Tectonomorphometric Analysis Using Remote Sensing and GIS Techniques in the High Folded Zone between Perat (Bekhme) Anticline and Bradost Anticline, NE Iraq

Ahmed F. Al- Ma΄amar **Mustafa R. Al-Obaidi**
Department of Geology, College of Science, University of Baghdad
ahmedryaman@gmail.com mustafa.r.s.alubaidi@gmail.com

Abstract

In this study, remote sensing and GIS analysis techniques are used to determine geological and morphometric properties of the High Folded Zone (HFZ), NE Iraq. In order to identify tectonic activity of study area, different indices including Hypsometric Integral (HI), Surface Roughness (SR), Surface Index (SI), Topographic Position Index (TPI), Incision Map and Stream Length gradient index (SL) were used for four rivers within our study area. For Geomorphological Mapping, we used ASTER level 3 having three bands in the Visible and Near InfraRed (VNIR) spectral with spatial resolution of 15m that were acquired on 15 September 2006. ASTER Digital Elevation Model (DEM) with resolution 15m was used with ASTER VNIR to construct an anaglyph image for 3D viewing based on ERDAS Imagine V.13 and Arc GIs V.10 as well as shaded relief. Quick Bird images with spatial resolution 0.6m were used for visual interpretation to determinate geomorphological units.

The Geomorphological units of the study area were classified into four units depending on their tectonics activities which are: unit of structural origin, unit of structural – denudational origin, unit of denudational origin and unit of fluvial origin. Each of these units includes different lithomorphologic landforms, which were developed as a result of tectonic activities, structural, lithologic (competent, incompetent) and climatic factors.

Keyword: geomorphological map GEM, digital elevation model (DEM), geomorphic indices, remote sensing, GIS, Zagros-Taurus.

الخلاصة

استخدمت تقنيات التحسس النائي ونظم المعلومات الجغرافية لتحديد المظاهر الجيولوجيه والخصائص المورفومترية للمنطقة الواقعة في نطاق المرتفعات العالية شمال شرق العراق. لتحديد الفعاليات التكتونية لمنطقة الدراسة استخدمت مختلف الادله المورفومترية والتي تضمنت كلا من (HI, SR, SI, TPI, SL) لاحواض اربعة أنهار ضمن منطقة الدراسة. ولانتاج الخريطة الجيومورفولوجية استخدمت الحزم الطيفية المرئية والتحت حمراء الثلاثة العائده لبيانات المستوى الثالث للمتحسس ASTER وبدقة مكانية 15م والملتقطة بتاريخ 15 ايلول 2006. تم استخدام بيانات نموذج الارتفاع الرقمي لاشتقاق مرئية الظلال، ولبناء صورة مجسمة 3D لمنطقة الدراسة بعد مراكبتها مع الحزم الطيفية المرئية بواسطة برنامجي الايرداس والارك جي اي اس. استخدمت بيانات القمر الصناعي كويك بيرد بدقة 0.6 سم لتفسير وتحديد الوحدات الجيومورفولوجيه. صنفت الوحدات الجيومورفولوجية في منطقة الدراسة الى اربع وحدات بالاعتماد على النشاطات التكتونية وهي: وحدات ذات اصل تركيبي، وحدات ذات اصل تركيبي–تعروي، وحدات ذات اصل تعروي واخيرا وحدات ذات اصل ارسابي. تتضمن كل وحدة مختلف الاشكال الارضية والتي تطورت كنتيجة للفعاليات التكتونية، التركيبية (صلبة وهشه) والمناخ.

الكلمات الدالة: خريطة جيومورفولجية، نموذج الارتفاع الرقمي، الادلة الجيومورفمترية، تحسس نائي، نظم معلومات جغرافية، زاكروس – طوروس.

1. Introduction

Tectonic geomorphology is defined as the study of landforms produced by tectonic processes, or the application of geomorphic principals to the solution of tectonic problem(Keller and Pinter, 2002). The application of Remote Sensing (RS) and Geographical Information System (GIS) is very suitable for structural geology, tectonic activity and geomorphology. RS and GIS are important tools for understanding tectonics activity from digital elevation models (DEMs). DEMs are very useful for modeling surface processes in addition to analyses of topography, lithology, landscapes and landforms.

Badura and Przybylski (2005), Al Dousari and ud din (2010), Sharma and Kujur (2012), and Jayappa et al. (2012) mentioned that DEMs are important methods to extract information about the surface model processes, topographic and neotectonics structures. In addition, DEM represents an active field of research in many tectonomorphometric applications, which target model surface processes. Faisal and Gloaguen (2011) and Daxberger (2013) explicate uncovering the tectonomorphometric evolution of any area is paramount for understanding the tectonic geomorphology at regional and local scales. Tectonic geomorphology is caused by the influences of vertical and horizontal earth deformation on fluvial, coastal, and glacial processes and the resulting landscapes (Bull, 2007). The morphology of the drainage basin, active thrust and fluvial reflected the active tectonics of the area, so the geomorphic indices are important tools to evaluate neotectonics (Bhatt et al., 2008). Shahzad and Gloaguen (2011) explicate any surface can be influenced by tectonics and they can be investigated to discriminate the spatial distribution of tectonic processes. Mumipour and Nejad (2011) and Siddiqui (2014) mentioned the morphometric indices could compute from the integration between the GIS and DEM to detect the neotectonics activity. Faisal and Gloaguen (2011) used TecDEM as a Matlab based tool for understanding the tectonic activity from DEMs, and these tools have ability to generate stream profiles, determine flow directions, delineate watersheds, and compute geomorphic indices.

The main objective of this study is to define morphological properties of tectonic activities by using RS and GIS from DEM. The study area is part of Taurus-Zagros belt. The direction of the Zagros belt is NW-SE, while the direction of the Taurus belt is E-W. The topography of the study area is dominated by formation ranging from the Jurassic to the Tertiary rocks(Ibrahim et al., 1984). Zagros Mountains topography is the result at highly scale–dependent interaction involving tectonic and surface processes.

Tectonic geomorphology deals with the geodynamics and geomorphic manifestation of crustal deformation processes. In Zagros–Taurus, bulk of the relief in mountain region has been formed by uplift along thrust fault striking sub-parallel to the trace of the thrust zone. By quantifying features, the tectonic uplift rates and constrains geomorphic process rates can be inferred. To understand the complex interrelation of these elements in regional scale, there is a need to develop new approaches and methodologies. The evidence of neotectonic activities are commonly available through various geomorphic signatures that can be studied using geological (such us active fault, lithology… etc.) and geomorphic aspects.

There are four main rivers in the study area dominated by the mountains ranges (anticlines) which are: (i) Greater Zab River (GZR), which has NW–SW trend and predominated by Bradost and Piris Anticlines, (ii) Ruwandoz River (RwR), which has NE–SW trend and predominated by the plunge of Korek and SE part of Bradost Anticlines, (iii) Alanah valley that has SE–N trend and pour in the (RwR) which is predominated by Korek and Harir Anticlines, (iv) W. Suse valley as a trend from SW–NE and pour into the GZR which is predominated by Piris and Perat (Bekhme) Anticlines.

However, at the NW of the study area and at the SE limb of Bradost Anticline, the GZR is impressed with tectonic activity from the meander of the river and cut across the Perat (Bekhme) Anticline and several major Cenozoic faults. The GZR cuts one of the important tectonic belts, which is Taurus-Zagros Orocline. At the NE of the study area and the SE limb of Bradost Anticline the RwR impressed with tectonic activity from the meander of the river because they cross of major fault until to pour the GZR. The most important morphological feature of the rivers is the meandering (Othman and Gloaguen, 2013). The change of the river from straight rivers to the meandering is impressed by tectonics and structural features such as fault and fracture (Huggett, 2007).

RS and GIS are useful tools and techniques to identify geomorphic units, because geomorphology reflects the tectonic activity of the study area. Geomorphology is defined as the science of landforms with an emphasis on their origin, evolution, form, and distribution across the physical landscape (Karwariya et al., 2013). Landscape depends on physical, chemical and biological processes that produce landforms. These landforms are upgrowth depends on the underlying geological structure. It includes mountains, plateaus, andulated hills, alluvial fans, gorges, river terraces, slopes, and gullies etc.(Bhat et al., 2013). Structural geomorphology means include rocks, fractures, faults and folds. In study area, there are different geomorphological units which are developed and these reflected the tectonic processes of faulting, tilting, folding, uplifting and subsidence – upon landforms(Huggett, 2007).

Sharma and Kujur (2012) mentioned that DEM with GIS tools can serve for finding geological boundaries and geomorphology features. Karwariya et al. (2013) clarify geomorphological mapping involves the identification and distinguishing of various landforms and structural features and this can influence a preservation area in many ways like slope gradient, elevation and aspect, affect the quantity of solar energy, water, nutrients and other materials, while the slope affects the flow of materials.

Geomorphological map (GEM) of the High Folded Zone HFZ is prepared depending on visual interpretation of satellite imagery ASTER, in addition to anaglyph and shaded relief.

Geomorphic indices have been developed as basic reconnaissance tools to identify area experiencing rapid tectonic deformation. These indices based on topography that are used in studies of active tectonics. Some of the geomorphic indices used for active tectonic studies are: Hypsometric Integral (HI), Surface Roughness (SR), Surface Index (SI), Topographic Position Index (TPI), and Stream Length gradient index (SL).

2. Study area

The study area lies in the NE part of Iraq. It's considered a best exposed of structural feature. It is laid within the HFZ, which is a part of the Unstable Shelf (Buday and Jassim, 1984). The study area is covered of 1086 km²; lying between the following geographical coordinates: 36° 30′ - 36° 53′ 45′′ N; 44° 00′ - 44° 30 E (Figure 1). This area is distinct by rugged topography which is mainly mountainous and flat terrain, hills and undulated plains. The altitude of the study area varies from 340 to 2117 m(a.s.l.). Many villages and towns distributed in the proposed area, such as Mergasur, Mazna, Khalifan, Harir, Bekhma, and Bujal.

