Remote Sensing Analysis of Recent Active Tectonics in Pamir Using Digital Elevation Model: River Profile Approach

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ABSTRACT

Digital elevation models (DEMs) are key component for computer-based analyses of river profiles, drainage basin as it provides elevation information for the land surface throughout the catchment of the area. During the Cenozoic uplift of Tibetan plateau and surrounding ranges due to India-Eurasia collision, the tectonic processes are interacting with the local random effects (e.g. Landslides, Glaciations and climatic Changes) and are linked with the development of a unique river network in this region. These rivers have distinct patterns and are controlled by different tectonic and climatic regions. Drainage history of the Pamir is related to continental movements of the plates, displacements of the tectonics, regional uplift and erosion of various individual tectonic units. This study focuses on the application of remote sensing techniques in order to show the spatial variation of uplift and deformation along the right bank tributaries of Pyanj (Vanch, Yazgulem, Aksu-Murghab-Bartang, Gunt-Alichur and Shokhdara) and one of the few left bank tributary (Shiveh river) and Pyanj itself. DEM data is used to extract river network in this area. Moreover, slopes and drainage areas are also calculated from Digital Elevation Model. Based on the stream power law, we make area-slope plot so as to derive channel parameters like concavity (θ) and steepness (K_s) which are related closely to uplift and deformation. The lineaments and major tectonic features have been digitized from geological maps of the region. The uplift, steepness and hack index maps have been generated by using some specially designed algorithms for this purpose. The results show that in main Pamir region the surface uplift and deformation rate vary significantly as compared to different regions and is in accordance with the orientation of the lineation. The reason can be summarized to highly complex and spatially variable geomorphology of the region due to the active tectonics. High resolution DEMs are needed to monitor carefully the ongoing complex faulting in the Hindukush part of mountains adjacent to Pyanj River.

Keywords— Digital Elevation Models, Image Processing, Pamir Indenter, Steepness and Concavity index, Pyanj River.

1. INTRODUCTION

During the last decade, the cartographic technology has developed at a rapid pace and river longitudinal profiling can be easily and effectively derived from topographic maps and DEMs (Digital Elevation Models) [1,5]. This study focuses on exploitation of DEMs as a tool to study active tectonics in the region of Pyanj River basin in Pamir using longitudinal river profile analysis. The courses of the great rivers of Asia have been influenced by the progressive Cenozoic collision of India and Eurasia and the subsequent tectonic events that raised the great south Asian mountain ranges. This collision not only caused extreme lateral displacement of tectonic units but also continued raising Tibetan plateau and its outskirt mountain ranges, causing considerable changes in regional climate and drainage networks [2, 4].

![Fig.1 Location map for rivers of the Pamir Indenter and adjacent topography on shaded relief map](image-url)
and most accurate method of generating basin-wide drainage-area data sets. In this study we focus on the effects of spatially variable rock uplifts on the steepness and concavity indices of the bed Rock River profiles.

2. TECTONIC SETTING OF PAMIR

Located in Central Asia, the Pamir lies at the western end of the Indo-Asian collision zone and is bounded by the Tien Shan to the north, the Hindu Kush to the south, the Tarim Basin to the east and the Tajik Depression to the west. The Pamir is surrounded by major fault systems. The Pamir arc came into being over the last 10 ma, as Indian plate moved northwards 530 km relative to Asia [5]. The present indentation is marked on the west by the predominantly ductile deformation northeast of the Herat fault; these faults curve northeastwards into thrust faults and mark shortening within the Central and North Pamir. On the east, the right-lateral Karakorum fault cuts the eastern flank and has displaced the suture zones more than 500 km northwards [6]. Interpretations of earthquake hypocenter relocations indicate active steeply south-dipping subduction along the Main Pamir thrust and shallow north-directed subduction of the Indian plate beneath Asia along the southern margin of the orogen. While Cenozoic deformation appears to have been dominated by north-south shortening along east-trending structures, active deformation within the Pamirs is dominated by north-trending faults and folds [7].

3. MATERIALS AND METHODS

3.1. Drainage Network Delineation and Data Handling

Any suite of computer scripts that can follow the path of pixels downstream while recording the elevations, cumulative streamwise distance, and contributing drainage area data is sufficient for collecting long profile data from a DEM. D8 algorithm is a frequently utilized scheme that underlies watershed and drainage network delineating by assuming that water in a given pixel will flow towards only one of its 8 neighboring pixels, whichever pixel lies in the direction of steepest descent on a 3×3 elevation grid matrix. We format the D8 flow grid from raster to vector. All pixels that have a flow code of zero are treated as basin outlets, which include the four edges of the DEM and the no data pixels in the DEM. The derived vector file stores data for a single basin or many disjoint sub-basins. Every pixel in a particular basin is the outlet pixel for a sub-basin that is
contained in this basin. Each of these sub-basins has many attributes, such as contributing area and relief. This vector file stores all of these attributes (in a compact way) for all of the pixels/sub-basins in a given basin. Finally, in order to display the river network, we created two more vector files using River tools. One is the link file that stores attributes for every channel link in the river network, and the other is a stream tree file that stores attributes for every Horton-Strahler stream in the river network. Moreover, in order to further calculate steepness and concavity, here we create drainage area grid as well. The drainage area is returned as numbers of pixels and square kilometers.

