

Topographic Fingerprints of Tectonic Deformation in the Zurbatiyah Region, Eastern Iraq: A Multi-Index DEM-Based Analysis

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ABSTRACT

This work conducts a morphotectonic analysis using the Topographic Position Index (TPI), Slope, Curvature, and Terrain Ruggedness Index (TRI) to elucidate the relationship between geomorphic indices and tectonic processes. ALOS PALSAR DEM data with a resolution of 12.5 meters were used in TPI applications for a 50-meter radius, where landforms and structural landform patterns were categorized. In an ArcGIS environment, Slope and Curvature maps and TRI, which assessed the relationship between fault zones and elevated blocks, were analyzed to evaluate terrain inclination, morphology, and roughness. The composite index, including TRI, slope, and curvature, effectively identified areas of geomorphic instability and morphotectonic boundaries at a regional level. The topographic class distribution revealed NW-SE oriented high ridges and axial troughs connected with folding and fault structures. Active thrusts and anticlines dominated steep slopes and regions of positive curvature, whilst the western sector, characterized by a low gradient, remained inactive. The combined strategy, with other methodologies, effectively enhanced the detection of neotectonic features and surface deformation dynamics. The method relies on understanding the landscapes' geomorphology evolution under the influence of tectonics in regions with intricate structure.

1. Introduction

Both the study of landforms and the evolution of relief features, concerning modern geomorphology, stem from the quantitative morphotectonic analysis, which enables the study of surface landforms with the satellites' DEMs of the region by using computer software (Radaideh & Mosar, 2019; Valkanou et al., 2024). More specifically, the Topographic Position Index (TPI),

along with Slope, Curvature, and Terrain Ruggedness Index (TRI), have been recognized for their merit in outlining geomorphic signatures of tectonic deformation. Such indices facilitate the delineation of landforms and the identification of structural ridges, axial valleys, uplift zones, and fault scarps.

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The TPI was first proposed by Weiss in 2001, and it has remained one of the most popular indices in morphotectonic interpretation because it discriminates between high and low landforms based on local elevation deviation (Roy et al., 2025). Also, TRI, developed by Riley et al in 1999, portrays roughness and variability of the terrain, which are important to changes within crustal deformation (Martinello et al., 2021). Additionally, slopes and curvatures, which lie at the base of terrain analysis, support interpretation of structural elements by demonstrating steps (Breaks) in Slope continuity alongside surface convexity or concavity (Jordan, 2003).

Morphometric analysis has shown that other regions of Iraq, particularly Zurbatiyah in the eastern part, within the morphotectonic zone of the Zagros Fold-Thrust Belt, still lack detailed descriptions.

The intricate arrangement of thrust faults, anticlines, and drainage systems makes the region suitable for DEM-based morphotectonic analysis. This research seeks to locate neotectonic features and assess active structural systems through the multi-component geomorphometry technique with the ALOS PALSAR DEM. This study uses composite indices of TPI, slope, curvature, and TRI to identify the areas where structural instability is intensive and deepen knowledge of the evolution of tectonic landform in this active seismotectonic region.

2. Study Area and Geological Background

The Zurbatiyah area is situated in the eastern region of Iraq, inside the administrative confines of Wasit Governorate (Figure 1). It physically spans around two latitudes ($33^{\circ}30'$ – $33^{\circ}6'$ N) and

two longitudes ($45^{\circ}42'$ – $46^{\circ}12'$ E). The highest elevated point of the study area slopes is about 963m above sea level in the northeast, while the lowest is about 40m above sea level. These slopes were mostly formed during the Oligo-Miocene. This area is at a critical geological location inside the Low-Folded Zone. It is regarded as a structural transition zone between the Inner Zagros and the unstable shelf of the Arabian Plate. The Himreen anticline is the only structure within the study area that runs almost parallel to the Iraqi-Iranian border. The southwestern limb of the anticline is within the study area, the major axis is in Iran, and all of the minor anticlines and synclines exhibit a similar trend to the major Himreen anticline, which notably deviates towards the north from its dominant NW-SE trend (Abdulnaby et al., 2021; Ahmed and Salman, 2020). According to the tectonic division of Iraq, which is divided into two main tectonic units: the outer and inner Arabian platforms. The outer platform comprises the Zagros Fold-Thrust Belt and the Mesopotamia Foredeep, which is characterized by instability. In contrast, the inner platform, which encompasses the western desert of Iraq, is stable (Fouad, 2010) (Figure 2).

The area has a sequence of sedimentary formations dating from the Miocene to the Pleistocene, including Ibrahim Formation, Serikagni Formation, Dhiban Formation, Jeribe Formation, Fatha Formation, Injana Formation, Mukdadiya Formation, and quaternary deposits (Figure 3). Moreover, many compressional and reverse faults traverse it, the most notable being the longitudinal Badrah-Amarah fault (Abdulnaby et al., 2016), which exhibits signs of recent tectonic activity, including changes in drainage direction and the discontinuity of rock strata.

