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Survey of Active Tectonics in Western Afghanistan Using Geomorphic Indices: A Case Study of the Northern Herat Basins

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Abstract: The ongoing convergence of the Eurasian, Helmand, and Iranian tectonic plates has positioned Afghanistan within a highly active tectonic zone, with spatial variations in deformation linked to regional plate dynamics. Western Afghanistan's Herat region, situated along the east-west trending Herat-Harirod fault system, exemplifies such dynamic activity. Rapid urbanization in this area underscores the critical need for robust neotectonics assessments to inform sustainable development. This study integrates multispectral satellite imagery (Landsat TM/ETM+, 30m DEM), geospatial analysis (ArcGIS), and geomorphometric techniques to evaluate tectonic potential. Key indices including valley floor width-to-height ratio (Vf), drainage basin shape (Bs), mountain front sinuosity (Smf), topographic basin asymmetry (T), drainage basin asymmetry (Af), and stream channel sinuosity (S) were computed to quantify tectonic activity. Field observations of Quaternary landforms, such as fault-induced river displacements, deflected drainage networks, and the juxtaposition of young and ancient alluvial fans, further corroborated remote sensing findings. The synthesized Landscape Activity Index (Lat), derived from these metrics, classifies the region as Class 1 (highest activity) within the tectonic activity spectrum. Results highlight active deformation, evidenced by deep V-shaped valleys, strike-slip faulting, and recurrent alluvial fan development. This study emphasizes the imperative of incorporating tectonic hazard assessments into urban planning frameworks to mitigate risks to infrastructure and communities. Proactive measures are essential to enhance resilience in this tectonically dynamic and rapidly developing region.

Keywords: Active Tectonics; Geomorphologic Indices; Catchment; Harirod Fault; Herat

1. Introduction

Morphotectonic studies play a pivotal role in understanding Earth's dynamic processes by combining laboratory analyses with field observations. These investigations provide quantitative measurements that allow geomorphologists to objectively compare landforms and assess tectonic activity. Key evidence includes fault dimensions, distinctive geomorphic features, watershed characteristics, and alluvial cone formations. Tectonic forces continuously reshape Earth's surface, creating primary landforms and driving regional transformations. Morphotectonics examines the relationship between these tectonic processes and surface manifestations, offering critical insights into landscape evolution [1,2].

Indicators such as triangular facets, drainage density, and channel spacing are particularly valuable for identifying active tectonics and spatial variations in deformation, especially in areas of anticlinal uplift [3–6].

The field of morphotectonics was formally established by Keller and Pinter (1996), who introduced the concept of "geomorphological tectonics" and developed quantitative indices to evaluate neotectonic movements. Subsequent research by Singh and Jain (2009), Walker et al. (2010), and Käßner and Gloaguen (2009) expanded these methodologies, demonstrating their applicability across diverse geological settings [7–10]. For example, Malik and Mohanty (2007) used geomorphic indicators to assess tectonic influences on Himalayan drainage systems, while MaO et al. (2021) highlighted the importance of understanding geomorphic process rates for accurate tectonic evaluations [11,12]. The reliability of these indicators was further confirmed by El Hamdouni et al. (2008), who demonstrated their effectiveness in delineating tectonically active regions [13].

Recent studies underscore the global relevance of morphotectonic analyses. In Iran, Hoseini et al. (2021) employed geomorphic indices to evaluate the Sirch region, while Sajadi et al. (2021) linked anomalous drainage patterns in the Qorveh-Dehgolan basin to active tectonics [14,15]. In India, Agrawal et al. (2022) identified deformation zones in Meghalaya using DEM-based morphometrics, and Ayaz and Dhali (2020) analyzed the Tista River's tributaries for evidence of tectonic activity [16,17]. The Himalayan region has been a focal point for such studies, with Khan and Govil (2023) attributing deformation in the Goriganga Basin to thrusts and lineaments, and Yousuf et al. (2023) classifying tectonic activity in the Kashmir Basin using geomorphic and structural indices [18,19]. Similar approaches in the Middle East by Jirjees et al. (2023) revealed moderate tectonic activity in Iraq's Rawanduz Basin, while Elnobi et al. (2022) assessed seismic hazards in Egypt's Wadi Araba Basin [20,21].

The integration of remote sensing and geophysical techniques has significantly enhanced morphotectonic research. For instance, Saibi et al. (2016) combined gravity and magnetic data with remote sensing to map subsurface structures in Afghanistan [22]. In Egypt, Abdelkareem and El-Baz (2016) traced the formation of the Nile Gorge to differential uplift of adjacent plateaus [23]. Modern tools like InSAR were employed by Vu et al. (2022) to analyze surface ruptures from the 2022 Afghanistan earthquake, while Sun et al. (2022) demonstrated the utility of LiDAR in studying China's Dushanzi Fault [24,25]. These advancements have enabled more precise assessments of tectonic activity and associated risks.

Morphometric analyses have yielded valuable insights into neotectonic processes. Rahbar et al. (2017) used mountain front sinuosity and other indices to evaluate activity in Iran's Bazargan Mountain, and Joshi et al. (2010) documented evidence of rejuvenation along the Kaurik-Chango Fault in the Himalayas [26,27]. Similarly, Lone (2017) correlated tectonic activity with basin morphology in the Jhelum River region, while Elias (2015) quantified neotectonic movements along Iraq's Khazir River using SRTM-derived data [28,29].

Studies of fault dynamics, river response, and alluvial systems have further enriched our understanding of tectonically driven landscape changes. Meyer et al. (2006) estimated a slip rate of 0.11 mm/year for Iran's Dehshir Fault during the Quaternary, and Maghsoudi et al. (2009) documented tectonic-induced channel shifts in the Tajan River [30,31]. Research by Abolfazl (2015) linked alluvial cone formation in Gozel Valley primarily to tectonic activity, with climate playing a secondary role [32]. These findings highlight the diverse ways in which tectonic forces shape Earth's surface.

Morphotectonic studies, supported by geomorphic indices and cutting-edge technologies, provide a powerful framework for assessing tectonic activity and associated hazards. This is particularly critical in regions like Afghanistan, where rapid urbanization necessitates accurate risk evaluations. Future research should focus on integrating multi-temporal datasets to refine tectonic models and improve hazard mitigation strategies. By advancing our understanding of Earth's dynamic processes, morphotectonics continues to play a vital role in both scientific research and practical applications.

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2. Geological and Tectonic Setting of the Study Area

The study area represents a geologically complex and tectonically active region situated at the convergence of three major continental plates: the Eurasian Plate to the north, and the Indian and Arabian Plates to the south Figure 1. This strategic location has resulted in the development of numerous ancient sedimentary basins separated by extensive fault systems formed through prolonged tectonic interactions. The geological framework of Afghanistan consists primarily of northeast-southwest trending terranes that originated as continental fragments during the Paleozoic through Tertiary periods [33]. These displaced crustal blocks gradually migrated northward before accreting obliquely against the stable Asian landmass, with the final major accretion event being the collision of the Indian Plate during the Cenozoic era [34]. This prolonged tectonic history has created a region characterized by intense deformation and complex structural patterns.

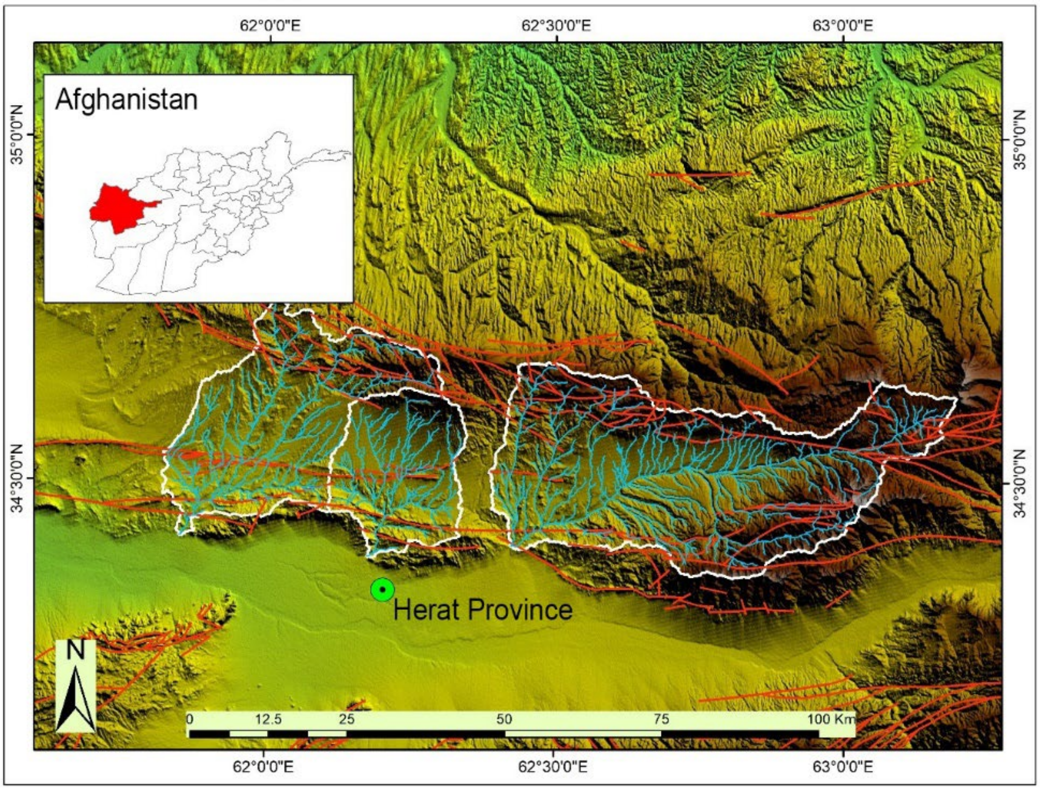

Figure 1. Topographic map of the study area.

