bull and McFadden, 1977; Jain et al., 2001; Datir and Verma 2004).Therefore, an attempt has been made to demonstrate the quantitative morphotectonic evaluation of up to the state boundary of Madhya Pradeshthrough DEM derived drainage parameters. This is a right bank tributary of Betwa River; a tributary of Yamuna joins after Chambal. The scope of the present investigation includes a brief outline of the tectonic, seismic, geological and geomorphic setting, a discussion of the geomorphic indices that are useful in defining tectonic controls on basin morphology.

METHODOLOGY

DEM (Digital Elevation Model) data is used for delineation of basin and sub basin boundaries, extracting drainage networks, measuring and computing various morphotectonic parameters and generation of longitudinal as well as transverse river profiles and slope maps. Slope can be defined as rate of change of elevation. The DEM is also used to generate three dimensional models of terrain by image drape. The present investigation involves SRTM-DEM with 90 m. spatial resolution intended for deciphering various morphotectonic parameters with the help of Geographic Information System (GIS).The SOI Degree sheets (Quarter Inch Topographic Maps) are used as reference maps. The present investigation utilizes few publications of GSI including the Tectonic Atlas of India, District Resource Maps, Geological and Geophysical maps of MP and India etc. to assess the regional geology and tectonic setup of the area. The spatial data including topographic maps etc. have been scanned and geo-referenced into UTM projection system and WGS-84 datum and digitized GIS platform.The remotely sensed data used in present study includes mainly, the images acquired by American satellite mission: LANDSAT-7 and sensor ETM+ (The Enhanced Thematic Mapper Plus) to obtain the information required for present investigation. This study utilizesthe techniques of digital image processing toimprove interpretability of different features and extract required information from the satellite images.

Morphotectonic Analysis

A base map has been generated from survey of India (SOI) topographic maps on 1:250,000 scale (Degree Sheets). The drainage map of the area is generated by digitizing topographic maps and satellite imagery and with the help of DEM, different drainage parameters have been measured. The important morphotectonic parameters computed are: - Drainage density, Stream frequency, Bifurcation Ratio, Elongation ratio, Form factor, Circularity ratio, Sinuosity parameters etc. These parameters then analyzed to assess the tectonic characters of the basin.

Identification of Markers of active tectonics

The river characteristics which have been suggested as indicators of active tectonics like, river meandering, braiding, head ward erosion, river migration, Palaeo-channels, buried channels etc. has been identified in the satellite images by visual inspection and digital enhancement techniques.The images available online with "google earth" have also been utilized for the advantage of high spatial resolution.

GEOLOGICAL SETUP

The area is occupied by litho-assemblages of various geological formations ranging in age from the Archaean to Quaternary period. The northern part of the area is composed essentially of variegated granite and granite gneisses with enclaves of meta-sediments and meta-basics belonging to the Bundelkhand Granitic Complex.

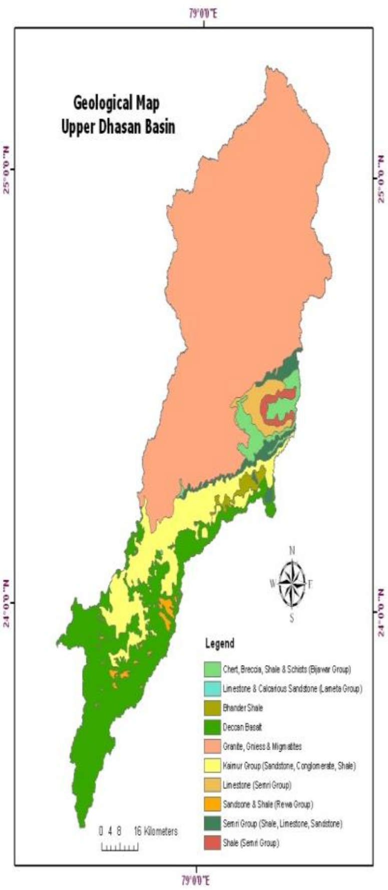

Fig: 1, Geological Map of Upper Dhasan Basin

The stratigraphic succession is given in Table-1.