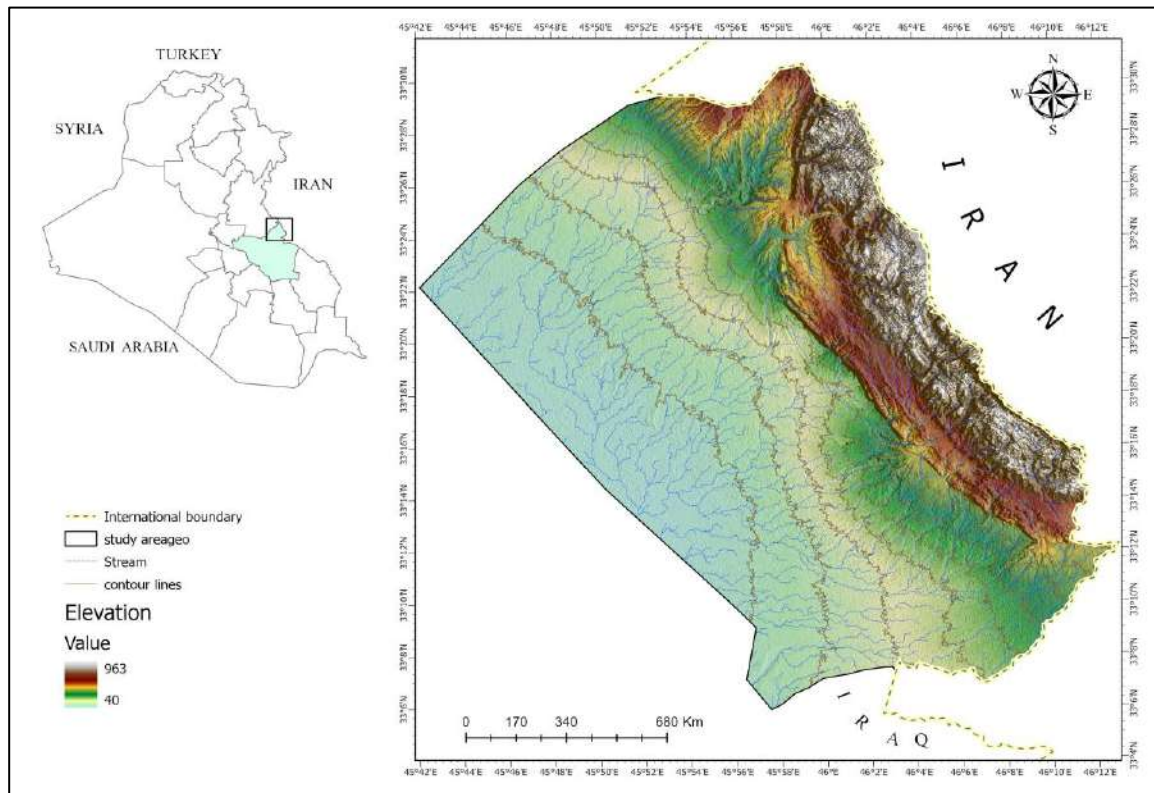


Fig. 1. Location map of the study area.