The structural architecture of the area in Figures 1 and 2 clearly reflects its dynamic tectonic history, exhibiting several distinctive geological features. A prominent pattern of oblique continental collision is evident through curved structural trends and rotated crustal blocks. The region displays multiple generations of both brittle deformation, expressed as extensive fault systems, and ductile deformation seen in large-scale folding [33]. Among the most significant structural elements are reactivated strike-slip fault systems, particularly the major Harirod Fault zone [35]. The most intense phase of deformation occurred during the Oligocene-Miocene period when tectonic reactivation of the Harirod Fault system generated substantial strike-slip displacement [35]. This event was especially pronounced in the southern Hariroud region, where it produced characteristic strike-slip deformation features. The fault activity created a 20-60 km wide deformation corridor bounded by the Harirod Fault to the north and the Qarghanaw, Bande Bayan, and Onay fault systems to the south, collectively forming what is known as the Middle Afghan Suture Zone [36].

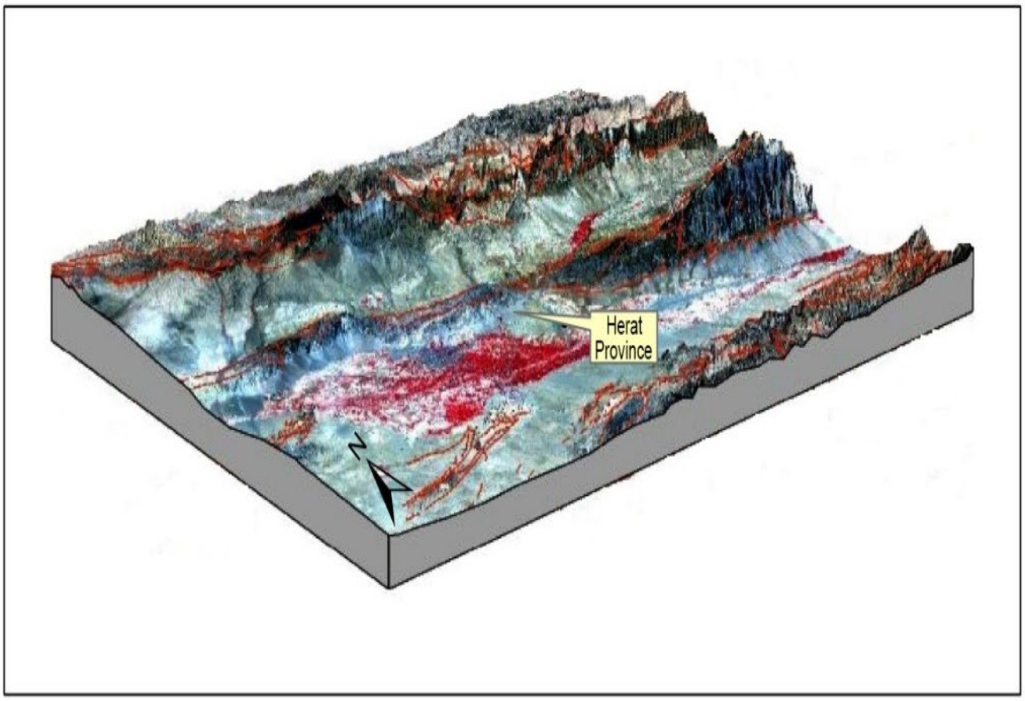

Figure 2. Three-dimensional map of the study area.

The study focuses specifically on Herat Province in western Afghanistan, an area of particular geological and tectonic significance. The province contains an exceptionally complete stratigraphic sequence ranging from Proterozoic basement rocks to Quaternary deposits, providing a remarkable geological record as showen in geological and structural map of the study area in Figure 3. The lithologies present are remarkably diverse, including metamorphic units such as micaceous schists and biotite-amphibolite complexes, plutonic rocks including granitic gneisses and migmatites, and various sedimentary formations of different ages. The tectonic framework is dominated by the east-west trending Hariroud Fault system and displays high seismic potential with multiple active fault strands. The area exhibits dramatic elevation variations from 1,000 to 2,750 meters, with pronounced topographic contrasts that provide clear evidence of recent and ongoing tectonic activity. These geological characteristics make Herat Province an ideal natural laboratory for studying active tectonic processes and their surface expressions.

From an urban and demographic perspective, Herat represents a major population center experiencing rapid urbanization, making the understanding of its tectonic hazards particularly crucial [37]. The combination of high population density and significant seismic risk necessitates precise tectonic hazard evaluation and informed urban planning. Our research employed a targeted approach to site selection, focusing on areas displaying unambiguous evidence of fault-controlled landscape modification and other tectonic geomorphological features. The scientific importance of this study lies in its contribution to understanding the dynamic tectonic processes shaping this complex convergence zone, while its practical significance stems from the urgent need for accurate seismic hazard assessments in this rapidly developing region. The findings will help bridge important knowledge gaps in our understanding of Afghan tectonics while providing valuable data for regional development planning and disaster risk reduction efforts.

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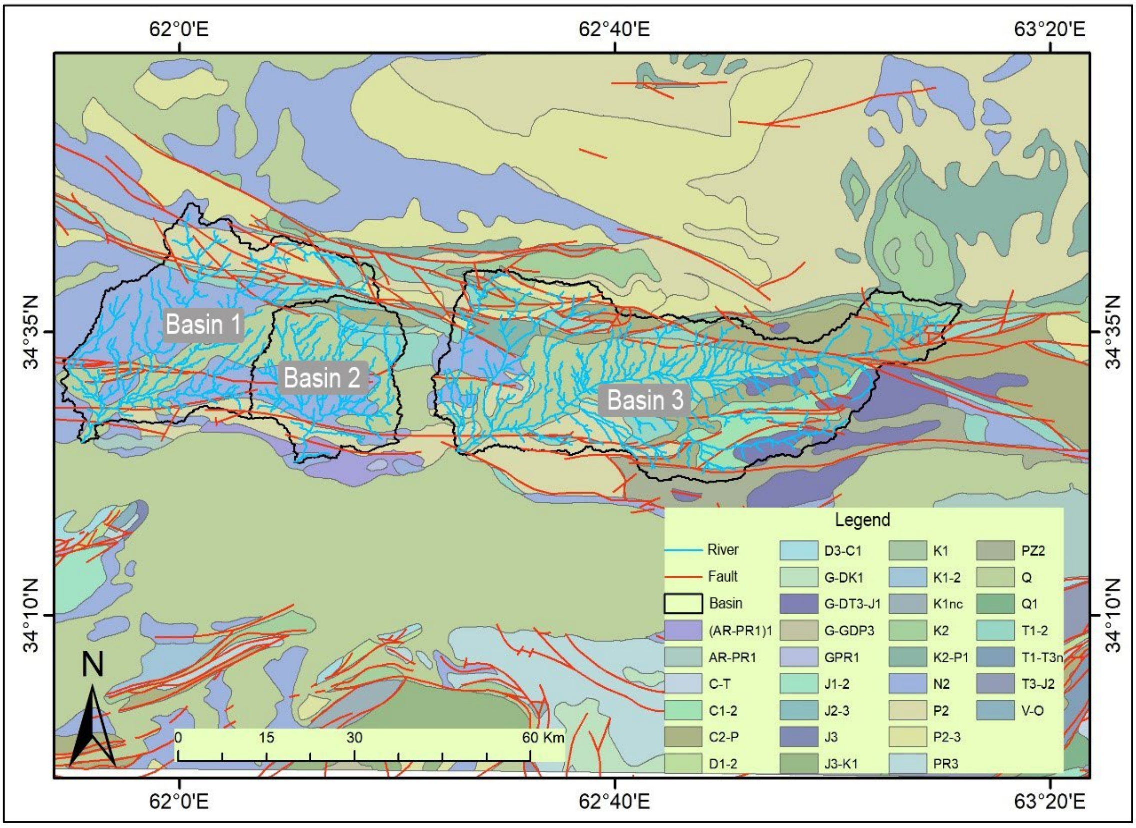

Figure 3. Geological and Structural Map of River Basins in Herat Province.