Stratigraphic Status		Lithological Character	Age
Unclassified		Alluvium/Laterite	Quaternary Recent
Deccan Trap Complex		Basaltic flows, intrusive and Inter-trappean beds	Upper Cretaceous
Lameta Group		Sandstone, Shale, Limestone, Claystone and marl	Upper Cretaceous
Vindhyan Super Group	-Bhander Group	Sandstone, Shale and Limestone	Neo-proterozoic
	-Rewa Group	Sandstone and Shale	
	-Kaimur Group	Conglomerate, Sandstone and Shale	Meso-proterozoic
	-Semri Group	Conglomerate, Quartzite, Sandstone, Limestone, Procellanite and shale	
Bijawar Group		Chert breccias, Shale and Dolomite. Basal volcanic, Conglomerate, Quartzite and Slaty Shale	Palaeo-Meso-proterozoic
Bundelkhand Granitoid Complex(BGC)		Basic dykes, Quartz reef, Pegmatite Veins, Granites in multiple phases Gneissic complexes with enclaves, Metasediments and Metabasics.	Archaean to Palaeo- proterozoic

QUANTITATIVE MORPHOTECTONIC ANALYSIS

The theoretical basis for the morphometric analysis involves relative adjustments between local base level processes (tectonic uplift, stream down cutting, basin sedimentation and erosion) and the fluvial systems which cross structurally controlled topographic mountain fronts (Bull and McFadden, 1977). Most of the morphotectonic indices used in this study were developed by Hack (1973), Orlova (1975), Bull and McFadden (1977), Rantsman(1979) and Wells et al. (1988). The drainage characteristics of a drainage basin give considerably clear indications about the shape, size and geomorphic characters of a basin. Parameters such as sinuosity, longitudinal profiles, valley floor to valley width ratios and mountain front sinuosity characterize the degree and nature of tectonic activity. In response to uplift a river changes its channel pattern by increasing sinuosity, straightening of course or braiding of channels. Evaluation of the characteristics of drainage patterns of a river basin using quantitative morphometric analysis provides information about the nature of the rocks exposed within the drainage area (Pakhmode et al. 2003). It is well documented that rivers respond rapidly and consistently to active tectonic deformation of the Earth's surface (Seeber and Gornitz, 1983; Ouchi, 1985; Holbrook and Schumm, 1999; Jain and Sinha, 2005; Turowski et al. 2006; Amos and Burbank, 2007).

Extraction of Drainage

Drainage represents the network of main streams in the catchment area, followed by the tributaries up to the first order.The drainage has been extracted using SRTM-DEM in GIS environment and corrected using base topographic data obtained from SOI maps.The lengths of the streams and areas of the basins were measured and ordering of streams has been done using Strahler's (1953) system. The methods adopted to calculate various linear parameters followed Horton (1945), Strahler (1953), Chorley (1957), the areal aspects using those of Schumm (1956), Strahler (1956, 1968), Miller (1953), and Horton (1932), and the relief aspects employing the techniques of Horton (1945), Broscoe (1959), Melton (1957), Schumm (1954), Strahler (1952), and Pareta (2004).The drainage map ofis shown in the Fig:3.

Area (Km²)	**Perimeter (Km)**	**Max. Length (Km)**
8171.01	662.98	212.00
Stream Order	**No. of Streams**	**Length (Km)**
1st	1282	2240.27
2nd	326	1155.02
3rd	73	670.57
4th	14	170.48
5th	3	242.02
6th	1	74.95
TOTAL	1699	4553.31

Table:-1, Linear aspects of Dhasan Basin

Linear Aspects of the drainage System

The linear aspects of drainage network such as stream order (Nu), bifurcation ratio (Rb), stream length (Lu) etc. have been calculated using the methods discussed above. Dhasan Basin is a 6th order drainage basin. Total 1699 streams were identified within the basin boundary and total length of the streams within basin boundary measured is 4553.31 Km. The area and perimeter of the basin are measured, 8171.01 Km2 and 662.98 Km. Table-2 shows the results of linear aspects of drainage Basins.

A. Stream Order (Nu)

Within the catchment area analysis the primary step is to work out the stream orders. within the gift study, the channel segments of the catchment area are stratified in keeping with Strahler's stream ordering system. The order wise total range of stream segments is understood because the stream range [Horton's (1945)]. Laws of stream range states that the quantity of stream segments of every form Associate in Nursing inverse geometric sequence with premeditated against order, most evacuation networks show a linear relationship, with tiny deviation from a line. The plotting of index of range of streams against stream order is given in Figure four.6, in keeping with the law planned by Horton provides a line. this implies that the quantity of streams sometimes decreases in progression because the stream order will increase.