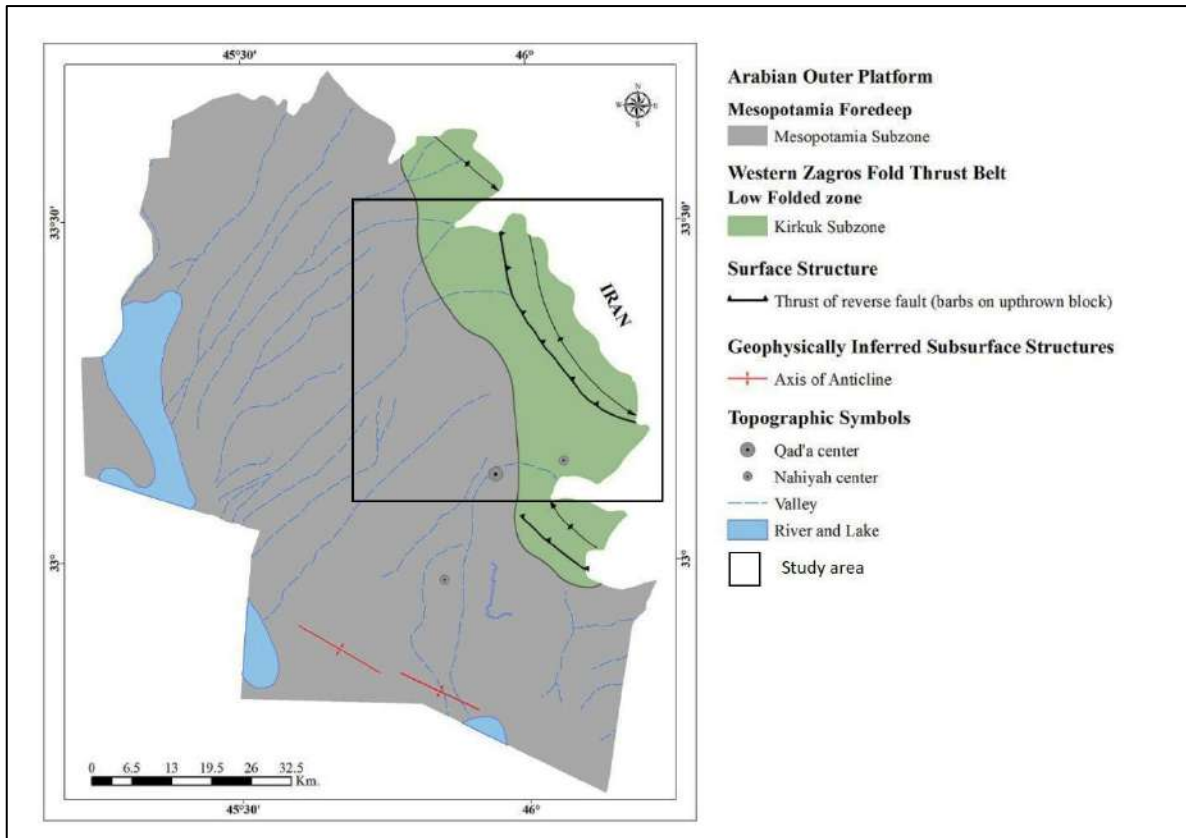


Fig. 2 Tectonic map of the study area (Fouad, 2012).

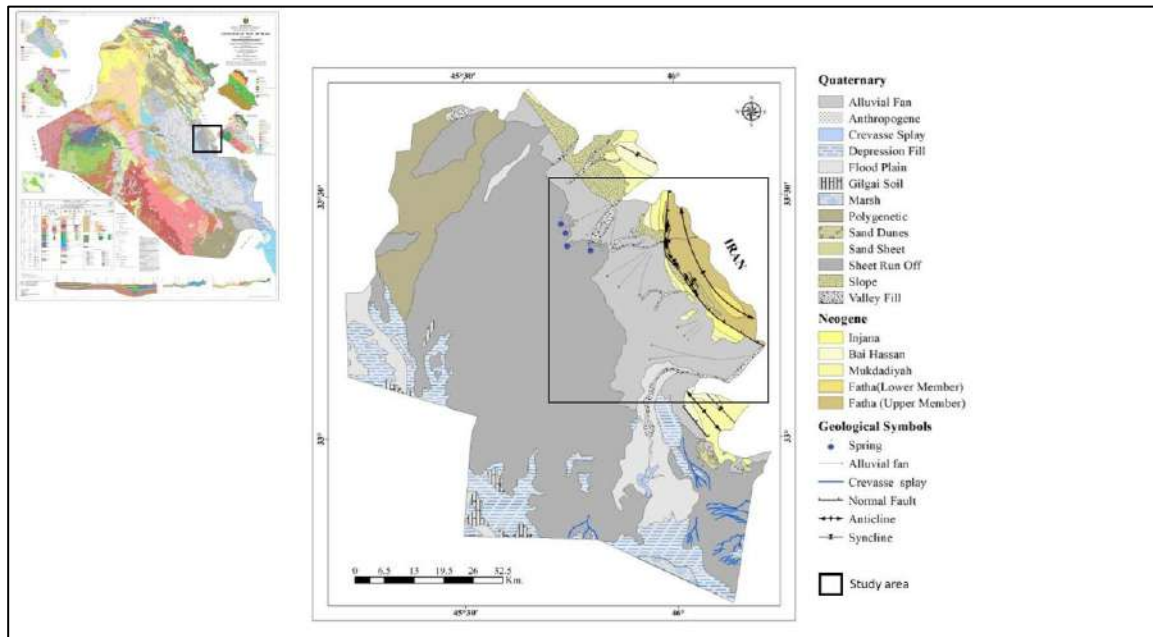


Fig.(3) The study area's geological map (Fouad, 2012).

3. Data and Methodology

3.1 Topographic Indices

Curvature is analyzed to determine a surface's convex regions as well as its concave regions. In particular, positive values of curvature suggest the existence of convex functions with ridges or upward blocks, while negative values indicate concave shapes such as valleys or fault-controlled basins. To enhance structural interpretation Jordan et al., 2005 used both Plan and Profile Curvature. Slope and Curvature were calculated using a 12.5m DEM in ArcGIS under Spatial Analyst Tools → Surface.