3. Geological settings

The Alpine Orogeny in Northern Iraq resulted from the collision between the Arabian and Eurasian plates (Hessami et al., 2001; Ibrahim, 2009; Omar, 2005). The study area is located in the NE margin of the Arabian plate, therefore; the study area undergoes the tectonic deformation that impression of the Arabian plate (Zebari, 2013). As a result of collision between Arabian plate and Iranian plate, the HFZ was formed during the Late Cretaceous and Mio-Pliocene periods.

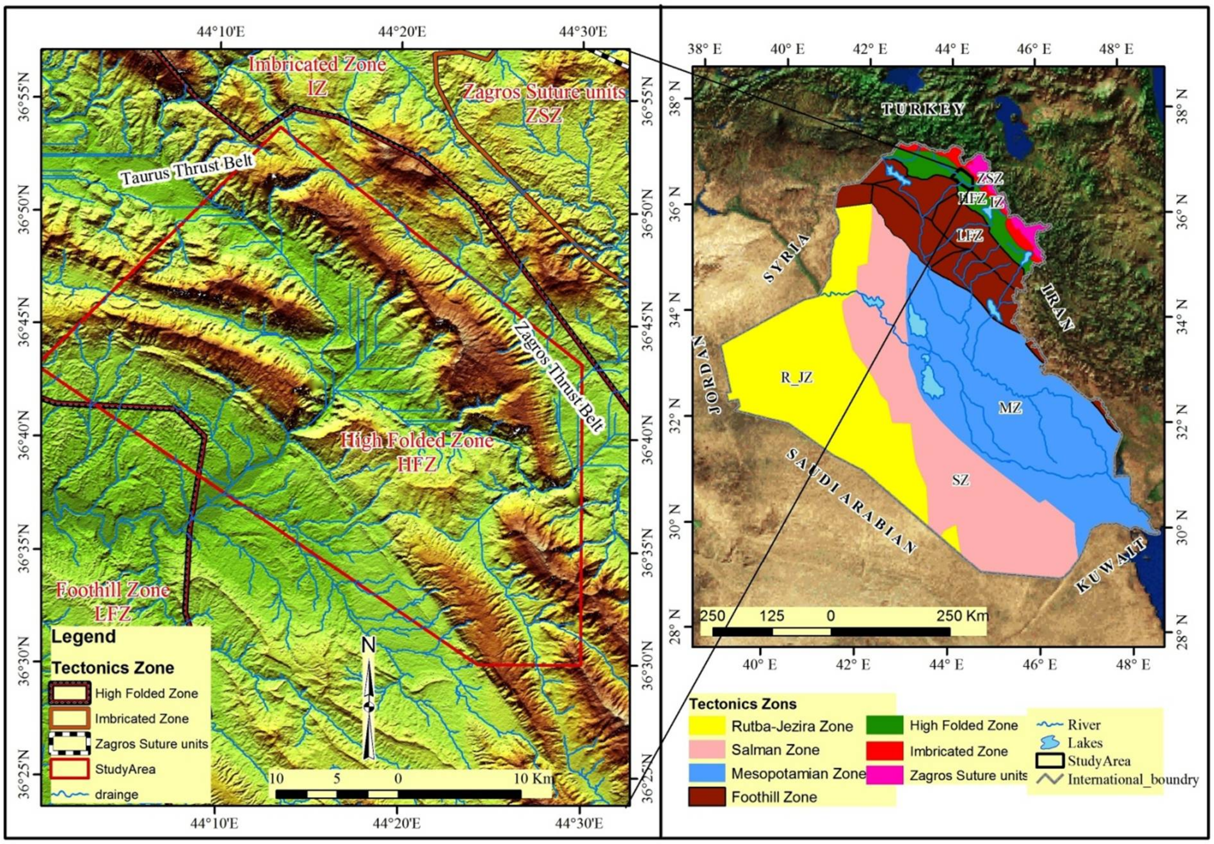


Figure 1: Location map and tectonic map of the study area in the HFZ between Taurus and Zagros thrust belt after (Jassim and Goff, 2006)

It's characterized by anticlines of high amplitude with Palaeogene or Mesozoic carbonates exposed in their cores. The zone was uplifted in the Cretaceous, Paleocene and Oligocene time, but was also the site of an Eocene molas basin (Jassim and Goff, 2006).The trending of Taurus and Zagros thrust belt was developed as a result of the collision of the Arabian-Turkish- Iranian plate (Jassim and Goff, 2006). The axis of anticlines have trend E-W in the N and NW parts of the study area, while they have NW-SE trending in the S and SE parts. The change of the trend of the axes of anticlines is related to the collision and convergent zone along the Taurus–Zagros Mountain system.

Jassim and Goff (2006) have divided Iraq into the subdivision tectonic zones based on tectonic and structural element and based on their subdivision, the study area located on the Unstable Shelf which represented by HFZ. The HFZ is covered by sedimentary rocks ranging in age from the Jurassic to the Tertiary, in addition to different types of Quaternary sediments (Figure 2). Depending on the previous works ((Ibrahim et al., 1984; Jassim and Goff, 2006; Omar, 2005; Sissakian, 1998; Zebari, 2013) the exposed formations are clarify in (Table 1). At the core of anticlines within the study area the exposed rocks almost are the Jurassic, while Cretaceous and Tertiary rock units crop out in limbs of anticlines. Quaternary sediments are being mainly accumulated in the synclines within the study area. The major folds in the study area are Bradost, Korak, Perat (Bekhme) and Harare Anticlines. The slopes of the study area is ranges from flat to 73°. These variance in slopes reflects the effect of tectonics, erosion and the disparity strength between the rocks from (competent and incompetent).

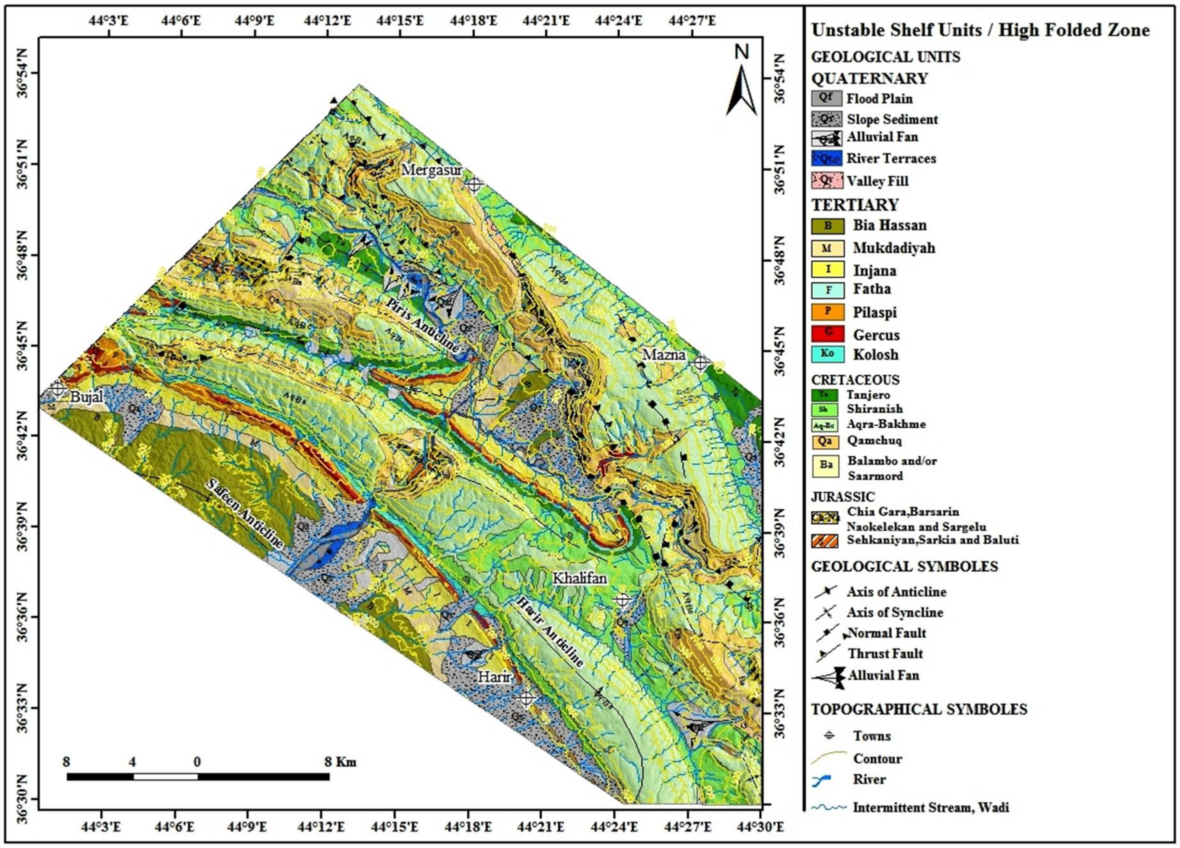


Figure 2: Geological map of area between Perat (Bekhme) and Bradost Anticlines in the HFZ, northern Iraq modified after (Ibrahim et al., 1984; Sissakian, 1998)

Table 1: Lithological succession of the study area modified after (Ibrahim et al., 1984; Jassim and Goff, 2006; Omar, 2005; Sissakian, 1998; Zebari, 2013)