3. Methodology

This study employs an integrated geomorphological and remote sensing approach to evaluate tectonic activity by quantifying landscape responses to deformation. The methodology combines field investigations, remote sensing data (Landsat TM/ETM and DEM30), and high-resolution topographic maps (1:50,000 scale) to extract hydrographic networks and compute six geomorphic indices. These indices, rooted in established tectonic geomorphology frameworks, provide quantitative insights into the spatial and temporal patterns of tectonic activity.

3.1. Data Acquisition and Processing

The analysis began with field surveys and the collection of geological maps (1:250,000 scale) to identify structural features such as fault traces and uplifted terraces. Satellite imagery and DEMs were processed in a Geographic Information System (GIS) to delineate drainage basins, stream networks, and topographic profiles. Spatial accuracy was validated through ground-truthing, ensuring alignment between remotely sensed data and field observations. Key morphometric parameters including basin boundaries, valley floor elevations, and mountain front geometries were extracted algorithmically to minimize subjective bias.

3.2. Geomorphic Indices and Tectonic Interpretation

To assess tectonic deformation within the study area, six key geomorphic indices were calculated. These indices serve as valuable tools in identifying the influence of tectonic activity on landform development and help in interpreting patterns of active deformation across the landscape.

The first index is the Drainage Basin Symmetry Index (AF), which evaluates the symmetry of a drainage basin to detect lateral tilting potentially caused by tectonic uplift or differential erosion. It is calculated using the Equation (1).

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$$AF = 100(\frac{\mathrm{Ar}}{\mathrm{At}}) \tag{1}$$

where Ar is the area of the basin on one side of the main stream, and At is the total catchment area. A value of 50 indicates a perfectly symmetrical basin, while significant deviations suggest tectonic forces at play. For example, an AF value of 70 indicates that 70% of the basin area lies on one side of the channel, implying possible tilting associated with fault movement [38].

The Valley Floor Width-to-Height Ratio (VF) is another important index that captures valley morphology and is sensitive to incision driven by tectonic activity. It is given by the Equation (2).

$$VF = \frac{2\mathrm{VFW}}{[(\mathrm{Eld}-\mathrm{Esc})+(\mathrm{Erd}-\mathrm{Esc})]} \tag{2}$$

where VFW is the valley floor width, EId and Erd represent the elevations of the left and right drainage divides, and Esc is the elevation of the valley floor. Narrow, V-shaped valleys with VF values less than 1 typically reflect rapid incision in tectonically active regions, whereas wider U-shaped valleys with VF values greater than 3 suggest relatively stable conditions with limited tectonic influence [13].

The Mountain Front Sinuosity Index (Smf) assesses the irregularity of mountain fronts and is expressed in Equation (3).

$$Smf = \frac{\mathrm{Lmf}}{\mathrm{Ls}} \tag{3}$$

where Lmf is the actual length of the mountain front along its base and Ls is its straight-line length. Values close to 1.0 represent straight and tectonically active fronts, while values exceeding 1.5 are indicative of fronts shaped primarily by erosional processes rather than active uplift [13].

Another index, the Drainage Basin Shape Ratio (Bs), evaluates the elongation of a basin, which can reveal structural influences on its form. It is given by the Equation (4).

$$Bs = \frac{\mathrm{BL}}{\mathrm{BW}} \tag{4}$$

where BL is the basin length and BW is the maximum width. Elongated basins with Bs values greater than 3 are often aligned with tectonic structures and suggest active deformation, whereas nearly circular basins with Bs values close to 1 typically indicate minimal tectonic control [38].

The River Sinuosity Index (S) measures the meandering nature of river channels and It is given by the Equation (5).

$$\mathrm{S} = \frac{\mathrm{C}}{\mathrm{V}} \tag{5}$$

where C is the actual length of the river channel and V is the straight-line length of the valley. Low values near 1.0 indicate straight, steep-gradient rivers typically associated with tectonically active zones. In contrast, higher values above 1.5 suggest meandering channels in low-gradient, stable environments where tectonic activity is limited [7].

To synthesize the influence of tectonics on the landscape, a composite Index of Active Tectonics (IAT) was computed by averaging the normalized values of the five previously mentioned indices and It is given by the Equation (6).

$$IAT = \frac{\mathrm{Smf}+\mathrm{Bs}+\mathrm{VF}+\mathrm{AF}+\mathrm{S}}{5} \tag{6}$$

This composite index facilitates regional comparisons and classifies tectonic activity into four categories: Class 1 (very high activity; IAT = 1.0–1.5), Class 2 (high activity; IAT = 1.5–2.0), Class 3 (moderate activity; IAT = 2.0–2.5), and Class 4 (low activity; IAT > 2.5), as proposed by El Hamdouni et al. (2008) and MAGHSOUDI et al. (2012) [13,31].

To synthesize these metrics into a single measure of active tectonics, we adopted the Index of Active Tectonics (IAT), defined as the arithmetic mean of Smf, Bs, Vf, AF, and S (Table 1). Based on the averaged value, areas are classified into four activity levels: values below 1.5 indicate very high tectonic activity (Class 1), between 1.5 and 2.0 high activity (Class 2), between 2.0 and 2.5 moderate activity (Class 3), and above 2.5 low activity (Class 4) (see Table 2). This classification facilitates comparative analysis across alluvial cones and adjacent basins, allowing us to map spatial variations in tectonic forcing and to link geomorphic expression with underlying fault mechanics.

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Table 1. Classification of Individual Geomorphic Indicators (El Hamdouni et al., 2008) [13].

Indicator	Class 1 (Very High)	Class 2 (High)	Class 3 (Moderate)
Smf	< 1.1	1.1 – 1.5	> 1.5
Vf	< 0.5	0.5 – 1	> 1
Bs	> 4	3 – 4	< 3
Af	< 15	15 – 50	> 50
S	> 2	1.5 – 2	< 1.5

Table 2. Classification of IAT Index (MAGHSOUDI et al., 2012) [13].

IAT Value (Average)	Class	Tectonic Activity Level
< 1.5	Class 1	Very High
1.5 – 2.0	Class 2	High
2.0 – 2.5	Class 3	Moderate
> 2.5	Class 4	Low

4. Results and Discussion

4.1. Assessing Active Tectonics

To evaluate the tectonic activity within the study area, key geomorphic indices were calculated for multiple drainage basins. These indices include the valley floor width-to-height ratio (Vf), the asymmetry factor of the basin (Af-50), the basin shape index (Bs), the river channel sinuosity (S), and the mountain front sinuosity (Smf). The computed values for each indicator provide insight into the geomorphic responses of the landscape to active tectonic deformation.

Valley floor width-to-height ratio (Vf) reflects the degree of incision in a valley. Lower values generally indicate steeper valley sides and higher uplift rates.asymmetry factor (Af-50) measures lateral tilting of a drainage basin, where deviations from a symmetric state may reflect tectonic tilting or structural control.

Basin shape index (Bs) is useful in determining the elongation of the basin, where more elongated basins are often structurally controlled. river sinuosity index (S) provides information on the extent of meandering in a river, which may be influenced by tectonic tilting, uplift, or subsidence. Mountain front sinuosity (Smf) evaluates how straight or irregular the contact is between mountainous terrain and the adjacent alluvial plain. A lower Smf suggests recent tectonic uplift and fault activity.

The results from the analyzed basins (see Table 3) demonstrate variations in these metrics, indicating differential tectonic influences across the region. For example, Basin 1 shows relatively low values for Vf (0.20) and Smf (1.40), suggesting possible recent uplift and active incision processes. In contrast, Basin 3 presents a higher Vf (0.56) and lower Smf (1.42), which may suggest reduced tectonic forcing or more matured landform development.

Table 3. Computation of Geomorphic Indices for Tectonic Activity in the Study Area.

Basin Name	Vf	Af-50	Bs	S	Smf
Basin 1	0.20	16	4	1.50	1.40
Basin 2	0.29	15	3	1.33	1.23
Basin 3	0.56	18	1.70	1.14	1.42

It is important to note that, while these morphotectonic indices provide valuable quantitative insight into landscape evolution, they should not be used in isolation to draw definitive conclusions about tectonic activity. A comprehensive understanding requires a combination of field investigations, geological mapping, geomorphic analysis, and integration of remote sensing and GIS-based modeling. The holistic interpretation of all data sources helps validate and contextualize the index-based findings, ensuring a more reliable assessment of tectonic activity.

4.2. Active Tectonic Index (IAT)

To further quantify tectonic activity in the study area, the Integrated Active Tectonics (IAT) index was employed. This composite index combines several geomorphic indices namely the stream sinuosity (S), asymmetry factor (Af), basin shape (Bs), valley floor width-to-height ratio (Vf), and mountain front sinuosity (Smf) into a unified evaluation framework. Each individual index was classified on a scale from 1 to 3, where 1 indicates high tectonic activity, 2 denotes moderate activity, and 3 represents low activity. The final IAT score was computed as the average of these classes for each basin.