3.1.1 Topographic Position Index (TPI)

According to McGarigal et al. (2009), TPI provides great insight with regards to the relationship between the tectonic processes and the landforms. Because of its potential to aid in the construction of topographic maps, Reu et al. (2013) state that TPI can detect geomorphic features like faults, folds, and even areas of ground movement (uplift or subsidence). The ALOS PALSAR DEM data as a primary dataset and a radius of 50m is considered the interest radius; with TPI, identifies the contour averaged ($\hat{z}$) region (R) defined (Gallant and Wilson, 2000). Weiss (2001) asserts that landforms can be

subdivided into distinct types and thus the classification of the terrain into landform classes was noted.

$$TPI = z_0 - \hat{z}$$

3.1.2 Slope, Curvature and TRI (Terrain Ruggedness Index)

Maps with a slope representation are made to understand the geomorphic features concerning tectonic significance. Jordan (2003) explains how larger, more common slopes are associated with structural features like tectonic faults, fault edges, structural uplifts, while lower slopes are linked to deposition basins or erosion zones.

To analyze a surface's shape, it is necessary to evaluate its convex and concave parts, which is known as curvature. Positive values mark upward-facing structures, also known as convex, while negative values mark concave forms, such as valleys or basins formed by faults. Jordan et al. (2005) applied Plan and Profile Curvature to deepen the interpretation of structures further. Slope and curvature calculations were performed in ArcGIS with slope and curvature plugins on a 12.5m DEM using the Spatial Analyst Tools → Surface.

The Terrain Ruggedness Index (TRI) assesses surface roughness and detects topographic alterations associated with tectonic activities. TRI effectively detects fault scarps, structural ridges, and raised blocks by calculating the elevation difference between a central pixel and its eight adjacent pixels within a Digital Elevation Model (DEM). This method adheres to the framework established by Riley et al. (1999), which defines TRI as the total of the squared elevation variances within each mobile unit and its borders, divided by the area of the cell. This method adheres to the framework established by Riley et al. (1999), which defines TRI as the total of the squared elevation variances within each mobile unit and its borders, divided by the area of the cell. This significantly indicates the terrain's variability in morphotectonic analysis (Trevisani et al, 2023).

A study cited by Trevisanni in 2023 showed that this explains the terrain variability in morphotectonic analysis. Riley et al. (1999), regarding measuring variance TRI within each mobile unit and their respective borders, as the sum of squared elevation variances per unit cell area, gives reason for variability. Incorporating both slope and curvature allowed the refined extraction of geomorphic barriers, locating spoil-in-slope regions and interpreting plausible fault-related deformational patterns throughout the area (Schillaci et al., 2015). Since the values of the TRI, Slope, and curvature indices differ qualitatively, reclassification was employed to simplify the criteria and standardize the values so they could be integrated using Spatial Analyst Tools → Reclass → Map Algebra → Raster Calculator, applying the formula:

$$\text{Combined-Index} = (0.5 * \text{TRI} + 0.3 * \text{Slope} + 0.2 * \text{Curvature})$$

The result and discussion

Topographic indices help understand geomorphological structure and landscape dynamics (Valkanou et al., 2024). It identifies topography and detects structural abnormalities

by measuring elevation fluctuation, surface roughness, and landform placement (Ghosh and Kundu, 2022). Geomorphologists employ these indices to distinguish ridges, valleys, plateaus, and slopes. Uplift zones, fault ridges, and structural boundaries generally have high TRI, slope, and TPI values in tectonically active places. Thus, these indices define topography and indicate neotectonic activity, helping to understand how tectonic processes change surface form.

The landforms in the study area were classified into five classes according to changes in TPI values (Figure 4). The result reveals a clear structural-topographic pattern consistent with the regional tectonic framework. Both very high peaks and high ridges are distributed northwest-southeast, parallel to fault lines and fold axes, indicating a direct structural influence on shaping the topography. The deep valleys along the highlands indicate active erosion or substantial fluvial intrusion along areas of structural weakness, such as fault ridges or axial valleys. This marked contrast between the highlands and adjacent valleys is likely due to neotectonic activity. Plains and shallow valleys occur primarily in the west and southwest of the area, consistent with the Mesopotamian plain. The spatial relationship between the TPI results confirms that the region is undergoing active geomorphological processes controlled mainly by tectonics.