Period	Epoch	Stratigraphy	Lithology	Thickness
Quaternary	Holocene	Floodplain	sand, silt, clay and rarely carbonite and igneous gravels and rock fragments, cemented by calcareous cement with some silicate.	?
	Holocene / Pleistocene	Valley fill/ Alluvial fans / Slope sediments		
	Pleistocene	River terraces	Silica and limestone pebbles with some metamorphic and igneous rocks. The pebbles are cemented by sandy, silty and rarely by clayey materials, usually gypsiferous in the top of the terrace.	
Tertiary	Pliocene	Bai Hassan	Alteration conglomerate, sandstone and claystone	300-850m
	Pliocene / Miocene	Mukdadiyah	Cycle deposits of pebbly sandstone, siltstone and claystone	200-500m
	Miocene	Injana	Cycle deposits of red sandstone, siltstone and claystone	150-400m
		Fatha	Thick red claystone, siltstone, limestone, marl, and gypsum	180-230m
	Eocene	Pila Spi	Mainly well bedded limestone	5-90m
		Gercus	Red sandstone, siltstone and clystone	80-100m
		Kolosh	Black claystone, siltstone and sandstone	100m
Cretaceous	Late	Tanjero	Khaki sandstone, claystone with conglomerate intermingling with olive green marl	450m
		Shiranish	Well bedded limestone and blue marl	100m
		Bekhme-Aqra	Well bedded very hard dolomitic limestone	400 m
	Early	Qamchuqa	Thick bedded to massive and very hard limestone and dolomites	635m
		Balambo and/or Sarmord	Well bedded limestone and marl	80m
Jurassic	Late	Chi Gara, Barsarin,‹ Naokelekan and Sargelu	Mainly bedded to massive dolomites, limestone and marl	150m
	Middle			
	Early	Sehkaniyan, Sarki and Baluti	Mainly limestone, dolomites, thin bedded limestone and shale	

1. Methodology

1.1. Geomorphological Mapping (GEM)

For geomorphological mapping (GEM), the study adopted ASTER three bands in the visible and near infrared (VNIR) spectral range (0.5-1.0 µm) with 15 m spatial resolution. This scene of ASTER was acquired on 15 September 2006. ASTER DEM with resolution 15 m has been produced from ASTER Nadir (N) and backward looking (3B) bands (0.76–0.86 µm). DEM was used with ASTER VNIR bands to construction anaglyph image for 3D viewing based on ERDAS Imagine V.13. In addition, contour line (interval 200 m) and shaded relief was extracted from DEM. QuickBird images were used for visual interpretation to determinate geomorphological units. These data were acquired on 29 August 2006. QuickBird scenes have three visible spectral bands, Blue (0.45 to 0.52 µm), Green (0.52 to 0.60 µm) and Red (0.63 to 0.69 µm) (Krause, 2005). These scenes are orthorectified, and radiometrically corrected 8-bit scenes, with 0.6 m spatial resolution. The geomorphological map was produced using ArcGIS 10 software.

-Geomorphological units

The study area (Table 2; Figure 3) was classified geomorpholgically depending on the researcher and on some available information from the previous works (Al- Mammar et al., 2011; Hamza, 1997; Witold and Hassan, 1986). Landforms of structure origin were mapped in the study area as two origins, which are unit of structural origin and units of structural- denudational origin. These landforms are related to the aspect of underlying structures (Karwariya *et al.,* 2013).

Table 2: Geomorphological units in the area between Perat (Bekhme) and Bradost Anticline in the High Folded Zone

Geomorphological units	Lithomorphologic	Action
Units of structural origin	Structural ridges: which represented by anticlinal ridges and synclinal ridges	Tectonics
Units of structural - denudational origin	Homoclinal ridges: which represented by cuesta, hogback and flat iron	Tectonics and erosion
Units of denudational origin	Glacis (pediment): which represented by erosional and deposional glacis	Tectonics activities, geology (lithology) and climate
	Badlands	
	Scree slope	
	Unstable slope	
	Water gap and wind gap	
	Erosional escarpment	
Units of fluvial origin	River terraces	Tectonics activities, erosion and deposits
	Alluvial fans	
	Floodplain	

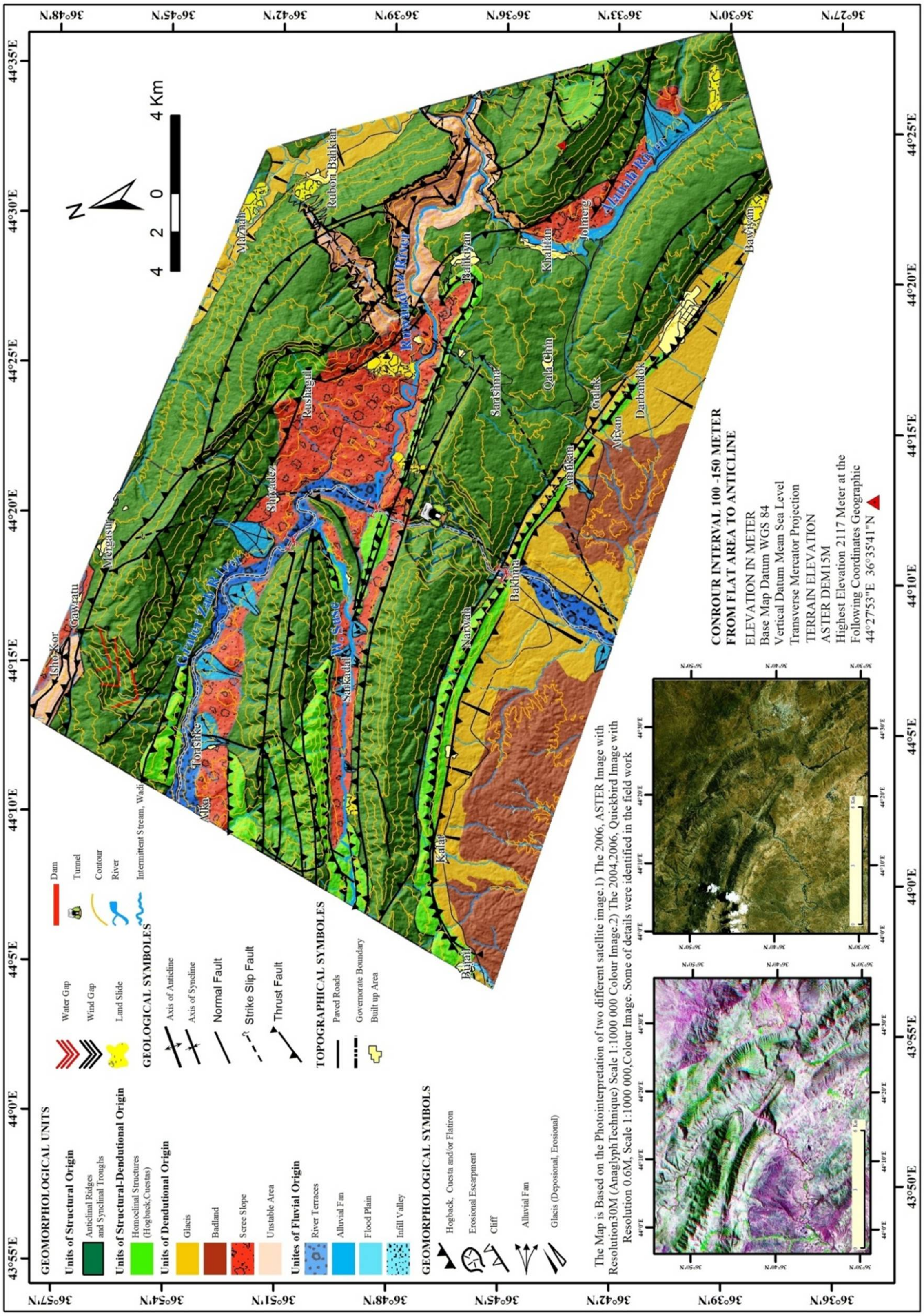


Fig. 3: Geomorphological map of area between Perat (Bekhme) and Bradost Anticlines in the HFZ

1.2. Tectonics geomorphology

we used shuttle Radar Topography Mission (SRTM, V. 4.1) with a spatial resolution of (90 m) to compute tectonics geomorphology and geomorphic indices. Environment for Visualizing Images (ENVI) software was used to process the DEM. Filled DEM was used to extract drainage network by compute flow direction, which depends on upslope and catchment area using D8 algorithm. Stream parameters are influenced by the choosing of the algorithm of stream delineation, stream parameter represented by contributing area, slope, elevation, downstream distance and Strahler order (Faisal and Gloaguen, 2011). These entire algorithms were implemented using TecDEM 2.2, a Matlab-based software to calculate HI, SR, SI, TPI, incision map, Knickpoint and SL. Finally, We extracted the drainage network with Strahler order rivers and drainage basins for the study area.

- **Hypsometric Integral Map (HI)**

HI considered an appropriate parameter to distinguish the development in landscape, which reflects the interaction between the tectonics and erosion (Markose and Jayappa, 2011; Othman and Gloaguen, 2013). Hypsometry represents the amount of surface that locats above a given elevation. From inspection, the HI value below 0.35 characterizes old or monadnock phase, from 0.35–0.6 mean the area is in the equilibrium (mature) phase; while the HI value above 0.6 represents the area in a inequilibrium (youthful) stage in its landscape development (Markose and Jayappa, 2011; Othman and Gloaguen, 2013; STRAHLER, 1952). To calculate the HI (Equation 1; (Othman and Gloaguen, 2013), we used moving windows for 50 pixels, which represent 1km^2.

$$HI = \frac{H_{mean} - H_{minimum}}{H_{maximum} - H_{minimum}} \qquad (1)$$

Where HI is the hypsometric integral value and H is the elevation. Elevation data were taken from the SRTM DEM 90 m.

Figure (4) explicates the HI for the study area. The HI values range from 0.54 to 0.092; the values (<0.35) were found in the flat area almost on the syncline toward the limb of anticlines and mostly eroded and less impressed by neotectonics. The HI values 0.35-0.54, which indicate equilibrium (mature) phase: and we indicate that in the structural ridges of Bradost, Harir and between Piris and Perat (Bekhme) Anticlines, as well as when the strike slip fault cut the gorge of Perat (Bekhme) Anticline towards Bradost anticline. The topography of the study area is mainly impressed by active thrust fault.