The purpose of using IAT is to integrate multiple geomorphic indicators to derive a more holistic understanding of neotectonic activity across drainage basins. This index reduces subjectivity and enhances reliability by averaging the numerical classes of each contributing parameter.

Based on the computed IAT values and following standard classification schemes, all three basins in the study area were identified as Class 1, which reflects a high level of recent tectonic activity. This suggests that these basins are actively deforming and may be under the influence of tectonic uplift, fault activity, or tilting, consistent with the broader geological context of the region. The repetition of Class 1 across the basins highlights the geomorphic dynamism of the terrain and underscores the importance of integrating geomorphic, geophysical, and field data to monitor and manage geohazards in the area.

These results are summarized in Table 4, which provides the classification scores for each parameter and the overall IAT class.

Table 4. Active Tectonic Index (IAT) Classification of the Basins.

Basin Name	IAT Class	IAT Value	S (Class)	Af (Class)	Bs (Class)	Vf (Class)	Smf (Class)
Basin 1	Class 1	1.4	1	1	2	1	2
Basin 2	Class 1	1.4	1	1	2	1	2
Basin 3	Class 1	1.4	1	1	2	1	2

4.3. Harirod Fault Evidence in the Study Area

Afghanistan is situated in a highly geodynamically active zone, where the ongoing collision between the Indian and Eurasian tectonic plates gives rise to frequent seismic events and a complex network of fault systems [39]. This tectonic setting has shaped the country's landscape and geological framework, characterized by several major transcurrent faults. Among these, the Harirod Fault in the northwest is notable for delineating a boundary between ancient metamorphic rocks and Mesozoic flysch deposits [40]. Further to the northeast, the Pamir region bordering northern Afghanistan experiences substantial seismicity along both its periphery and interior. This activity is largely associated with a north-northeast trending sinistral transtensional fault system that extends into the Hindu Kush range in Afghanistan [41].

In central and southern Afghanistan, the terrain is subdivided into multiple geotectonic units and fault blocks. Of particular interest is the Katawaz fault block in the southeast, which exhibits significant petroleum potential due to its thick sedimentary cover and favorable reservoir conditions [42]. A detailed understanding of these geological structures is essential not only for evaluating seismic hazard but also for exploring natural resource opportunities in the region.

As previously discussed, it is not feasible to draw a definitive conclusion based solely on geomorphic indices. Therefore, to strengthen the tectonic interpretation in the study area, we sought tangible field evidence that reflects neotectonic activity. Based on geological observations, remote sensing data, and geomorphic analysis, four distinct locations exhibiting signs of active tectonics were identified within the study area. These locations are presented in Figure 4.

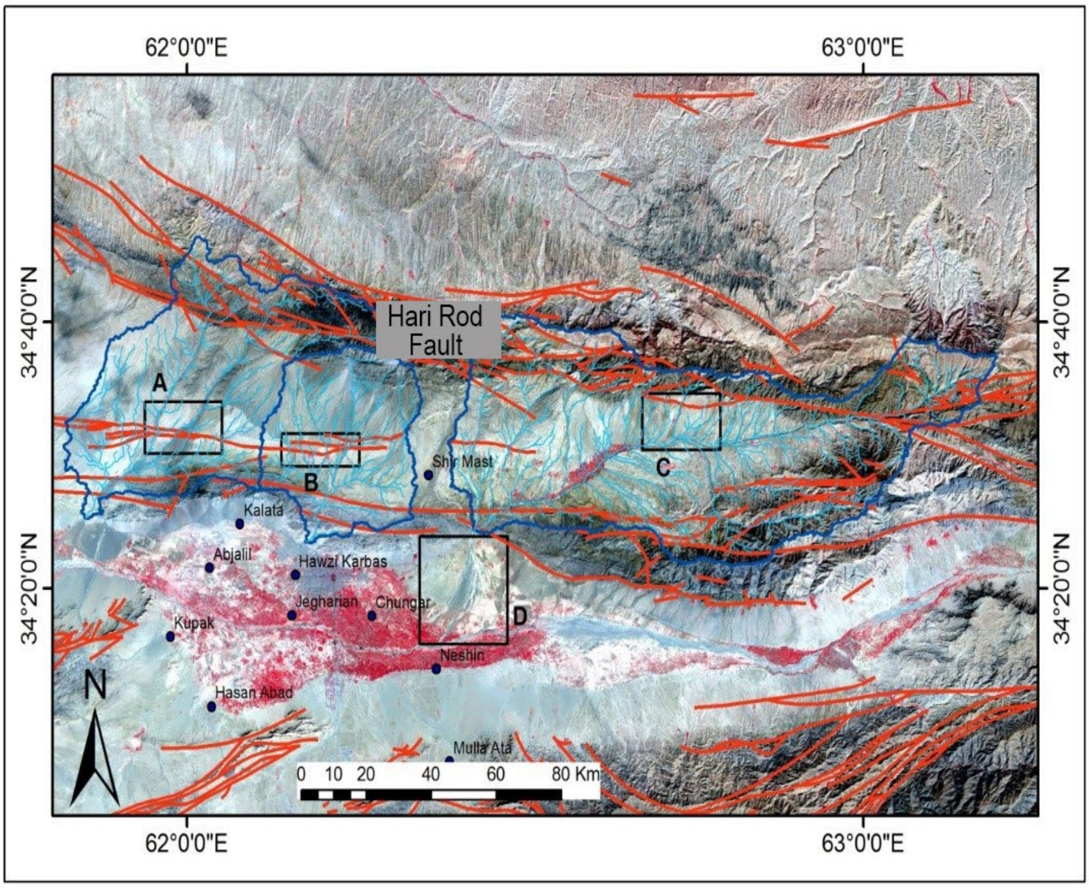

Figure 4. The spatial distribution of tectonic effects identified in the study area.

4.4. Influence of Tectonic Activity on Hydrographic Patterns

Tectonic activity plays a crucial role in shaping hydrographic patterns and the organization of drainage systems. Numerous studies have demonstrated that neotectonic processes significantly influence surface dynamics within river basins, often observable through analyses of stream longitudinal profiles and interpretations of remote sensing data such as SRTM imagery [43]. The morphometric characteristics of drainage networks serve as effective tools for detecting neotectonic activity, with rejuvenated evolutionary stages commonly found in areas recently impacted by tectonic deformation [15,44].

River systems are particularly responsive to tectonic disturbances, which can lead to variations in channel gradient, base level shifts, and modifications in meandering behavior. A wide array of morphotectonic and hydrological indicators such as deflection zones, abrupt slope changes, and fluctuations in streamflow parameters like velocity and discharge provide valuable insights into the geomorphic consequences of tectonic forces [45]. Collectively, these observations highlight the dual influence of both ancient orogenic processes and contemporary tectonic movements in governing drainage development and controlling morphogenetic dynamics across tectonically active landscapes.

4.5. Tectonic Influence on River Systems and Hydrography

Tectonic activity plays a pivotal role in shaping river systems and broader hydrographic patterns. Active tectonics can modify river gradients, channel morphology, and flow direction, directly impacting navigation, sediment transport, and flood control [38]. Rivers are particularly sensitive to tectonic disturbances and often respond through adjustments in their slope, base level, and meandering behavior [45]. Morphometric analysis of drainage basins has proven effective in identifying neotectonic influences. For instance, in the Upper Acheloos River basin, variations in basin shape and stream gradients were linked to tectonic rejuvenation [44]. Similarly, in the Kielce-Łagow Valley, neotectonic forces altered river networks, with structural features such as anticlines and synclines redirecting watercourses [46]. These findings emphasize the essential role tectonic processes play in the evolution and modification of hydrographic systems across different geological contexts.

In the present study area, the impact of local faulting on river morphology is strikingly evident. A prominent fault line has caused a significant deviation in the river's path, extending its length from approximately 900 meters to 1800 meters. This transformation is documented through a series of temporal profiles, illustrating the river's progressive displacement to its current configuration (Figure 5).