The slope map shows that the steep slope zones reflect recent crustal deformation due to tectonic uplift, fault scarps, and erosional escarpments (Figure 5). Low slope regions (zero–2°) dominate the western region, suggesting tectonic quiescence and sediment storage in low-energy depositional environments. The abrupt transition between uplift and flat areas also defines potential morphotectonic boundaries (Rozycka et al., 2021), which coincide with some lineaments and breaks in the drainage network. Such terrain differences support the interpretation of late or ongoing tectonic activity and contribute to the distinction between geomorphological units affected by structure control.

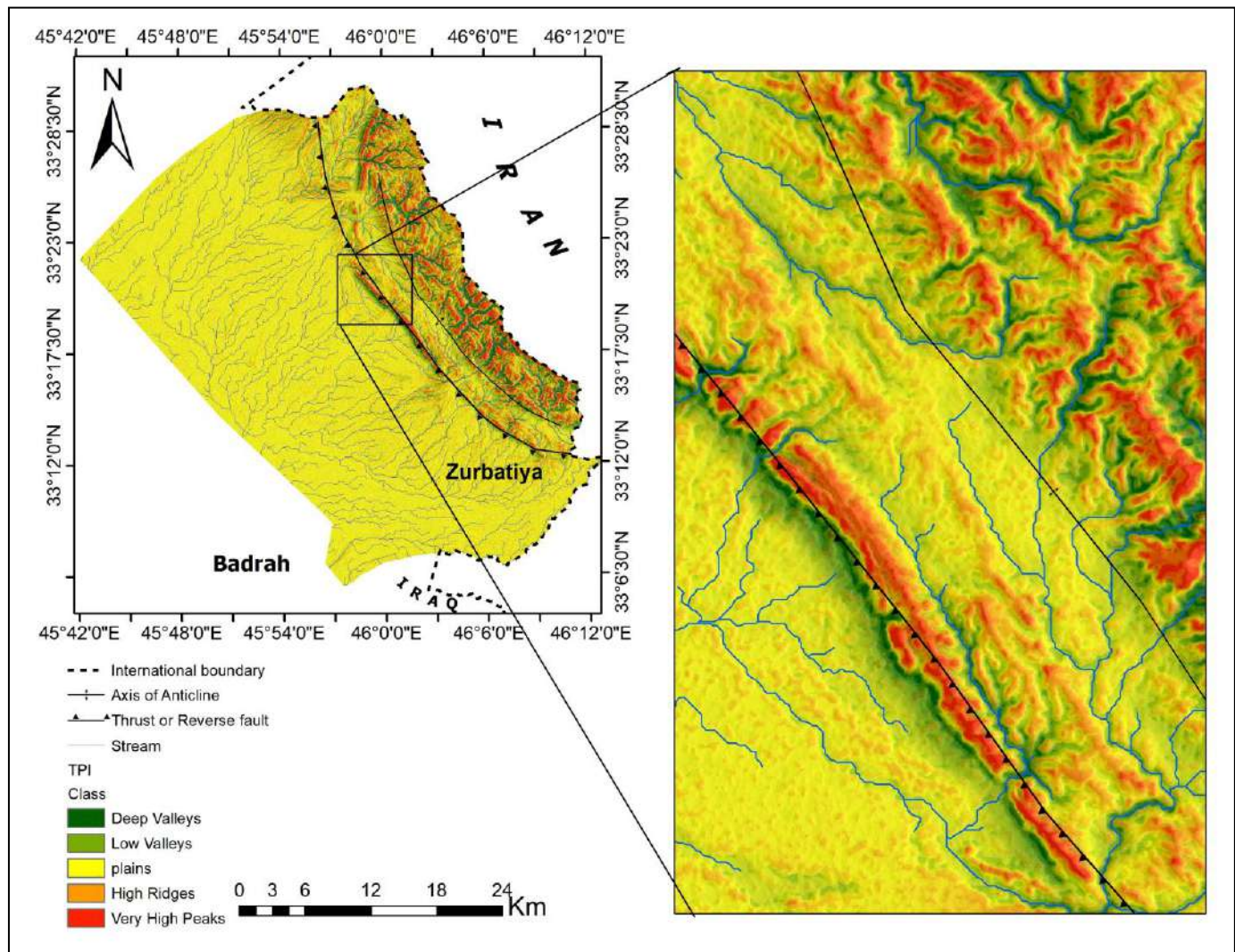


Fig (4). Landform Classification based on TPI analysis.

According to the curvature map, landforms in the study area alternate between convex and concave. Curvature allows the distinction between tectonically uplifted zones and decreasing regions. (Ehsani and Quiel, 2008). Positive curvature regions, especially in the northeastern and central upland, are convex slopes associated with tectonic uplift, anticline crests, or ridge tops (Figure 4). These zones are near high slopes and roughness, confirming an active structural effect. Negative curvature dominates valley systems and drainage channels, indicating erosional concavity and sediment transfer. The link between tectonic control and geomorphic processes is evident in

these concave zones' alignment with structurally guided streams and fault-controlled depressions.