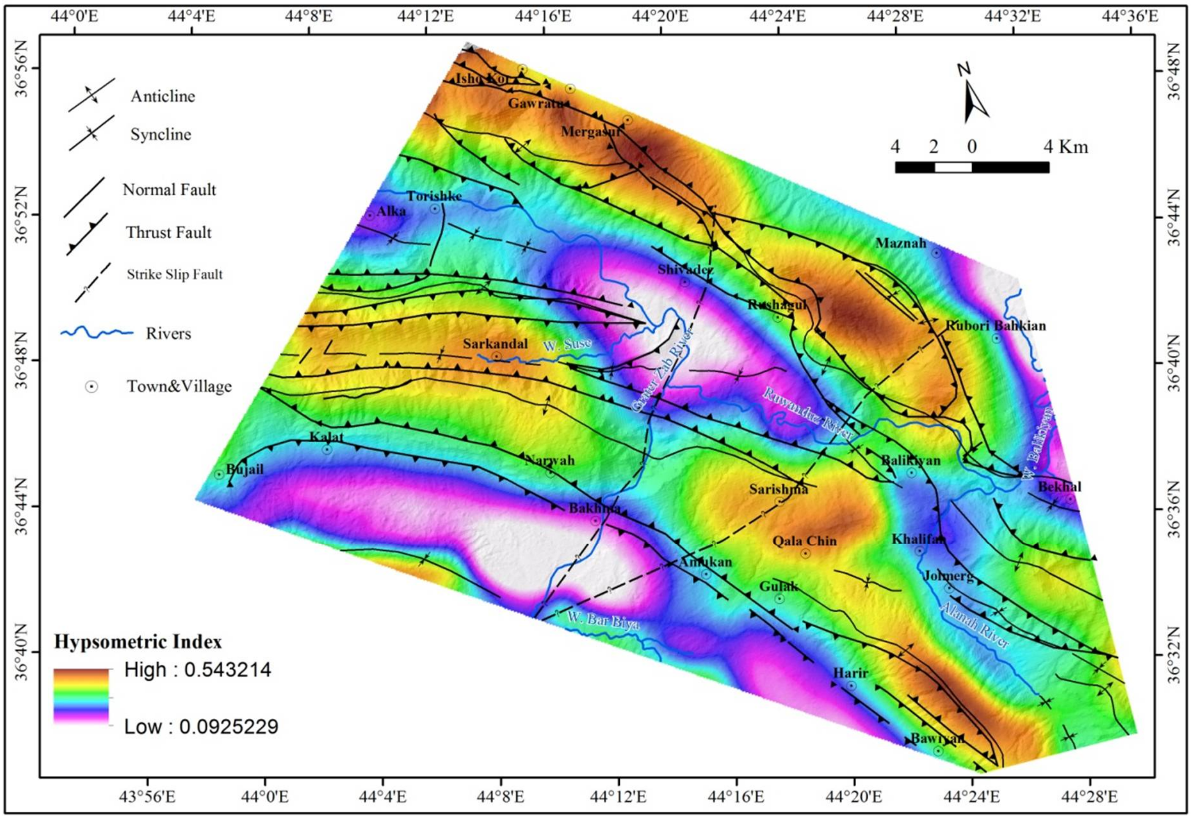


Figure 4: show HI based on hillshade of area between Perat (Bekhme) and Bradost Anticlines in the HFZ

- **Surface Roughness Map (SR)**

SR is a measure of the texture of a surface and, is quantified by the vertical deviations of a real surface from its ideal form (Ahmad et al., 2013). Previous studies suggest that SR can be used to study the morphological characteristics of a region(Grohmann et al., 2009; Shahzad and Gloaguen, 2011)**.** In any surface grid, SR is described as a ratio between surface area and flat area (Shahzad and Gloaguen, 2011). SR represents the relation between the landscape evolution and neotectonics. Lower values of SR indicate relatively flat topographic basins which refer to a region of intermediate slope gradient and orientation. Areas with high SR values correspond to sharp changes in the slope gradients and orientations, which could be due to abrupt scrap edges (possibly neotectonic or lithological control) (Ahmad et al., 2013). To create SR, we used moving windows for 50 pixels which represent 1km^2. The result of the SR map indicates that the area in (1.10) corresponds to rapid variations in slope gradients and orientations. It means abrupt scrap edges that refers to neotectonic or lithological. We indicated in the area between the Perat (Bekhme) Anticline and specifically from the axis of the anticline to the NW limb of Piris Anticline, Korke Anticline, SE limb of Bradost anticline is affected by landslide. This region is impressed by a fault. Low value of SR (1.003) represents flat area intermediate slope gradient and orientation as shown in Figure 5.

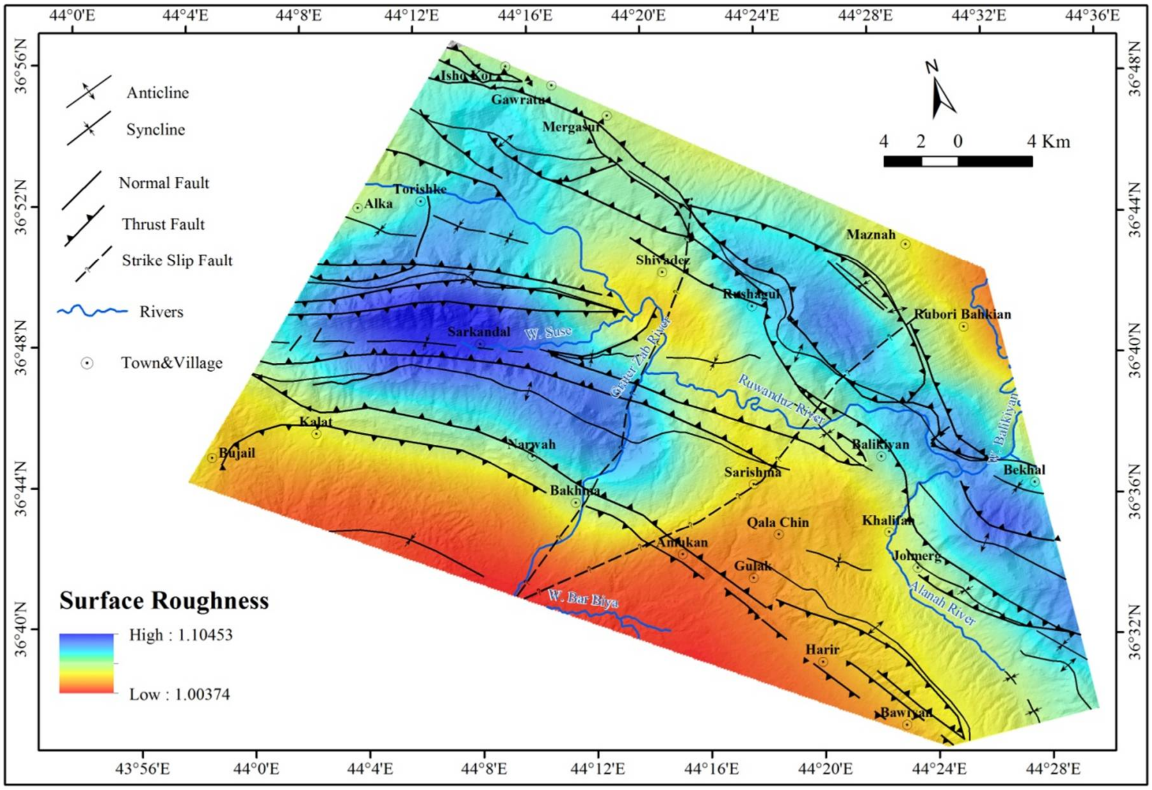


Figure 5: Show SR based on hillshade explain the ratio between surface area and flat area

- **Surface index Map (SI)**

SI (Equation 2) is a new tool in TecDEM V. 2.2, which highlighted to classify landscapes depends on their erosional stage. This index is suggested by Andreani *et.al.* (Andreani et al., 2014). The stage of erosion is impressed by the rocks type (competent, incompetent). Positive SI values represent preserved areas that are mainly corresponding to severe eroded lithology, while negative SI values correspond to easily eroded lithology (Andreani et al., 2014).

$$SI = \left(\frac{HI - HI_{min}}{HI_{max}}\right) * \left(\frac{H - H_{min}}{H_{max}}\right) - \left(\frac{SR - (1 + SR_{min}}{SR_{max}}\right) \qquad (2)$$

Where SI is surface index, HI is the hypsometric integral value (Equation 1) (Othman and Gloaguen, 2013) H is the elevation data taken from SRTM 90 m, and SR is the surface roughness value, which represent in any surface grid, the ratio between surface area and flat area (Shahzad and Gloaguen, 2011). Figure 6 shows the positive value of SI (0.282) which represents severe eroded lithology of sedimentary competent rocks (thick layer of limestone of Qamchuqa, Aqra- Backhma Formations), affected by thrust fault and series of lineament in multidirectional. The low value -0.846 represent more easily area erosion with incompetent rocks (friable).