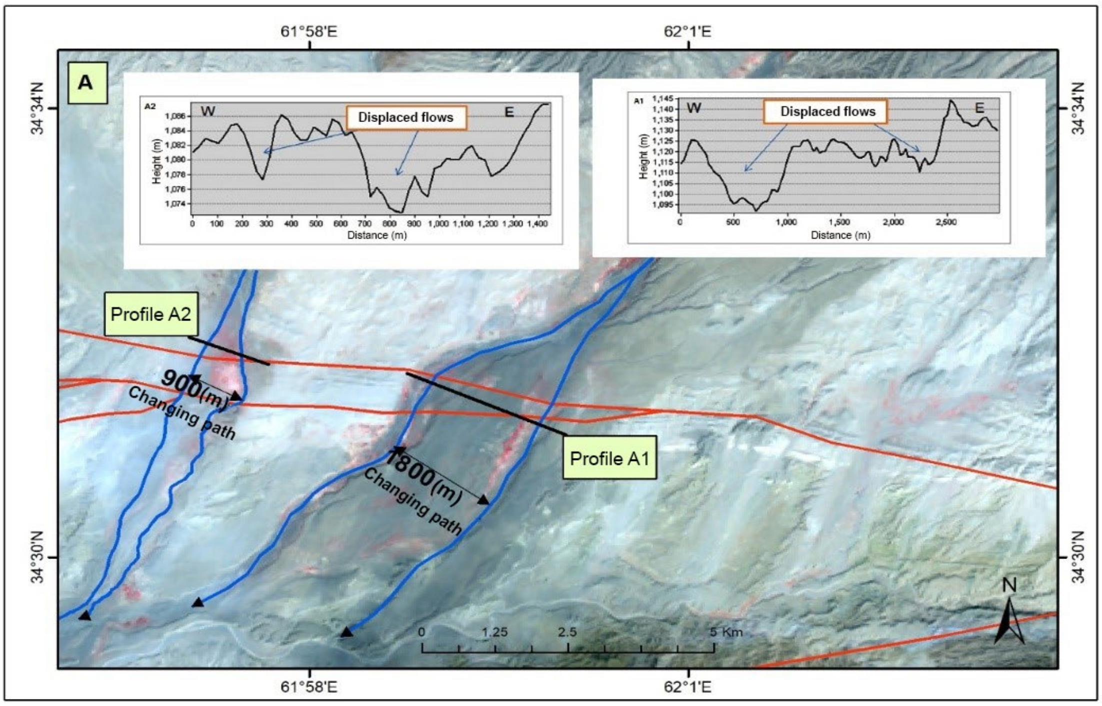

Figure 5. Tectonic Deformation Indicators at Location A in the Study Area.

In Section B of the area, the river veers sharply to the right from its original course. Over time, this deviation has become more pronounced, eventually forming a coherent and unified new river path (Figure 6). A primary contributing factor is the obstructive nature of fault-induced ridges, which divert the natural flow and compel the river to alter its direction (Figure 7).

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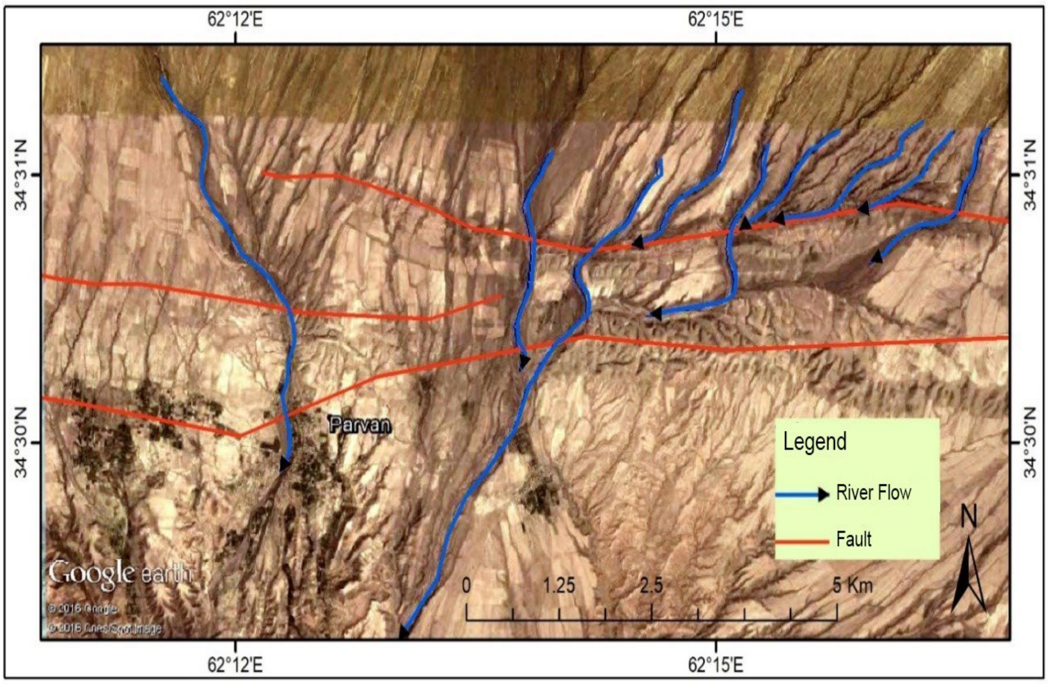

Figure 6. Tectonic Influence on River Morphology at Location B in the Study Area.

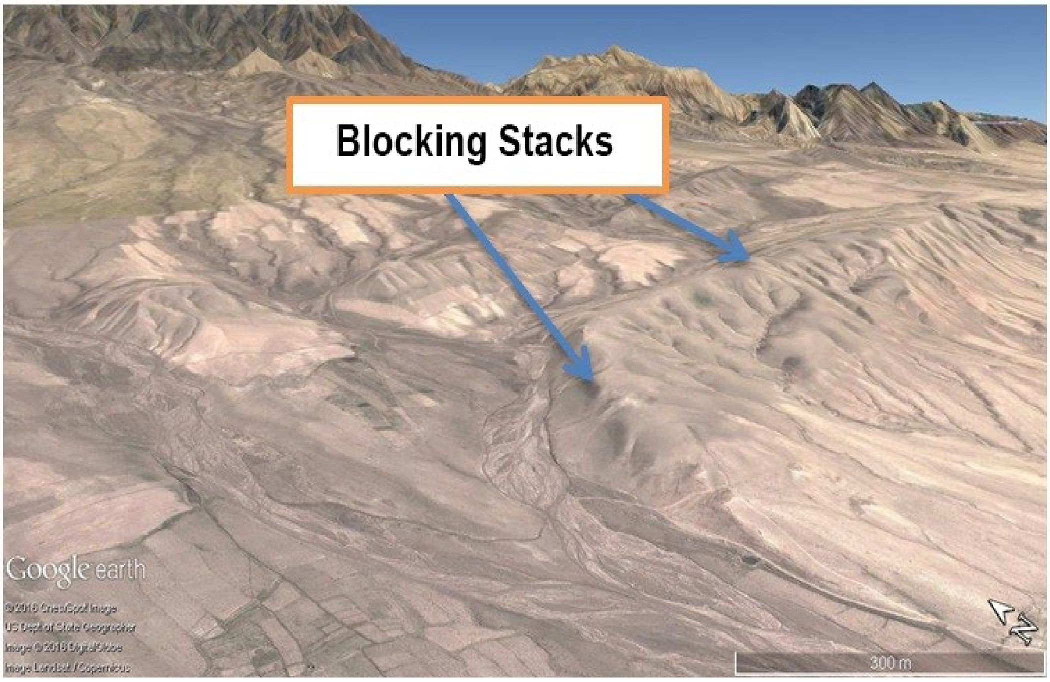

Figure 7. Blocking stacks and Associated Tectonic Activity.

Another notable geomorphic feature observed in the study area is the presence of headless rivers. These are the result of fault activity that severed the upstream flow, leading to the isolation of river segments. Cross-sectional profiles clearly depict these disruptions, with one profile indicating a depth of nearly 50 meters, suggesting considerable tectonic influence (Figure 8).

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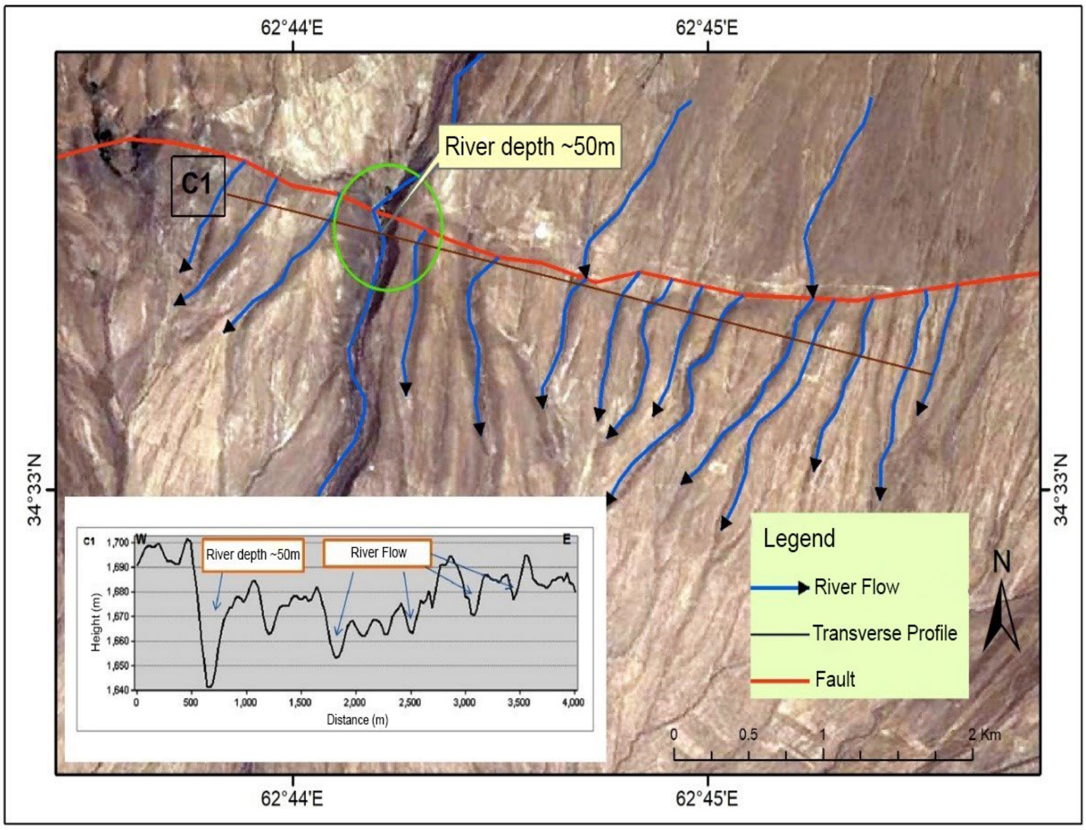

Figure 8. Tectonic Evidence Analysis at Location C in the Study Area.