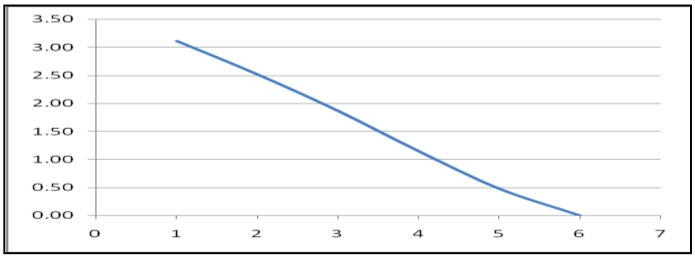

Fig:-3, Logarithm of number of streams versus stream order; Upper Dhasan Basin

B. Stream Length (Lu)

Stream length is one in every of the foremost vital hydrological options of the basin because it reveals surface runoff characteristics streams of comparatively smaller lengths ar characteristics of areas with larger slopes and finer textures. Longer lengths of streams ar typically indicative of praise gradients. Generally, the full length of stream segments is most in 1st order streams and reduces because the stream order will increase. the amount of streams of assorted orders within the basin is counted and their lengths from mouth to drain divide ar measured with the assistance of GIS code. The plot for Dhasan basin shows Brobdingnagian deviation from its general behavior indicates that the piece of land is characterised by relatively a lot of variation in lithology and topography.

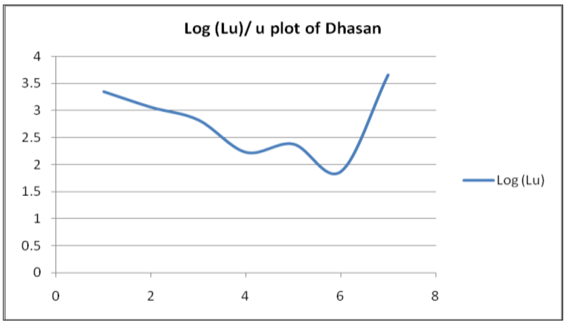

Fig-4, Logarithm of stream lengths versus stream order plot;Upper Dhasan Basin

A. Drainage Density (D)

Horton (1932), introduced the drainage density (D) is an important indicator of the linear scale of landform elements in stream eroded topography. It is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area. Mathematically,

Drainage density (D) = (Total Length of the streams)
/ (Area of the Basin)

The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. It has been observed from drainage density measurements made over a wide range of geologic and climatic types that a low drainage density is more likely to occur in regions of highly resistant or highly permeable subsoil material under dense vegetative cover, and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahaler, 1964).

The drainage density (D) of Dhasan is 0.56 Km/Km^2. The types of rocks also affect the drainage density. Generally, lower values of D tend to occur on granite, gneiss and schist regions. This basin also runs on this type of rocks leading to corroborate low drainage density observed in the basin.

B. Stream Frequency (Fs)

Stream frequency (Fs) can be expressed as the total number of stream segments of all orders per unit area (Horton, 1932). i.e.

Stream Frequency (Fs) = (Total number of streams)
/ (Area of the Basin)

The Stream Frequency for Dhasan is 0.21, exhibits positive correlation with the drainage density indicating increase in stream population with respect to increase in drainage density.

C. Texture Ratio (T)

Texture ratio (T) is an important factor in the morphometric analysis of drainage basin. This can be expressed as follows:

Texture Ratio (T) = (Total Number of Streams
/ Perimeter of the Basin)

Texture ratio indicates underlying lithology, infiltration capacity and relief aspects of the basin. Texture Ratio for Dhasan basins is 2.56, can be categorized as low.

D. Elongation Ratio (E)

Schumm (1956) used an elongation ratio (Re) defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. i.e.***Elongation Ratio (E) =*** $(2\sqrt{A/\pi})/L$,Where, A is the area of the basin and L is the Maximum length of the basin. It is a very significant index in the analysis of basin shape. Elongation Ration near 1.0 indicates nearly circular basin with very low relief whereas, tectonically disturbed rivers show relatively lesser elongation ratio indicating more elongated shape (Strahler, 1964). The values of Elongation Ration for Dhasan is 0.48 implies that the basin is elongated in shape and appears to be tectonicallyactive.