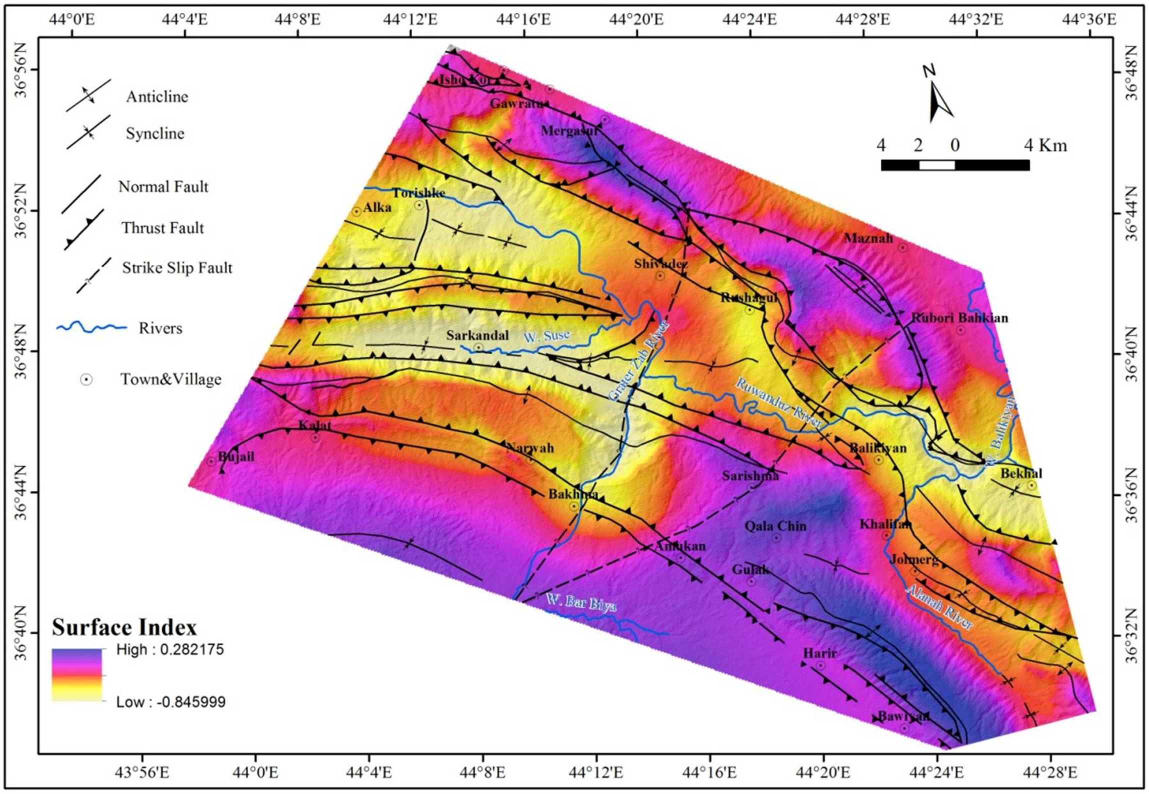


Figure 6: SI based on hillshade the stage of erosion in study area

- **Topographic Position index (TPI)**

TPI is a new tool in TecDEM2.2, which clarifies a simple way to classify landscapes as valleys, ridges and flat areas, this index is suggested by Andreani *et.al*.(Andreani *et al.,* 2014). Its implementation in tectonic geomorphology and it discriminates the shape of the valleys and detectes other important features such as wind gaps and Knickpoint (KPs) when associated with the extracted river (Dada *et al.,* 2013; Reyaz Ahmad DAR *et al.,* 2013) and (Andreani *et al.*, 2014)Positive TPI values mean the cell is higher than its surroundings viz elevated area while negative values mean it is lower cell in other words flat area, shallow valleys… etc. (Dada *et al.,* 2013).

Figure 7 shows the value of TPI of 883.871 which represents the structural ridge units originated due to tectonic process (anticline ridges of Bradost, Piris, Korck, Perat (Bekhme), Harir). While the value of 534.879 represented units of structural–denudational originated due to tectonic process (homoclinal ridges) dissected by dense drainage predominate by fractures. The value of 185.887, represented by unit of denudational is affected by tectonic activity (scree slope, unstable slope, badland, pediment, wind and water Gap), another feature detect on the main river of GZR, RWR, Alanah valley,W.Sus valley Was KPs impressed by fault. The value range from (-512.098 - -163.106) represents the flat area (flood plain, terraces, alluvial fans).

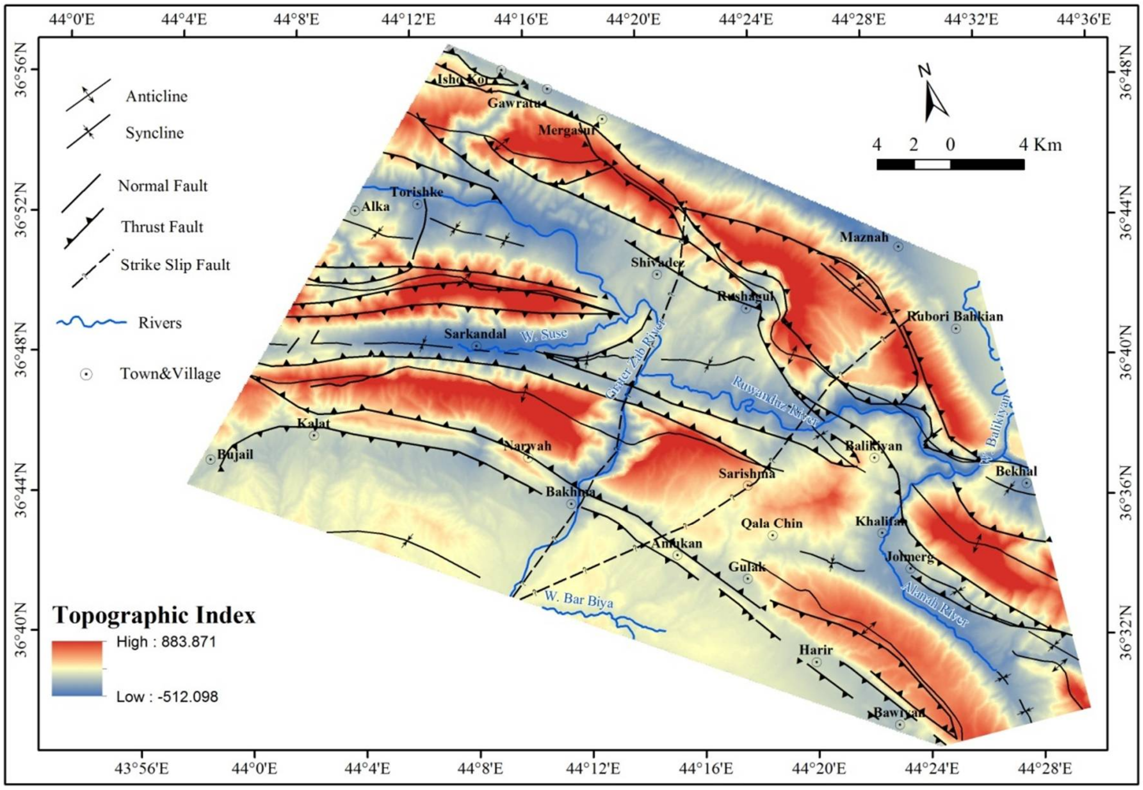


Figure 7: TPI based on hillshade shows the distribution of tectonic geomorphology

- **Incision Map**

The Incision map shows relative or local relief and is a tool for quantifying relative elevation. It is calculated by measuring the difference between the maximum and minimum elevation within a moving window. The calculation of relative relief is influenced by the shape and size of the moving window and is a well documented problem (Shahzad and Gloaguen, 2011) (Mumipour and Nejad, 2011). The moving window should be large enough to include at least two major ridges and/or valleys otherwise the results will not represent local relief but simply the slope gradient (Shahzad and Gloaguen, 2011). We used moving windows for 50 pixels, which represent $1km^2$ to create incision map. The value of 1643.16 represented high gradients in Bradost Anticline (erosional escarpment), affected by thrust fault, series dense of lineament in multidirectional as shown in Figure 8. This map also shows a series of change in the gradient. Water and wind gap are related to extreme incision impressed by fault along the GZR.

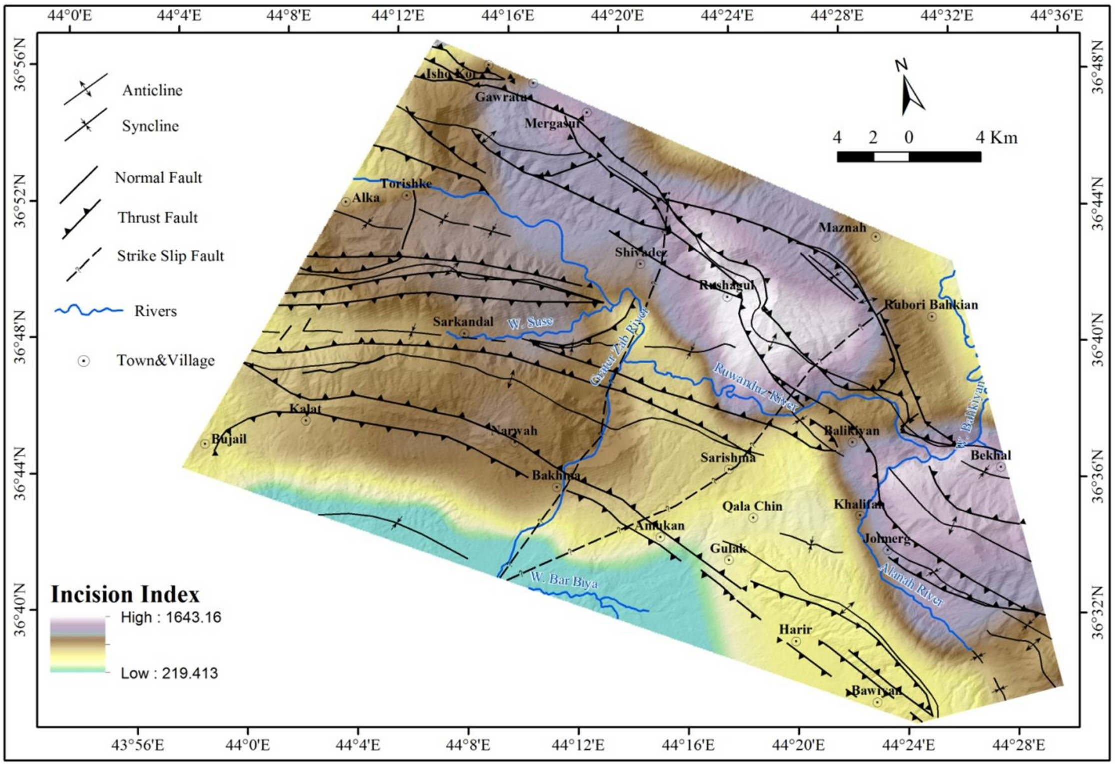


Figure 8: Incision map based on hillshade where clarify the difference between the maximum and minimum elevation.