4.6. Impact of Tectonic Activity on Alluvial Cone Formation and Sediment Displacement

A truncated alluvial cone was observed within the study area, and analysis of tectonic indicators revealed ongoing tectonic activity in the region. The evidence gathered from these indicators supports the conclusion that tectonic processes have affected the area. Satellite imagery analysis further confirmed the presence of faults and tectonic movements that have caused the displacement of portions of the alluvial cones. These movements have led to the creation of both new and existing cones, as illustrated in Figure 9A,B. Figure 9A,B show two to three alluvial cone surfaces (T1, T2, and T3) in the region, as seen in Figure 10. The presence of multiple faults has contributed to the formation of these different alluvial cone levels. Fault displacements in areas where alluvial cones form have caused sedimentary deposits to shift, resulting in the creation of new cones near older ones. Consequently, cones are rapidly generated along fault lines, leading to the formation of new cones while older cones are abandoned. Satellite images of the study area further highlight these processes.

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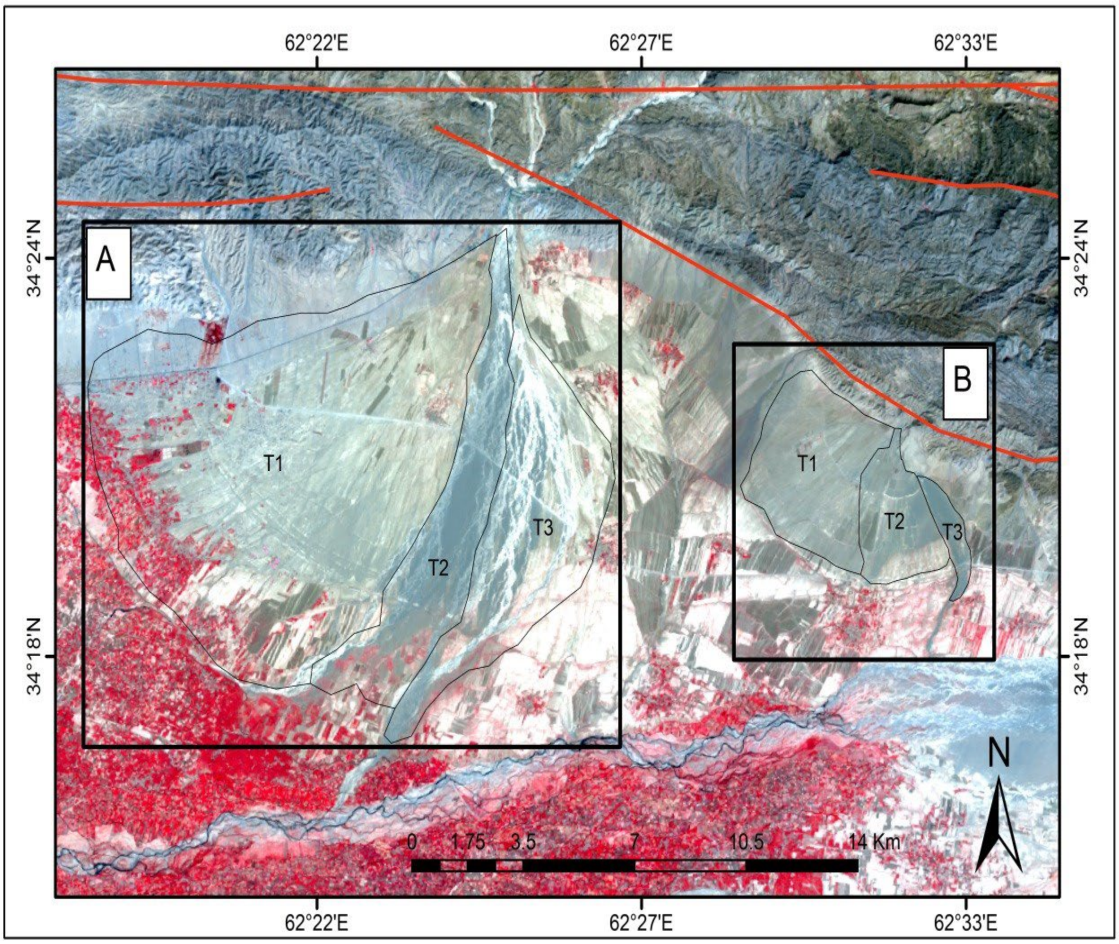

Figure 9. Shows the marked locations for identifying sediment movement across the surface of the alluvial cone.

Figure 10 provides a detailed view of the surfaces of both the new and old alluvial cones in Area A. The image clearly shows the distinctive layers and topography of these cones, highlighting the variations between the older and more recent formations. Notably, the alluvial cone in this area exhibits a distinct tilt to the left, which is a key indicator that this section is actively undergoing sedimentation processes. The leftward slope suggests that the sediment movement is concentrated in this part of the cone, with sediment being deposited in the direction of the slope. This tilted feature is a significant sign of ongoing tectonic activity, which continues to influence the sedimentary dynamics and the formation of new alluvial structures in the region.

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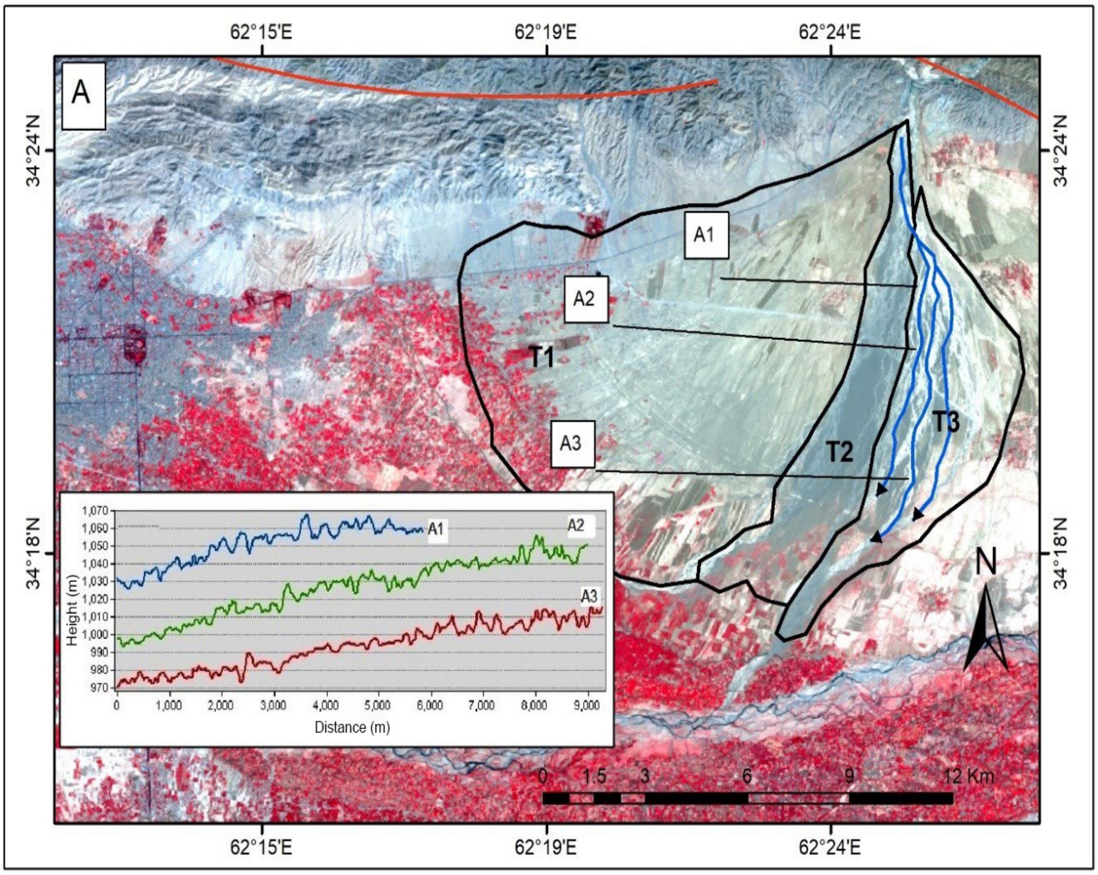

Figure 10. Shows the new and old alluvial cone surfaces in Area A.