The TRI map indicates that the highly and moderately rugged zones are predominantly located around the study region's eastern terrain and anticlinal ridges (Figure 4). These zones have a robust geographical correlation with fault and terrain structure, facilitating the analysis of dynamic tectonic deformation. The western plains have low TRI values (Level to Nearly Level), indicating tectonic stability and robust depositional environments.

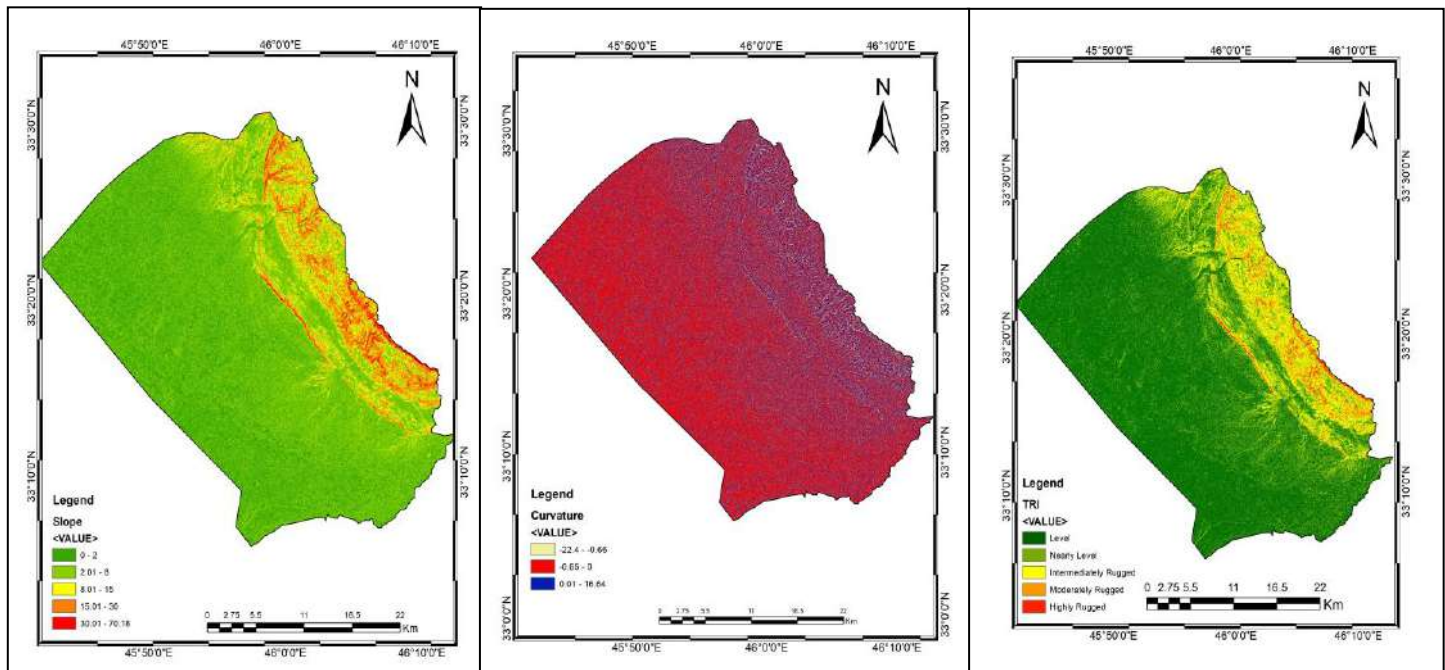


Fig (5). Slope, Curvature, and TRI of the study area.

Combining TRI, Slope, and Curvature indices into a composite analysis helps interpret tectonic patterns more comprehensively and provides an advanced and accurate understanding of terrain structure and landforms (Das, 2021; Rezaei Arefi et al., 2025). This combined analysis improves the delineation of structural domains and provides strong evidence for identifying neotectonic activity. The composite map is categorized into three classifications within the research region

(Figure 5). The geologically active areas (red) align with the thrust fault system and folded ridges suggesting constant deformation and uplift occurs in that area. The moderately active regions (yellow) mark either a more structural or transitional level of activity. On the other hand, the low-activity zones (green) which are mostly in the western part tend to indicate stability in tectonic movements and sedimentation.