- **Knickpoint (KP)**

KP is a steep reach in a fluvial long profile, reflecting localized bed incision (GARDNER, 1983). KP is a localized discontinuity zone in the longitudinal profile of a river, where disturbs the generally equilibrium riverbed profile from concave to convex near this point, and its forms in bedrock channel in response to an abrupt base-level fall or a change in the resistance of bedrock (Huang *et al.*, 2012). KPs are important tool to understand the landscape response to a base level fall and the corresponding sediment fluxes from rejuvenated catchments (Shahzad *et al.*, 2009). SL reflects relationship between stream power, rock resistance and tectonics activities (HACK, 1973). SL (Equation 3; Hack (1973) is a useful parameter to evaluate if change in stream slope is due to rock resistance or tectonic deformation in particular (Bhat *et al.*, 2013; Daghastani and Salih, 1993).

$$SL = (\Delta H/\Delta L) * L \qquad (3)$$

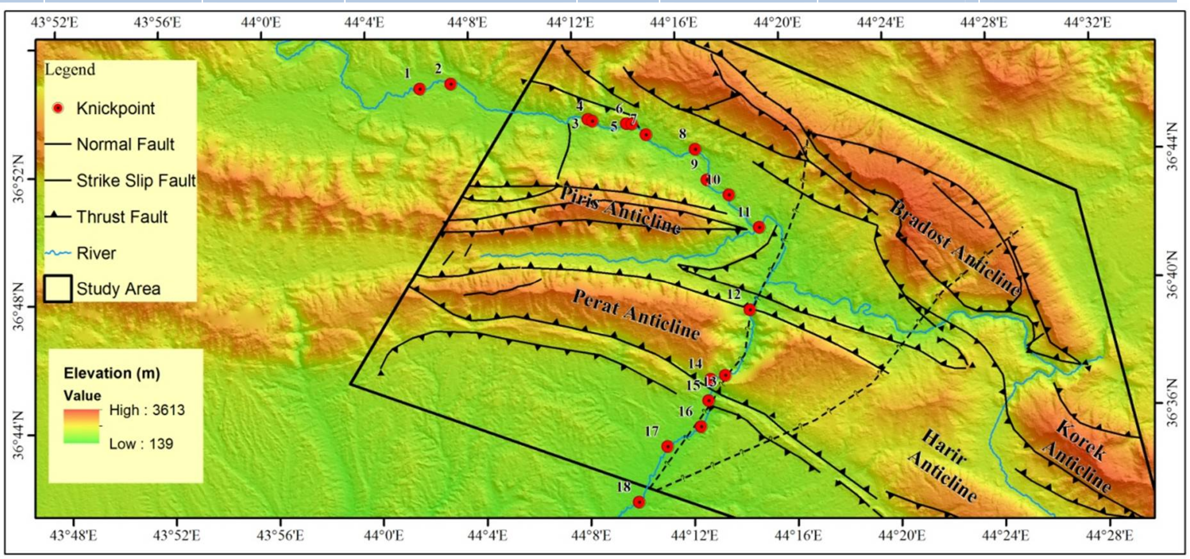
Where SL is the stream length gradient index, L is the stream length measured from the drainage divide at the source of the longest stream in the drainage basin above a locality on a reach. ΔH is the difference in elevation between the ends of the reach**;** ΔL ***is*** the length of the reach. The high value of SL reflects rocks are resistant or active tectonics has resulted in vertical deformation on the surface (Keller, 1986).

Rivers in the study area flow and cut across most of the important lithology Cretaceous, Tertiary and Quaternary uplift, only in Perat (Bekhme) Anticline the GZR cut across antecedent gorge and the bedrocks of Jurrassic. Several KPs are explicit along the longitudinal profiles of the main rivers. The longitudinal profile of the GZR, RWR, Alanha and W. Sus valleys are related to the altitude of the adjacent anticlines (Bradost, Piris, Perat (Bekhme), Harir and Korek).

As observed from the longitudinal profiles to the GZR Figure 9, there are 18 KPs (Table 3) formed along the incision bed river as a result of recent tectonic deformation and erosion of the valley floor. We observed irregular distribution of the KPs along the GZR. KPs from 1 to 11 are impressed by a thrust fault along the river with the meander of river at KP8, as well as the influence erosion of the rocks into bed river and deposits alluvial fans in both limbs of Bradost and Piris Anticlines, KP11 are affected by compression of plunging of the Piris Anticline with plunging of syncline in addition to the thrust fault, while the other from 13 to 18 are impressed by strike slip fault, except KP12 represented the Dam of Bakhma. The sharpness and closer each other of KPs observed most active fault, which means indicates neotectonics influence. This situation reflected disequilibrium stage unstable area.

Table 3: Knickpoints and SL of GZR

No.	Knickpoint	SL index	Elevation (m)	No.	Knickpoint	SL index	Elevation (m)
1	1	105	468	10	10	354	434
2	2	130	468	11	11	383	437
3	3	233	493	12	12	456	435
4	4	236	442	13	13	502	567
5	5	262	472	14	14	514	433
6	6	266	465	15	15	527	383
7	7	276	457	16	16	543	389
8	8	314	451	17	17	573	369
9	9	336	427	18	18	611	372



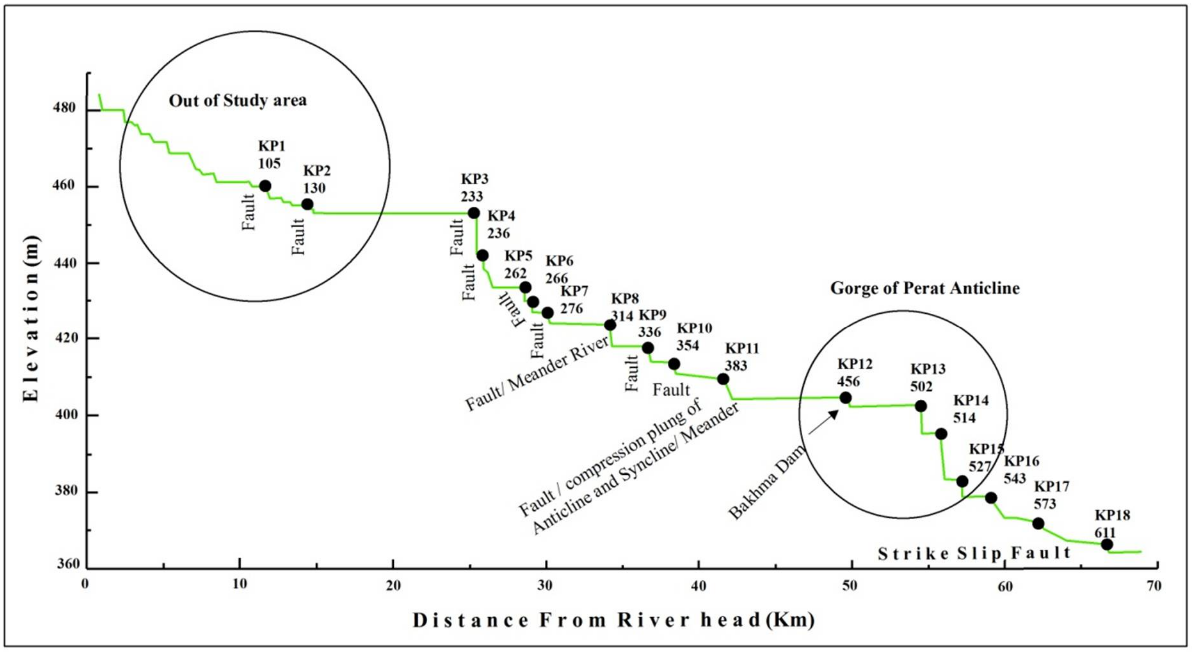
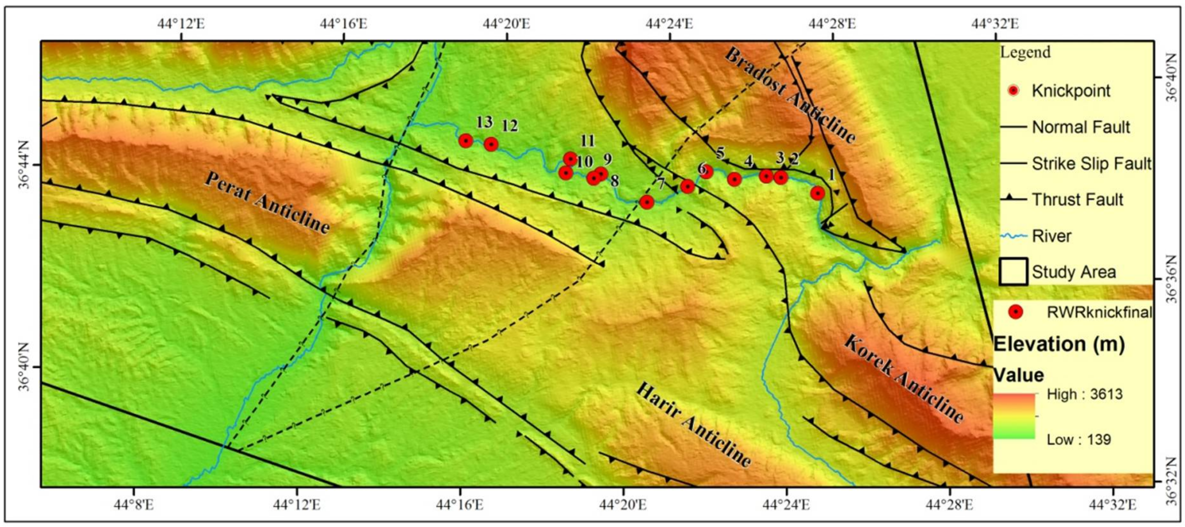


Figure 9: a) Distribution of the KPs along the GZR in the study area. b) Bed river profile of the GZR clarifies distribution and behavior of the KPs

From the observation of the longitudinal profile of the RWR Figure 10, 13 KPs (Table 4) are formed along the incision bed river as a result of tectonic activities, in addition to the erosion bedrock of the river. KP1 and KP2 reflected severe active tectonics and severe incision in the SE limb of the Bradost Anticline as a result of active thrust fault and trace of normal fault which bring different rocks, neither the KPs from 1 to 6, which lies on the unstable limb of Bradost Anticline that affective of active thrust. Closer of Kps each other reflected tectonics activities. KP 7 is impressed by a strike slip fault in addition to being impressed y the thrust of syncline. KPs 8, 9, 10 and 11 are formed as a result of compression fault between anticline and syncline, as well as landslide from severs incision on the SE limb of Bradost Antcline which led to unstable limb. Other KPs 12, 13 are impressed by the fault and the meander of the river until pour to the GZR. This situation reflected disequilibrium stage unstable area.