Figure 11 provides a detailed view of the outer surface of the alluvial cone in Area B, highlighting the pathways and concentration of fine, thread-like drainage channels commonly referred to as hair channels indicative of active sediment transport. These channels suggest recent fluvial processes shaping the surface morphology of the cone. The figure also reveals clear distinctions between the surfaces of older and newer alluvial cones, emphasizing the geomorphic evolution of the area over time. As seen in the Google Earth imagery, Area B, much like Area A, exhibits multiple generations of alluvial cones. These range from the oldest surface (T1), which appears more eroded and stable, to the youngest (T3), which is more sharply defined and actively evolving due to ongoing sedimentation and tectonic influences. This stratification of cones serves as compelling evidence of both temporal and spatial changes influenced by neotectonic activity in the region.

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Figure 11. Highlights the contrasting surfaces of the new and old alluvial cones in Area B, as captured in the Google Earth imagery.

The T3 cone stands out due to its recent formation and the presence of gizzard channels on its surface, as depicted in Figure 12. Figure 12 provides a closer look at the new and old alluvial cone surfaces in Area B.

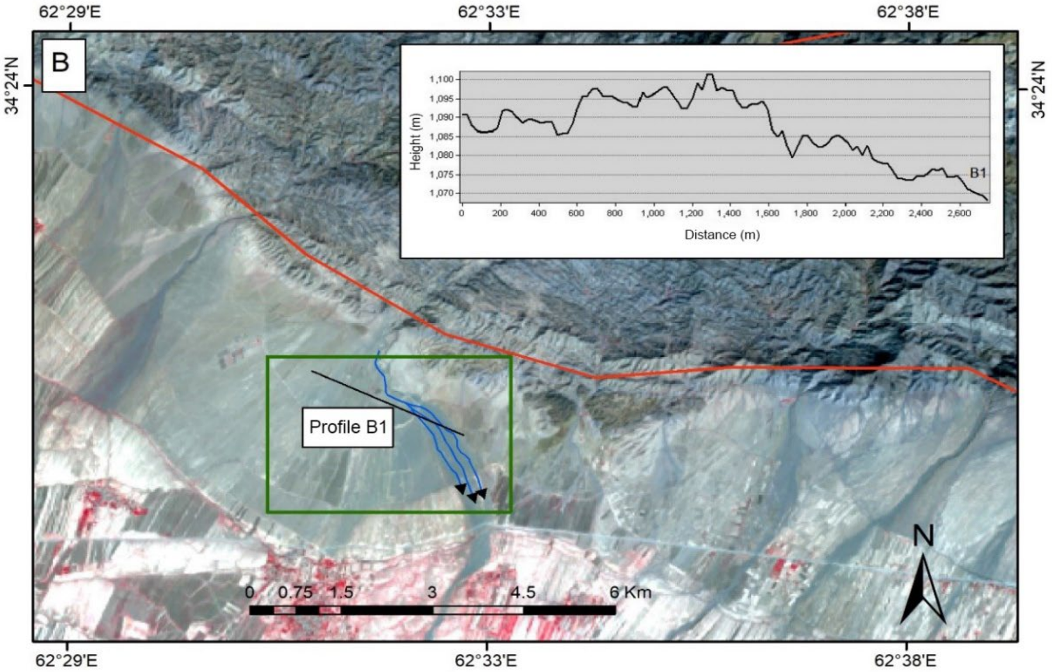

Figure 12. Illustrates the new and old alluvial cone surfaces in Area B.

Distinct surfaces of both the new and old cones were easily observable in this area, as shown in Figure 13. The profile illustrated in Figure 13 reveals that the cone is tilted towards the east, with the new cone situated in the same location and undergoing changes. Figure 13 depicts the various surfaces of both new and old alluvial cones in Area B, as observed from a Google Earth perspective.

Figure 13. Presents the distinct surfaces of the old and new alluvial cones in Area B, based on Google Earth imagery.

5. Conclusion

The integration of geomorphological indices, field observations, and remote sensing data provides compelling evidence of active tectonics in the study area. The analysis of mountain front sinuosity (Smf) revealed values classified as Class 2, indicating moderate tectonic activity. Smf values below 1.1, observed in localized zones, correlate with straighter mountain fronts and higher tectonic uplift rates, while values exceeding 1.5 were rare, suggesting limited erosional modification. River channel sinuosity (S), which reflects adjustments to tectonic gradients, further supports this interpretation. S values ranging from 1.14 to 1.50 across the basins classify the region as Class 1, highlighting tectonically induced channel straightening despite minor meandering in low-gradient areas.

The asymmetry of drainage basins, quantified by the Af index, underscores tectonic tilting. Deviations from the symmetrical baseline (Af = 50) were significant, with Af values decreasing to Class 1 thresholds in active basins. This asymmetry aligns with field-observed fault scarps and tilted strata, confirming lateral displacement driven by regional tectonics. Valley morphology, assessed through the valley floor width-to-height ratio (Vf), further corroborates these findings. Narrow, V-shaped valleys ($Vf \leq 5$) dominate the region, classified as Class 1, and reflect rapid incision in response to ongoing uplift. The absence of broad, U-shaped valleys (Vf approaching 1) rules out prolonged tectonic stability.

The elongation of drainage basins, measured by the Bs index, classifies the region as Class 2, indicating transitional tectonic activity. Moderately elongated basins (Bs = 3–4) suggest gradual tilting, contrasting with circular basins ($Bs \approx 1$) typical of stable regions. Synthesizing these indices into the Index of Active Tectonics (IAT) yields a Class 1 designation, signifying very high tectonic activity. This classification aligns with geomorphic evidence, including 50-meter-deep valleys, displaced alluvial fans, and strike-slip faulting that has offset river channels by up to 1,800 meters.

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Field investigations revealed two to three tiers of alluvial cones along the Kohistan fault line, with modern cones superimposed on ancient ones, indicating recurrent fault movements. Channel migrations and abrupt shifts in depositional patterns within these cones further attest to sustained tectonic stress. The deep incision of valleys and steep topographic gradients mirror the Vf and S index results, collectively illustrating a landscape dynamically responding to active deformation.

While geomorphic indices provide a robust framework for assessing tectonic activity, their interpretation requires contextual integration with geological and field data. The high tectonic activity class (IAT Class 1) underscores the necessity for seismic hazard mitigation in infrastructure planning. Future studies should employ chronological dating of displaced landforms and high-resolution seismic profiling to quantify deformation rates and refine regional hazard models.

CRediT authorship contribution statement:
The main idea was conceptualized by Mohammad Amini, whereas the methodology was defined by Mohammad Amini, Reza Jafari, Fatima Zahra Zidane and Najeebullah Kakar. The data was collected by Mohammad Amini. The software analysis was performed by Mohammad Amini, Reza Jafari, Fatima Zahra Zidane and Najeebullah Kakar. The original draft was prepared by Mohammad Amini and reviewed and edited by Longsheng Deng. The overall work was carried out under supervision of Longsheng Deng.

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References

[1] YOUNG R A, HACK J T, MORISAWA M. Geomorphic evolution of the Colorado Plateau margin in west-central Arizona: A tectonic model to distinguish between the causes of rapid symmetrical scarp retreat and scarp dissection[J]. Tectonic Geomorphology: London, Allen and Unwin, 1985: 261-278.

[2] BAHADORI A, HOLT W E, FENG R. Coupled influence of tectonics, climate, and surface processes on landscape evolution in southwestern North America[J]. Nature Communications, 2022, 13(1): 4437.

[3] MANEERAT P, BÜRGMANN R. Geomorphic expressions of active tectonics across the Indo-Burma Range[J]. Journal of Asian Earth Sciences, 2022, 223: 105008.

[4] BAHRAMI S, CAPOLONGO D, MOFRAD M R. Morphometry of drainage basins and stream networks as an indicator of active fold growth (Gorm anticline, Fars Province, Iran)[J]. Geomorphology, 2020, 355: 107086.

[5] AMINE A, EL OUARDI H, ZEBARI M. Active tectonics in the Moulay Idriss Massif (South Rifian Ridges, NW Morocco): New insights from geomorphic indices and drainage pattern analysis[J]. Journal of African Earth Sciences, 2020, 167: 103833.

[6] WELLS S G, BULLARD T F, MENGES C M. Regional variations in tectonic geomorphology along a segmented convergent plate boundary pacific coast of Costa Rica[J]. Geomorphology, 1988, 1(3): 239-265.

[7] EDWARD A. KELLER AND NICHOLAS PINTER. Active Tectonics: Earthquakes, Uplift, and Landscape[M/OL].1996.https://www.geokniga.org/bookfiles/geoknigaactivetectonicsearthquakesupliftandlandscape_0.pdf.

[8] SINGH T, JAIN V. Tectonic constraints on watershed development on frontal ridges: Mohand Ridge, NW Himalaya, India[J]. Geomorphology, 2009, 106(3-4): 231-241.