3.2. Calculation of Steepness, Concavity Indices and Model fitting
The calculation is based on the stream power model that detachment-limited incision into bedrock is often modeled as a power law function of contributing drainage area and channel gradient [8-9].

\[
S = k_A^{-\theta} \quad \text{(1)}
\]

\[
S = \left( \frac{U}{K} \right)^{\frac{1}{n}} A^{-\left(\frac{m}{n}\right)} \quad \text{(2)}
\]

m and n are positive constants related to basin hydrology, hydraulic geometry, and erosion process. Where the coefficient \((U/K)^{\frac{1}{n}}\) sets the channel steepness, \(k\), and the ratio \(m/n\) is the intrinsic channel concavity, which equals the actual concavity \(\theta\) under conditions of uniform \(K\) (erosion co-efficient), \(U\) (uplift rate), m, and n.

3.3. Tectonic Analysis
Tectonic information is extracted from the longitudinal profiles and the data obtained for steepness and concavity mostly give similar information, because a downstream transition between two different steepness values is normally bridged by a zone of very high or low concavity [10]. A stretch with anomalously high channel gradient index means that stream is highly energetic and it is may be associated to, a belt of resistant rocks, a zone of differential uplift, or erosional disequilibrium between two drainage networks and vise versa. In our case, for the large scale studies, abrupt spatial changes of channel gradient (at major knickpoints) are caused by tectonics, by river capture, or in the headwaters, or by climate change (e.g former extent of the quaternary glaciers). The sharpness of the knickpoints is a relative measure, that how recent the tectonic or river capture event, or glacier retreat was occurred [11]. In general, the sharper the knickpoint, the more recently it developed.

3.4. River Profile Analysis
We analysed 24 rivers in the Pamir (Pyanj Basin) and they are, Pyanj-Amu, its right bank tributaries (Pamir, Shokhdara, Ghunt-Alichur, Aksu-Murghab-Bartang, Yazgulemi, Vanch) and one left bank tributary Shiveh. The Pyanj profile shows consistency with compression and shortening of its course during the formation of Pamir indenter. The Pyanj makes a slight decrease in gradient as it makes a right angle turn to the northwest near Ishkashim and here it may mark a very old river capture event (Fig.8 Pyanj profile) since there is relatively a low pass to the southwest into the Warsaj-Qonduz drainage. This river capture might have been occurred millions of years ago and there is little evidence left now [2].

Fig. 3 Pyanj River Profile analysis with selected knick points and stream indices

The north-northward section of the Pyanj behaves like an antecedent river. It shows the steepest gradient and flows over a distorted subcrustal zone marking the change from a north to south dipping subducted slab that underlies the hindukush and northern Pamir. The reason for this is still unknown, in this section Pyanj might have been controlled by the deeper tectonics by forming a thin and weak continental crustal zone. Also Pyanj River interacts with the central Badakhshan fault, Henjvan fault and finally Darvaz fault as shown in (fig.2). Due to the strike slip movements of these faults there are two sharp bends in the course of the Pyanj river when it flows along these faults and finally cut them and then leave. The left bank tributary in the section is Shiveh river and it shows a low gradient profile, it is may be because it flows along a major thrust zone of Easily weathered and shattered rock and has a permanent glacial source, but there is no sign of glaciation in its lower reaches. The 530 Km northward movement of the Pamir indenter since its formation, suggest that the present great U-Bend in the Pyanj is because of this northward translation [6].

4. CONCLUSION

Digital elevation model (DEM) is key component for computer-based analyses of river profiles and drainage basin extraction as it provides elevation information for the land surface throughout the catchment of the area. In our study area, with the exception Pyanj River the rest of the
river follow the structural grain of the mountains and these rivers continued to develop with the rise of this region. The change in their courses is due to their interaction with the tectonics, landslides blocking and glaciers.

The geomorphic indices like steepness and concavity serve as good indicators to monitor the uplift conditions in an active neotectonic region. The river profile analysis shows higher uplift rates on NNE west of Pyanj and thus shows higher incision rates throughout its course except in the central Pamir plateau in its Pamir tributary and second beyond Pyandzh town in its lower Amu reaches as shown in the Fig.4.

Fig.4 Uplift map of Pyanj basin, showing Darvaz and Panjsher faults

The further work is underway regarding regional uplift and stream fault correlation, fractal dimension of rivers etc.

REFERENCES