Table 4: Knickpoints and SL of RWR

No.	Knickpoint	SL index	Elevatiom (m)	No.	Knickpoint	SL index	Elevatiom (m)
1	1	67	583	8	8	181	479
2	2	86	538	9	9	185	438
3	3	93	507	10	10	198	424
4	4	109	570	11	11	208	428
5	5	123	464	12	12	253	442
6	6	134	502	13	13	265	427



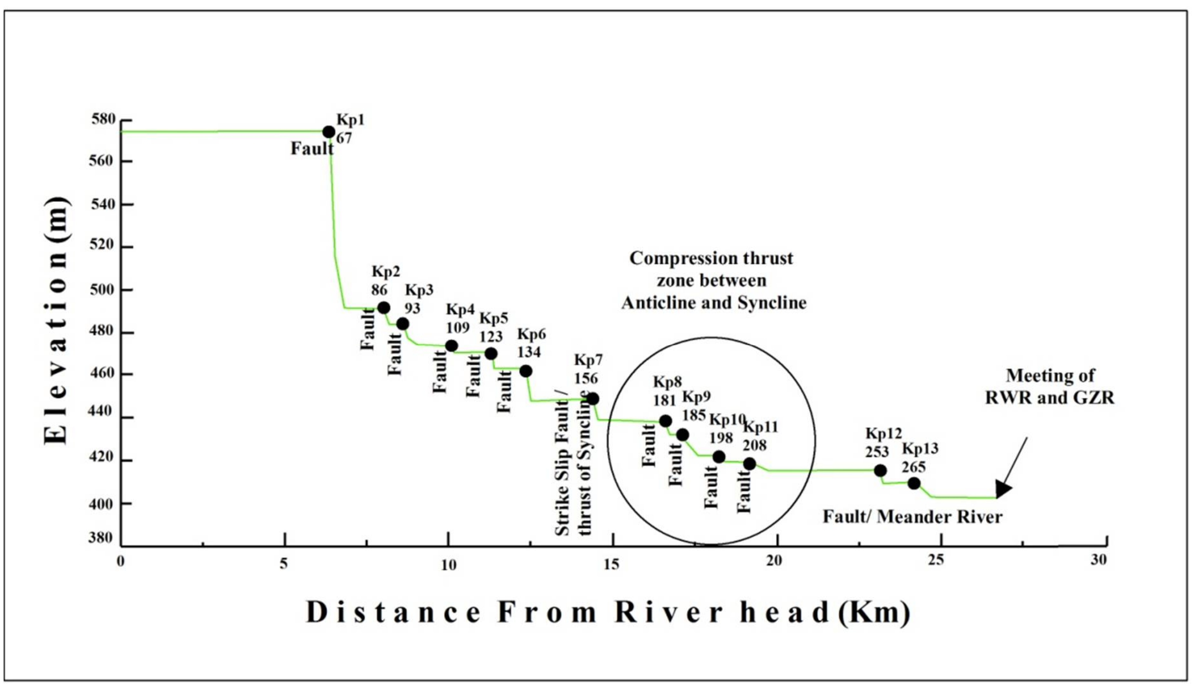


Figure 10: a) Distribution of the KPs along the RWR in the study area. b) Bed River Profile of the RWR clarifies distribution and behavior of the KPs

In Figure 11, the longitudinal profile of the Alanah valley, shows 7 KPs (Table 5) are formed as a result of the plunging of the Makok Anticline (KP 1, 2 and 3), which lies between Korek and Harir Anticlines reflecting trace of faulting, in addition to, severe incision of the rocks. The KPs of (4, 5, 6, and 7) are formed as a result of plunging of Korek Anticline and they are surrounded by a thrust fault. This situation reflected equilibrium stage stable area.

Table 5: Knickpoints and SL of Alanah River

No.	Knickpoint	SL index	Elevation(m)	No.	Knickpoint	SL index	Elevation(m)
1	1	95	1008	5	5	261	640
2	2	102	976	6	6	271	730
3	3	111	881	7	7	282	614
4	4	249	726				

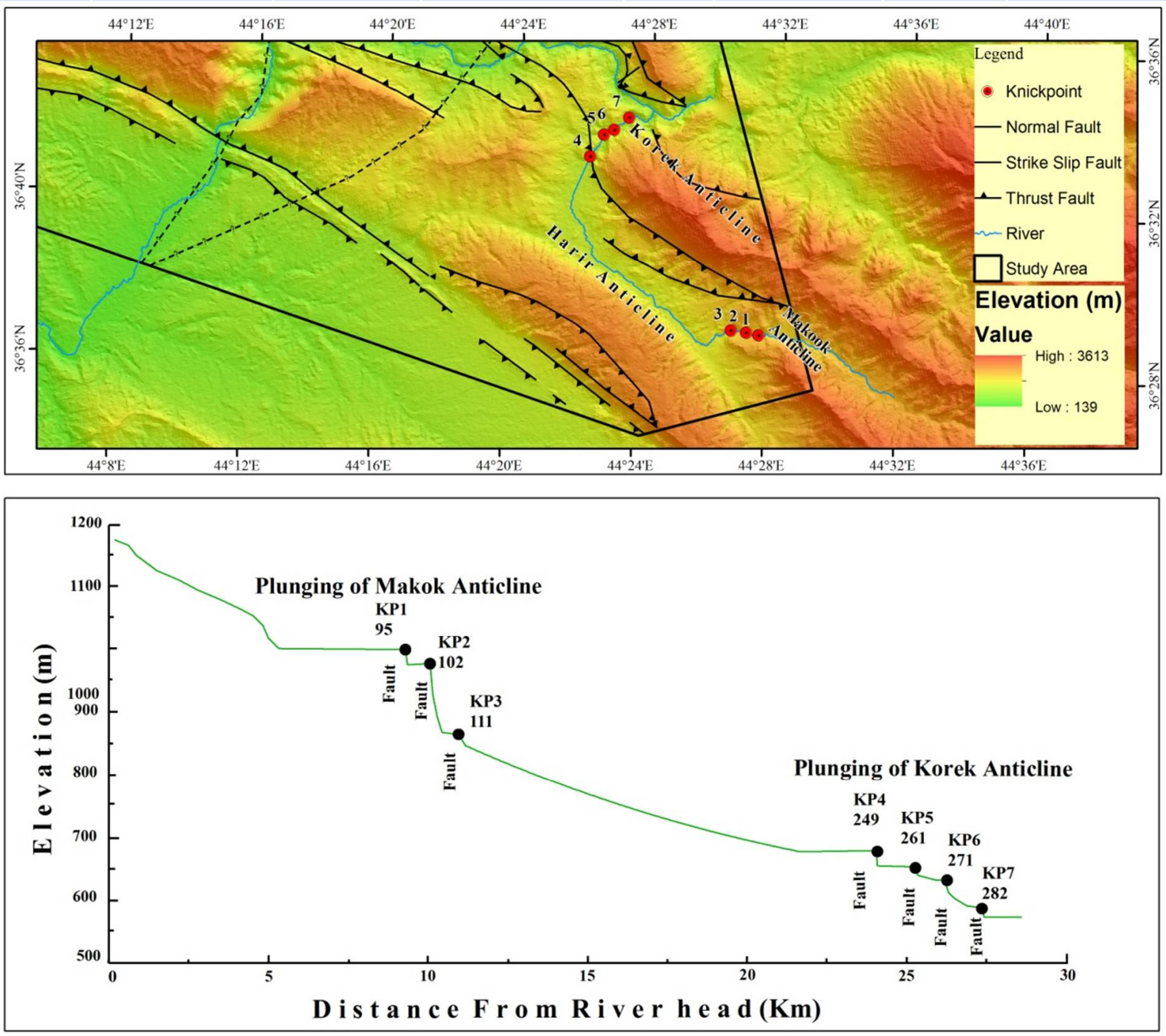


Figure 11: a) Distribution of the KPs along the Alanah Valley in the study area. b) Bed river profile of the Alanah valley clarifies distribution and behavior of the KPs

Figure 12, the longitudinal profile of the W.Suse river, shows 8 KPs (Table 6) are formed as a result of the trace of faulting along the valley except the (KP 6, 7 and 8) are impressed by compression between the plunging of the Piris Anticline and plunging of syncline as well as thrust fault of the Syncline, In addition to the strong erosion of the rocks. This situation reflected equilibrium stage stable area.