[9] WALKER R T, TALEBIAN M, SAIFFORI S. Active faulting, earthquakes, and restraining bend development near Kerman city in southeastern Iran[J]. Journal of Structural Geology, 2010,

Doi: https://doi.org/10.63333/eem.v1n25 Vol. 1 No. 2 (2025)

32(8): 1046-1060.

[10] KÄSSNER A, GLOAGUEN R. Neotectonic information from drainage basin geometry in the Tajik Depression[C]//2009 IEEE International Geoscience and Remote Sensing Symposium: 2. IEEE, 2009: II-353.

[11] MALIK J N, MOHANTY C. Active tectonic influence on the evolution of drainage and landscape: geomorphic signatures from frontal and hinterland areas along the Northwestern Himalaya, India[J]. Journal of Asian Earth Sciences, 2007, 29(5-6): 604-618.

[12] MAO Y, LI Y, YAN B. Response of Surface Erosion to Crustal Shortening and Its Influence on Tectonic Evolution in Fold-and-Thrust Belts: Implications from Sandbox Modeling on Tectonic Geomorphology[J]. Tectonics, 2021, 40(5): e2020TC006515.

[13] EL HAMDOUNI R, IRIGARAY C, FERNANDEZ T. Assessment of relative active tectonics, southwest border of the Sierra Nevada (southern Spain)[J]. Geomorphology, 2008, 96(1-2): 150-173.

[14] HOSEINI N, SHAFIEIBAFTI S, GHANBARIAN M A. Morphotectonic evaluation of Sirch mountains using water basin geomorphic indices[J]. Sustainable Development of Mountain Territories, 2021, 13(2): 208-214.

[15] SAJADI P, SINGH A, MUKHERJEE S. Multivariate statistical analysis of relationship between tectonic activity and drainage behavior in Qorveh-Dehgolan basin Kurdistan, Iran[J]. Geocarto International, 2021, 36(5): 540-562.

[16] AGRAWAL N, GUPTA L, DIXIT J. Geospatial assessment of active tectonics using SRTM DEM-based morphometric approach for Meghalaya, India[J]. All Earth, 2022, 34(1): 39-54.

[17] AYAZ S, DHALI M K. Longitudinal profiles and geomorphic indices analysis on tectonic evidence of fluvial form, process and landform deformation of Eastern Himalayan Rivers, India[J]. Geology, Ecology, and Landscapes, 2020, 4(1): 11-22.

[18] KHAN M N, GOVIL H. Assessment of On-going tectonic deformation in the Goriganga River Basin, Eastern Kumaon Himalaya Using Geospatial Technology.[J]. Journal of Applied & Natural Science, 2023, 15(4).

[19] YOUSUF M, BUKHARI S K, BHAT G R. Tectonogeomorphic investigation of Kashmir Basin NW Himalaya[J]. Geology, Ecology, and Landscapes, 2023, 7(4): 384-404.

[20] JIRJEES S J, SEEYAN S, HASSAN I. Geomorphic Indices Analysis of the Rawandoz River Basin, Erbil, Kurdistan Region, Iraq[J]. The Iraqi Geological Journal, 2023: 57-70.

[21] ELNOBI M, BASHIR B, ALSALMAN A. Geospatial Analytics for Preliminarily Landscape Active Tectonic Assessment of the Wadi Araba Basin, Western Gulf of Suez, Egypt[J]. Applied Sciences, 2022, 12(23): 12152.

[22] SAIBI H, AZIZI M, MOGREN S. Structural investigations of Afghanistan deduced from remote sensing and potential field data[J]. Acta Geophysica, 2016, 64: 978-1003.

[23] ABDELKAREEM M, EL-BAZ F. Mode of formation of the Nile Gorge in northern Egypt: a study by DEM-SRTM data and GIS analysis[J]. Geological Journal, 2016, 51(5): 760-778.

[24] KHAC D V, TRINH P T, TAPPONNIER P. Surface ruptures and land deformation from the 21 June 2022 Afghanistan earthquake[J]. Vietnam J. Earth Sci, 2022, 44(3): 447-450.

[25] SUN W, WEI Z, SUN H. Review on the application of airborne LiDAR in active tectonics of China: Dushanzi reverse fault in the Northern Tian Shan[J]. Frontiers in Earth Science, 2022, 10: 895758.

[26] RAHBAR R, BAFTI S S, DERAKHSHANI R. Investigation of the tectonic activity of Bazargan Mountain in Iran[J]. Sustainable Development of Mountain Territories, 2017, 9(4): 380-386.

[27] JOSHI M, KOTHYARI G C, AHLUVALIA A. Neotectonic evidences of rejuvenation in KaurikChango fault zone, Northwestern Himalaya[J]. Journal of Geographic Information System, 2010, 2(3): 169-176.

[28] LONE A. Morphometric and Morphotectonic Analysis of Ferozpur Drainage Basin Left Bank Tributary of River Jhelum of Kashmir Valley, NW Himalayas, India[J]. J. Geogr. Nat. Disasters, 2017, 7(1000208): 1-1000208.

[29] ELIAS Z. The neotectonic activity along the lower Khazir River by using SRTM image and geomorphic indices[J]. Earth Sci, 2015, 1(1): 50-58.

[30] MEYER B, MOUTHEREAU F, LACOMBE O. Evidence of Quaternary activity along the Deshir Fault: implication for the Tertiary tectonics of Central Iran[J]. Geophysical Journal International, 2006, 164(1): 192-201.

[31] MAGHSOUDI M, JAFARI A M, BAGHERI S S S. STUDY THE ACTIVE TECTONIC OF KEFRAVAR CATCHMENT AREA BY USING GEOMORPHIC INDICES AND GEOMORPHOLOGICAL EVIDENCES[J]. 2012.

[32] MADADI A, FARAJI MONFARED A. Study of Effective Factors in Gozal Darre and Karafs Alluvial Fans Formation and Investigation of Tectonical Activities on Southern Slope of Khrqan Mountain[J]. Geography and Development, 2014, 12(37): 195-206.

[33] SHRODER J F, EQRAR N, WAIZY H. Review of the Geology of Afghanistan and its water resources[J]. International geology review, 2022, 64(7): 1009-1031.

[34] WNUK C. Coal resource potential of Afghanistan[J]. International Geology Review, 2016, 58(3): 321-341.

[35] ALLEN M B, VINCENT S J. Fault reactivation in the Junggar region, northwest China: the role of basement structures during Mesozoic-Cenozoic compression[J]. Journal of the Geological Society, 1997, 154(1): 151-155.

[36] TRELOAR P J, IZATT C N. Tectonics of the Himalayan collision between the Indian plate and the Afghan block: A synthesis[J]. Geological Society, London, Special Publications, 1993, 74(1): 69-87.

[37] SAMIMI S A B, ANDO T, KAWISH K. A STUDY ON THE TRANSFORMATION OF HERAT OLD CITY: In case of the Momandha Quarter[A]. 琉球大学, 2017.

[38] KELLER E A N P. Active Tectonics: Earthquakes, Uplift, and Landscape (2nd Edition)[M]. Pearson, 2001.

[39] CRONE A J. Earthquakes pose a serious hazard in Afghanistan[R]. Geological Survey (US), 2007.

[40] AUDEN J B. Afghanistan-west pakistan[J]. Geological Society, London, Special Publications, 1974, 4(1): 235-253.

[41] SCHURR B, RATSCHBACHER L, SIPPL C. Seismotectonics of the Pamir[J]. Tectonics, 2014, 33(8): 1501-1518.

[42] ALFRED S, DIETRICH W, HANS-PETER W. Geology and petroleum potentials of central and south Afghanistan[J]. AAPG Bulletin, 1972, 56(8): 1494-1519.

[43] DA SILVA G P R, ETCHEBEHERE M L, SAAD A R. Análise de perfis segmentados de drenagem para a avaliação morfotectônica na bacia hidrográfica do alto Rio Jaguari (SP-MG)[J]. Geosciences= Geociências, 2012, 31(2): 259-271.

[44] LYKOUDI E, ANGELAKI M. THE CONTRIBUTION OF THE MORPHOMETRIC PARAMETERS OF AN HYDROGRAPHIC NETWORK TO THE INVESTIGATION OF THE NEOTECTONIC ACTIVITY: AN APPLICATION TO THE UPPER ACHELOOS RIVER.[J]. Bulletin of the Geological Society of Greece, 2004, 36(2): 1084-1092.

[45] BISWAS M, PAUL A, JAMAL M. Tectonics and channel morpho-hydrology—a quantitative discussion based on secondary data and field Investigation[J]. Structural Geology and Tectonics Field Guidebook—Volume 1, 2021: 461-494.

[46] KOWALSKI B J. Przejawy młodej aktywności tektonicznej w Dolinie Kielecko-Łagowskiej w Górach Świętokrzyskich i jej wpływ na układ sieci wodnej[J]. Przegląd Geologiczny, 1995, 43(4): 307-316.