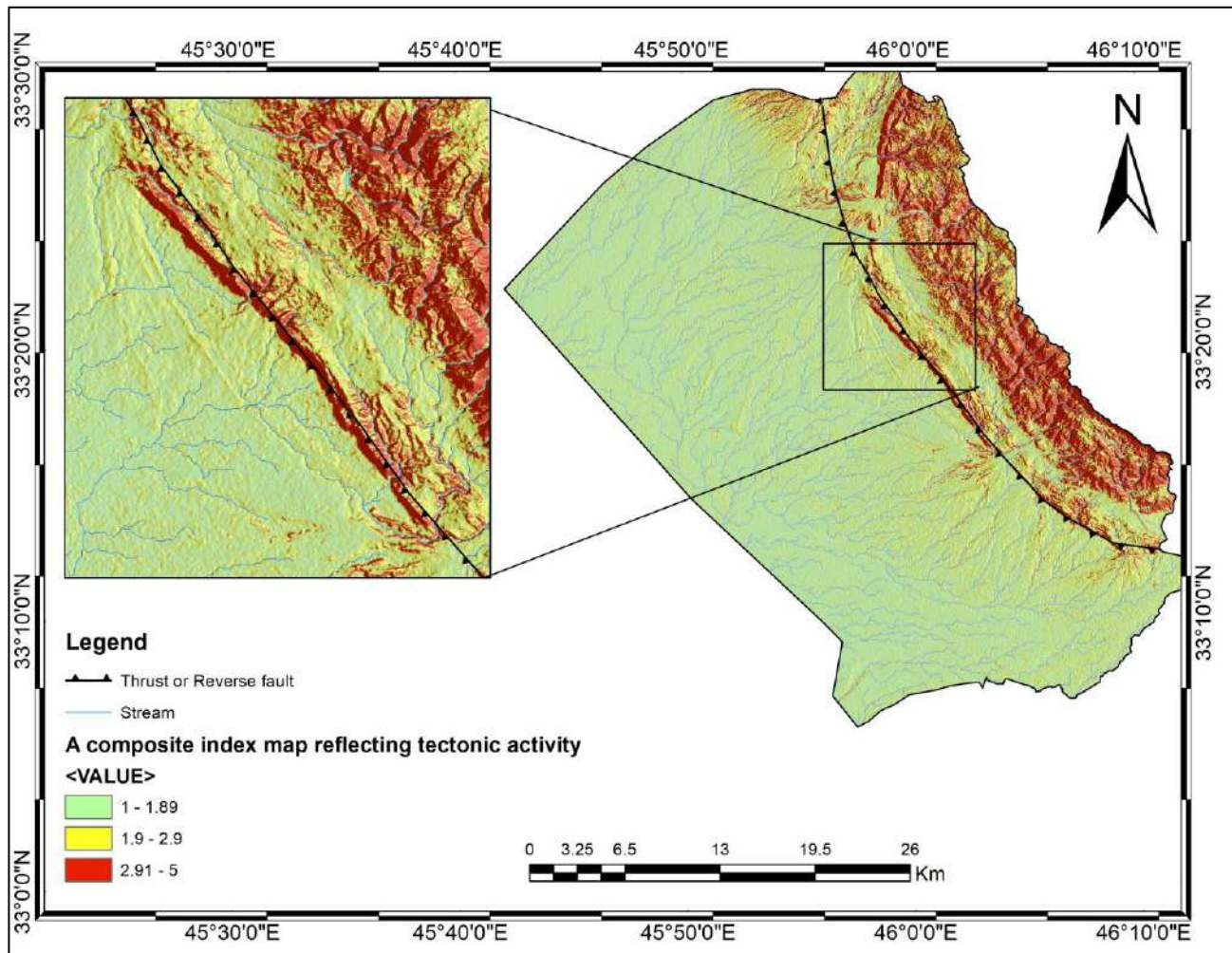


Fig (5). Composite Morphotectonic map utilizing TRI, Slope, and Curvature Indices.

4. Conclusions

The utilization of geomorphometric indices TPI, slope, curvature, and TRI in conjunction with ALOS PALSAR DEM data facilitated the recognition of fault-controlled landforms, such as structural ridges, axial valleys, and uplifted zones, which align with regional tectonic trends. The composite morphometric approach proved crucial in distinguishing between active and stable zones and in elucidating the link between geomorphic characteristics and underlying tectonic processes. This study's results indicate that topographic markers substantially improve the recognition of neotectonic events and terrain dynamics. The document introduces a methodology for neotectonic geomorphology investigation, land use strategizing, and geo-hazard evaluation in dynamic areas.