Table 6: Knickpoints and SL of W.Suse Valley

No.	Knickpoint	SL index	Elevation (m)	No.	Knickpoint	SL index	Elevation (m)
1	1	10	865	5	5	158	543
2	2	76	683	6	6	198	452
3	3	104	624	7	7	205	454
4	4	145	576	8	8	221	418

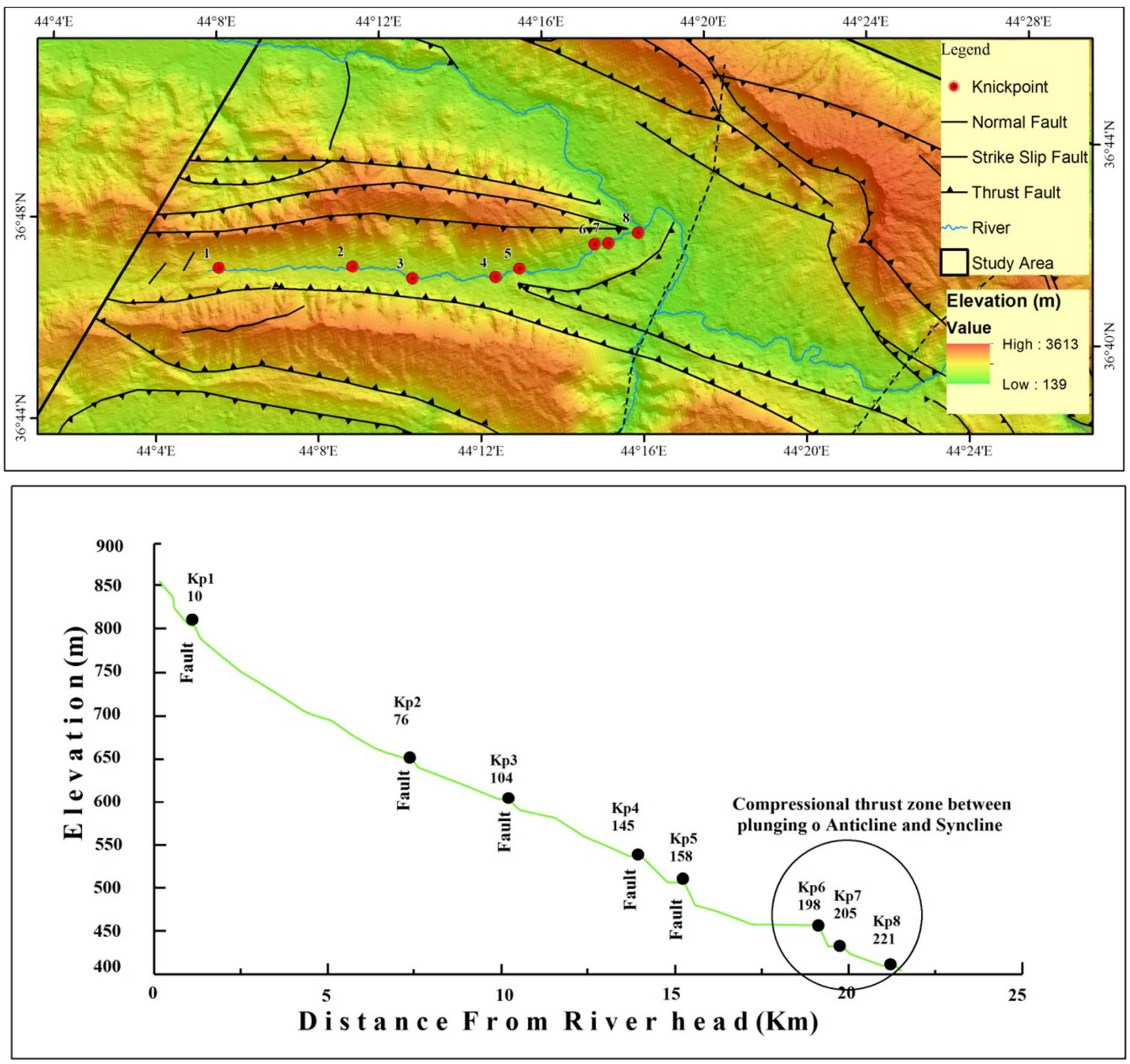


Figure 12: Distribution of the KPs along the W.Sus Valley in the study area. b) Bed river profile of the W. Sus clarifies distribution and behavior of the KPs

The longitudinal profile of the incised valley of the Bradost Anticline towards GZR as shown in Figure 13, we observed 4 KPs (Table 7). KP 1is impressed by strike slip fault and two sets of thrust fault along the valley incision which also cut the axes and curved the ridge of anticline as well as erodes the differential of the rocks. Kp2 is impressed by thrust fault of the plunging of the syncline when the valley pours to the GZR. KPs 3 and 4 are formed along the strike slip fault and impressed by thrust fault in the gorge of the Perat (Bekhme) Anticline.

Table 7: Knickpoints and SL of valley of the Bradost Anticline

No.	Knickpoint	SL index	Elevation (m)	No.	Knickpoint	SL index	Elevation (m)
1	1	25	875	3	3	173	575
2	2	68	435	4	4	186	433

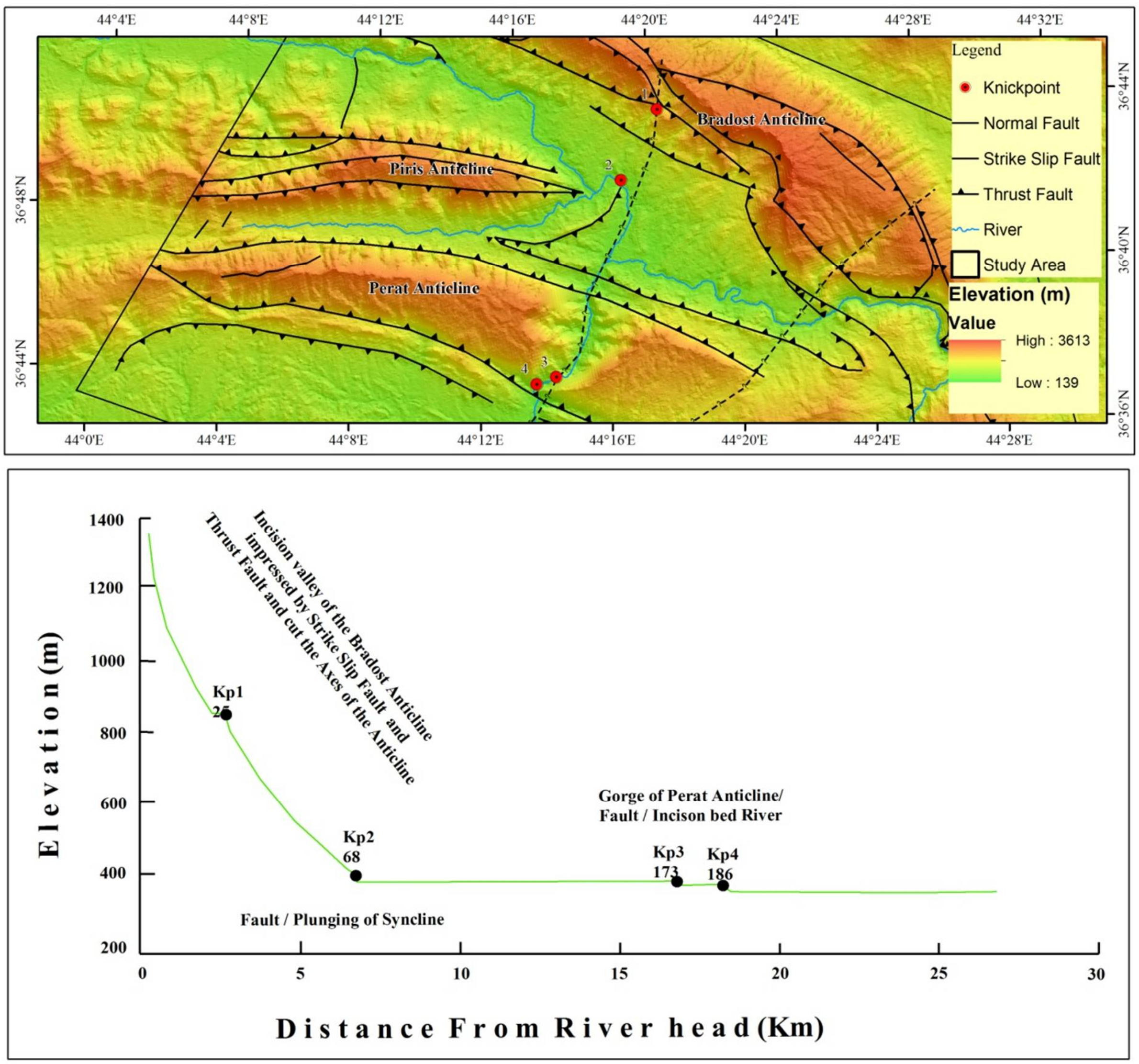


Fig. 13: Distribution of the KPs along the incised valley of Bradost Anticline towards GZR. b) Bed river profile of the incised valley clarifies distribution and behavior of the KPs.

Conclusion

Through the study tectonogeomorphological in study area several geomorphic indices were implemented by using TecDEM 2.2, a Matlab based software applying tectonic geomorphology on the DEM. According to general results:

Indices	Value	Effect	Action
HI	0.35-0.092	Mostly eroded less impressed by neotctonic (Mondnock phase)	Tectonics
	0.35-0.54	Equilibrium (Mature phase), topography of the study area is impressed by active thrust fault	
SR	1.003	Intermediate slope gradient and orientation	Neotectonics
	1.10	Rapid variation in slope gradient and orientation (abrupt scarp)	
SI	-0.846	More easily area erosion incompetent rocks	Tectonics
	0.282	Severely eroded of competent rocks	
TPI	883.871	Structural Ridge	Tectonics activities, lithology,climate and erosion and deposition
	534.879	Structural- Denudational Homoclinal ridge	
	185.887	Denudational origin	
	-163.106 to -512.098	Fluvial origin	
Incision map	1643.16	High gradient (erosional escarpment) affected by thrust fault and dense of multidirection lineament	Tectonics

The folding, thrusting and large strike slip faulting along the GZR towards Bradost anticline as a result of the compressional tectonic force. Therefore asymmetric en-chelon folds are formed, trending NW-SE and E-W.

River profile is sensitive for any vertical motion as a result of relative uplifted in the past. Change in stream slope is due to rock resistance or tectonic deformation, which led to form knickpoints. Knickpoint formation along the main rivers due to base level change caused by affective of the thrust fault, strike slip fault, differential bed river, landslide in addition to plunging of the Anticline and Syncline. The closer of knickpoints and the severe between each one suggest that neotectonic activities are impressed in the study area.

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