E. Circularity Ratio (C)

Miller (1953) defined a dimensionless circularity ratio (C) as the ratio of basin area to the area of circle having the same perimeter as the basin. i.e.,***Circularity Ratio (C) =*** $4\pi A/(P)^2$

Where, A is area and P is perimeter of the basin. He described the basin of the circularity ratios ranging from 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials. The circularity ratio of Dhasan-0.23 of corroborates the Miller's range which indicates that the basin is elongated in shape, low discharge of runoff and high permeability of the subsoil.

F. Form Factor Ratio (Rf)

Quantitative expression of drainage basin outline form was made by Horton (1932) through a form factor ratio (Rf), which is the dimensionless ratio of basin area to the square of basin length. Basin shape may be indexed by simple dimensionless ratios of the basic measurements of area, perimeter and length (Singh, 1998). The form factor value of the Betwa basin, Dhasan basin and Ken basin are 0.32, 0.18 and 0.31 respectively. Which indicate lower value of form factor and thus represents elongated in shape. The elongated basin with low form factor indicates that the basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin.

RESULTS

Surface geodynamic processes lack the differentiation between pure tectonic changes in drainage system and natural geomorphic responses. Therefore, only surface observations are not sufficient to infer the complete tectonic phenomena, but a careful examination of surface processes and quantitative assessment of morphotectonic parameterscontribute significantly towards the interpretation of tectonic controls on drainage systemover the prolonged geologic times. Hence, a comprehensive study is carried out to assess the morphotectonic signatures of river system and geomorphic landforms through DEM derived parameters and the results have been presented in this paper.Evaluation of the characteristics of drainage patterns of a river basin using quantitative morphometric analysis provides information about the nature of the rocks exposed within the drainage area. The drainage pattern in the study area covers almost all the types including, dendritic, parallel to sub parallel, circular, radial, pinnate type etc.In Upper Dhasan Basin, three distinct higher drainage density zones are identified along the western basin boundary at the Bundelkhand granite due to intense fracturing in rocks and two prominent higher density zones are associated with the South-west boundary of the basin along with parallel high density NE-SW zones across the basin.The geomorphic landforms of the study area include dissected plateau, alluvial plains, intermountain valleys, younger and older flood plains, residual, structural and Denudational hills, long narrow linear ridges and scattered mesa and butte. Morphometric analysis of is carried out using Strahler's (1953) system. The Dhasan River is a 6th order Tributary of Betwa River. A number of morphotectonic parameters have been computed for study area. The length of the streams and area of the basins were measured. The parameters computed include linear and areal aspects of drainage basins, Sinuosity indices, Valley floor to width to valley height ratios, Stream length gradient index, basin asymmetry factor, Transverse topographic symmetry factor etc.The plot for Dhasan basin shows huge deviation from its general behavior indicates that the terrain is characterized by comparatively more variation in lithology and topography. Bifurcation ratios characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern. Bf for Dhasan = 3.93 to 5.21, suggest that the geological structures affect the drainage significantly in Dhasan. The mean bifurcation ratio value is 4.26 for Dhasan which also indicates that the geological structures are disturbing the drainage patterns considerably.The drainage density (D) of Dhasan exhibit drainage density 0.56 Km/Km^2 and categorized under low drainage density class. Generally, lower values of drainage density tend to occur on granite, gneiss and schist regions. This basin also runs on this type of rocks leading to corroborate low drainage density observed in the basin. The Stream Frequency forDhasan is 0.21 exhibit positive correlation with the drainage density indicating increase in stream population with respect to increase in drainage density.Texture Ratio for Dhasan basin is 2.56 can be categorized as low.Elongation Ration near 1.0 indicates nearly circular basin with very low relief whereas, tectonically disturbed rivers show relatively lesser elongation ratio indicating more elongated shape (Strahler, 1964). The values of Elongation Ration for Dhasan is 0.48 implies that the basin is elongated in shape and appears to be tectonically active. The circularity ratio of Dhasan-0.23 corroborates the Miller's range (0.4 to 0.5). This indicates that the basin is elongated in shape, low discharge of runoff and highly permeable subsoil. The form factor value of Dhasan basin 0.18 (lower value of form factor), indicating elongated basin shapes. The elongated basin with low form factor indicates that the basin will have a flatter peak of flow for longer duration. The Longitudinal River Profiles for the basin appears segmented having nick points, indicate the deviation from a stable river profile (slightly concave longitudinal profiles), and may be induced by tectonic, lithological and/or climatic factors (Hack, 1973).The SL-Gradient index can be used to evaluate relative tectonic activity (Keller and Pinter, 2002). Although an area on soft rocks with high SL values indicates recent tectonic activity, anomalously low values of SL may also represent such activity when rivers and streams flow through strike-slip faults (Keller and Pinter, 2002). The reaches of initial course of the rivers flowing through hard rock terrain show relatively lower SL-Gradient Index values, indicative of less potential for tectonics but the anomalously high SL index values are observed in the regions of middle and reaches of northern parts characterized by uniform lithology indicates significantly high potential for tectonic activities. The Basin Asymmetry Factor (AF) values are very important for evaluating the relative active tectonics in different basins. The AF-50 values for Dhasan = 4.48 indicates the possibilities of tectonic tilting slightly high in Dhasan. Valley Floor Width to Valley Height Ratio, (Vf-Index) ranges in Dhasan basin from 0.42 to 22.86. Relatively lower values of Vf indicate V-shaped valleys and high values indicate U-shape valleys.Basin Shape Index (Bs) shows high values suggesting elongated shapes, generally associated with tectonically active basins. Dhasan basin shows Bs value 3.22. This suggests that Dhasan is tectonically active.The values of Standard Sinuosity Index (SSI) are ranging from 1 to 1.3, indicating straight to slightly sinuous course and the values of Topographical Sinuosity Index (TSI) greater than Hydrological Sinuosity Index (HIS) values for majority of the segments of river implies structurally controlled river course and tectonically active. The nature of the valleys keeps on changing between rectilinear to sinuous. The River Terraces, Rapids and Falls, Knick Points, Fault Escarpments etc. are direct evidences of active tectonics. More than one set of river terraces are identified in the river banks of the study area through transverse river valley profiles. The first river terrace is older and subsequent terraces are relatively new. Longitudinal River profiles of the river under investigation show several knick points and rapids and falls.