5. References

- [1]. Abdulnaby, W., Mahdi, M., Al-Mohmed, R., & Mahdi, H. H. (2016). Seismotectonics of Badra-Amarah Fault, Iraq-Iran Border, 4,(2321-0982), 27-33.
- [2]. Abdulnaby, W., Mahdi, M., Al-Muhammed, R. A., Darweesh, N. A., & Hashoosh, A. M. (2021). Geology of Bajalia Anticline of the Low Folded Zone of Iraq. Magallaḥ Al-Kuwayt Li-l-ʿulūm. <https://www.semanticscholar.org/paper/Geology-of-Bajalia-Anticline-of-the-Low-Folded-Zone-Abdulnaby-Mahdi/46e978dd9a86cfb3404c66855a9cb107d82e0718>
- [3]. Ahmed, S. H., & Salman, M. A. A. (2020). Geology and Structural Description of Shakrok Anticline; Northern Iraq. Iraqi Journal of Science, 2017-2032. <https://doi.org/10.24996/ij.s.2020.61.8.18>

- [4]. Das, S. (2021). Hydro-geomorphic characteristics of the Indian (Peninsular) catchments: Based on morphometric correlation with hydro-sedimentary data. *Advances in Space Research*, 67(8), 2382–2397. <https://doi.org/10.1016/j.asr.2021.01.043>
- [5]. De Reu, J., et al. (2013). Application of the topographic position index to heterogeneous landscapes. *Geomorphology*, 186, 39–49. <https://doi.org/10.1016/j.geomorph.2012.12.015>
- [6]. Ehsani, A. H., & Quiel, F. (2008). Geomorphometric feature analysis using morphometric parameterization and artificial neural networks. *Geomorphology*, 99(1), 1–12. <https://doi.org/10.1016/j.geomorph.2007.10.002>
- [7]. Fouad, S. F. A. (2010). Tectonic and Structural Evolution of the Mesopotamia Foredeep, Iraq.
- [8]. Fouad, S. F. A. (2012). Western Zagros Fold – Thrust Belt, Part I: The Low Folded Zone. *Iraqi Bulletin of Geology and Mining*, 5.
- [9]. Ghosh, S., & Kundu, S. (2022). Morphometric characterization and erosion assessment of gullies in the lateritic badlands of Eastern India. *Geocarto International*, 37(25), 10096–10129. <https://doi.org/10.1080/10106049.2022.2032390>
- [10]. Jordan, G. (2003). Morphometric analysis and tectonic interpretation of digital terrain data: A case study. *Earth Surface Processes and Landforms*, 28(8), 807–822. <https://doi.org/10.1002/esp.469>
- [11]. Jordan, G., et al. (2005). Extraction of morphotectonic features from DEMs. *Int. J. of Applied Earth Observation and Geoinformation*, 7(3), 163–182. <https://doi.org/10.1016/j.jag.2005.03.003>
- [12]. Martinello, C., et al. (2021). Optimal slope units partitioning in landslide susceptibility mapping. *Geomatics, Natural Hazards and Risk*, 12(1), 1908–1929. <https://doi.org/10.1080/17445647.2020.1805807>
- [13]. McGarigal, K., et al. (2009). Surface metrics: An alternative to patch metrics for the quantification of landscape structure. *Landscape Ecology*, 24(3), 433–450. <https://doi.org/10.1007/s10980-009-9327-y>
- [14]. Radaideh, O. M. A., & Mosar, J. (2019). Tectonics controls on fluvial landscapes and drainage development in western Switzerland. *Tectonophysics*, 766. <https://www.sciencedirect.com/science/article/pii/S0040195119302860>
- [15]. Rezaei Arefi, M., et al. (2025). Geomorphological Analysis Utilizing Surfacein interrupture Theory. *Quantitative Geomorphological Research*, 13(4). <https://doi.org/10.22034/gmpj.2025.493524.1540>
- [16]. Riley, S. J., et al. (1999). A terrain ruggedness index that quantifies topographic heterogeneity. *Intermountain Journal of Sciences*, 5(1–4), 23–27.
- [17]. Roy, D., et al. (2025). A GIS-based integrated assessment of geomorphometry. *Journal of Earth System Science*, 134(1). <https://link.springer.com/article/10.1007/s12040-025-02557-7>
- [18]. Różycka, M., et al. (2021). Tectonic versus rock-controlled mountain fronts – A geomorphometric approach. *Geomorphology*, 373, 107485. <https://doi.org/10.1016/j.geomorph.2020.107485>
- [19]. Trevisani, S., et al. (2023). Hacking the topographic ruggedness index. *Geomorphology*, 439, 108838. <https://doi.org/10.1016/j.geomorph.2023.108838>
- [20]. Valkanou, K., et al. (2024). Identification of geomorphic and morphotectonic features. In G. Petropoulos & C. Chalkias (Eds.), *Geographical Information Science*. Elsevier. <https://doi.org/10.1016/B978-0-443-13605-4.00009-6>
- [21]. Weiss, A. D. (2001). Topographic position and landforms analysis. Poster presented at the ESRI User Conference. https://www.jennessent.com/downloads/tpi-poster-tnc_18x22.pdf