MAJOR OUTCOMES AND DISCUSSION

The area under present investigation is bounded by Bundelkhand Gneissic Complex in the north and Narmada Basin in the south. Narmada basin is considered tectonically active by various earlier workers. The precise GPS measurements have also suggested that the Central Indian plate is moving at almost constant rate toward NE. This rate is measured to be46.38 ± 4.2mm per year in the azimuth 47.400 in ITRF 1997 reference frameas per the crustal velocity recorded at Bhopal Permanent GPS station (Jade S., 2004). The Narmada basin has experienced devastating tectonically triggered seismic events in recent past (Jabalpur Earthquake, 22nd May, 1997, Magnitude-6).These evidences force to revise the presumption of considering the area between SONATA measure tectonic zone and Massive Bundelkhand Craton as a tectonically stable/rigid landmass.Therefore, Dhasan River flowing in this region has been taken for detailed morphotectonic investigation. A number of analyses have been carried out and some important inferences have been made. Most of the parameters studied (mentioned in result section) suggest that the basin is tectonically active, though the degree of potential is yet to discover. Middle part of the basin shows high Bouguer Gravity anomaly values (NGRI, 1978) and follow the high gravity trend running from Allahabad to Ratlam, traversing roughly from East to West and the Asmara lineament correlated with southern boundary of Faizabad Ridge, traversing the study area same the way (Ramsay, 1995; GBF after Tewari, 1995; Boundary of Faizabad Ridge after Hari Narain and Kaila, 1982). The Upper Dhasan basin is a part of the central low gravity zone, characterized by thick sediment deposition in geological past (NGRI, 1978, Bouguer Gravity Map of the Vindhyan Basin and its adjoining regions).The surface geomorphic features and fluvial processes can also be influenced or seems to be influential with the gravity anomalies; However the gravity low or gravity high values are principally the matter of chemical composition of underlying rocks.Apart from these highly correlating and coinciding findings many signatures of river migration,straight course of streams, fractures developed in transverse and longitudinal manner and shifting of streams in order to adjust their path according to the tilting and uplifting or down warping of river beds etc. observed in satellite imageries. Therefore, the major outcome of this study is to underline that the is a structurally controlled and tectonically active basin and needs further investigation to assess the geodynamic behavior of the region as a whole.

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