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DETERMINATION OF DISSECTION INDEX (DI) USING GIS TECHNIQUES: A CASE STUDY ON HAKARİ RIVER BASIN

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Abstract

Advancements in remote sensing technologies, particularly Digital Elevation Models (DEMs) and Geographic Information Systems (GIS), have significantly improved the accuracy, efficiency, and computational speed of morphometric index calculations and analyses. Horizontal and vertical dissection are essential parameters used to characterize topographic features and the degree of terrain dissection. These analyses are primarily based on factors such as drainage density and the spatial distribution of landforms. However, to date, there is no fully automated method or software tool available for the direct computation of these parameters. This study aims to calculate these parameters using GIS-based methodologies within ArcMap 10.4.1 software by leveraging ALOS-PALSAR satellite-derived DEM data with a 20-meter resolution. A 2×2 km grid of interpolation points was generated to facilitate the computation of the dissection index, with Inverse Distance Weighting (IDW) identified as the most suitable interpolation method. The analysis of horizontal and vertical dissection can contribute to a better understanding of the spatial distribution of morphogenetic processes, serving as a fundamental tool for landform segmentation and geomorphological mapping. Furthermore, it can be applied in various fields, including landscape unit classification, pedogenesis-morphogenesis equilibrium studies, and environmental assessment.

Keywords: *relief morphometry, GIS, terrain dissection index, DEM, watershed*

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INTRODUCTION

Morphometry, derived from the Latin term meaning "Science of Form," is widely utilized in geographical studies. It refers to the quantitative analysis of geometrically shaped elements. Given the broad scope of morphometry, this article focuses specifically on relief morphometry, which examines landform structures from a geographical perspective [7]. The term "morphometry" was first introduced by

Corley in 1957 and has since been used to analyse the characteristic features and morphological processes of river basins through various morphometric methodologies. In contemporary research, geographic information system (GIS)-based software programs perform morphometric analyses primarily using the Strahler and Shreve classification methods.

Landforms are shaped by geological and geomorphological processes occurring on the Earth's surface. The primary objective of studying landforms in any given area is to identify and analyse their morphometric characteristics. Morphometric parameters constitute a fundamental component of the natural geographical framework of a region, as they quantitatively describe the geomorphological features, landform structures, and overall relief associated with specific morphological processes. Currently, Geographic Information System (GIS) techniques are widely employed to calculate and analyse various morphometric parameters of river basins and terrain features [3]. In recent years, GIS and Digital Elevation Models (DEM) have proven to be highly effective tools not only in the analysis of river basins but also in the development of conservation strategies. Furthermore, physiographic quantitative methods have become indispensable in geomorphological research, particularly in assessing the evolution of surface water bodies. These methods provide a comprehensive understanding of the studied area by applying numerical parameters to analyse morphological processes, landforms, and relief structures. The significance of the findings derived from such analyses is substantial, as they play a crucial role in environmental protection, assessing erosion intensity, and informing land management strategies [1].

The variability of relief can be assessed through various morphometric parameters. This study aims to determine the dissection index (DI) of the Hakari River basin, located in the Gubadli region, using GIS technologies and tools. The analysis is based on data derived from a 20-meter resolution Digital Elevation Model (DEM) obtained from the ALOS-PALSAR satellite system. The dissection index is a crucial morphometric parameter that quantifies the degree of erosion through both horizontal and vertical dissection, thereby providing insights into the developmental stage of a given physiographic area or river basin.

Relief dissection is categorized into two primary types: horizontal dissection, also referred to as "dissection density," and vertical dissection, known as "dissection depth." Mapping both the depth and density of relief dissection is essential for geomorphological and landscape studies, as it enhances the understanding of terrain evolution and erosion dynamics [2,5].

Object and methodology of research. The Gubadli district, located in the southwestern part of the Republic of Azerbaijan, shares borders with Lachin to the north, Zangilan to the south, Khojavend and Jabrayil districts to the east, and Armenia to the west. The region is predominantly mountainous, with key water sources including the Bargushad and Hakari rivers, the Meydan ravine, and numerous springs. The study area is situated between 39°20'45.0"N latitude and 46°35'10.0"E longitude, covering an area of approximately 802 km² (Figure 1). The Hakari River, which traverses the district, is the left-bank tributary of the Araz River and ranks as the second-largest river in the Lesser Caucasus, following the Tartar River [14] .

The basin exhibits distinct climatic conditions, vegetation cover, and geological characteristics, making it a significant research area for studying the spatial distribution of natural processes and assessing environmental dynamics.

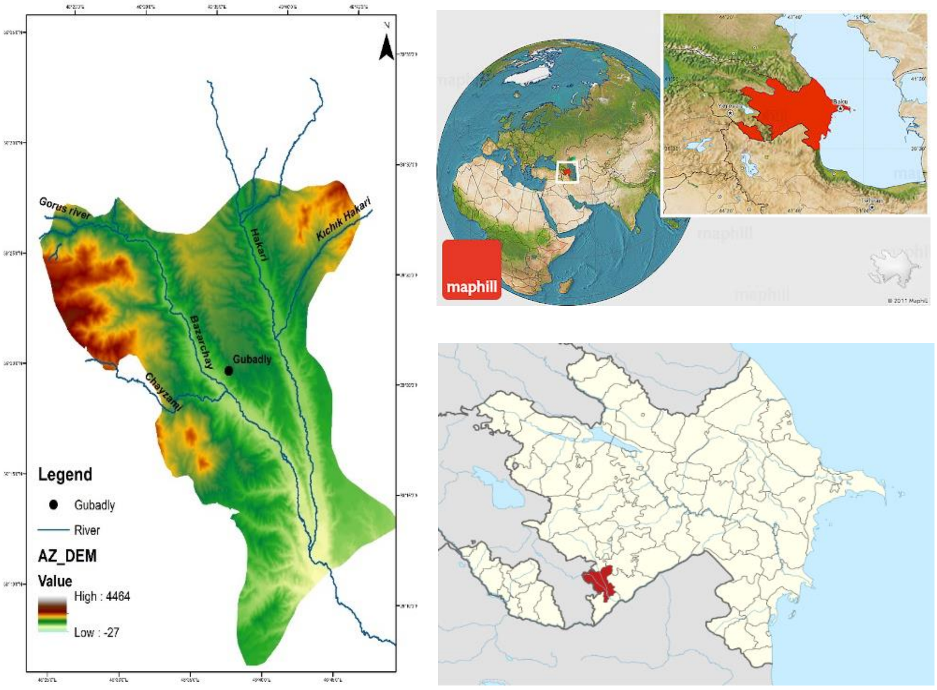

Figure 1. Digital model elevation (DEM) and location of the study area.

3.Research results, analysis, and discussion. In order to conduct this research, the Hakari River basin and its relief were initially delineated, with primary and sub-basins identified using the D8 flow direction method. Subsequently, the entire river network was digitized. The maps presented in Figures 1 and 2 were derived from 1:25,000 scale topographic maps, and the study area was analysed within a GIS environment using ArcGIS 10.4.1 software.

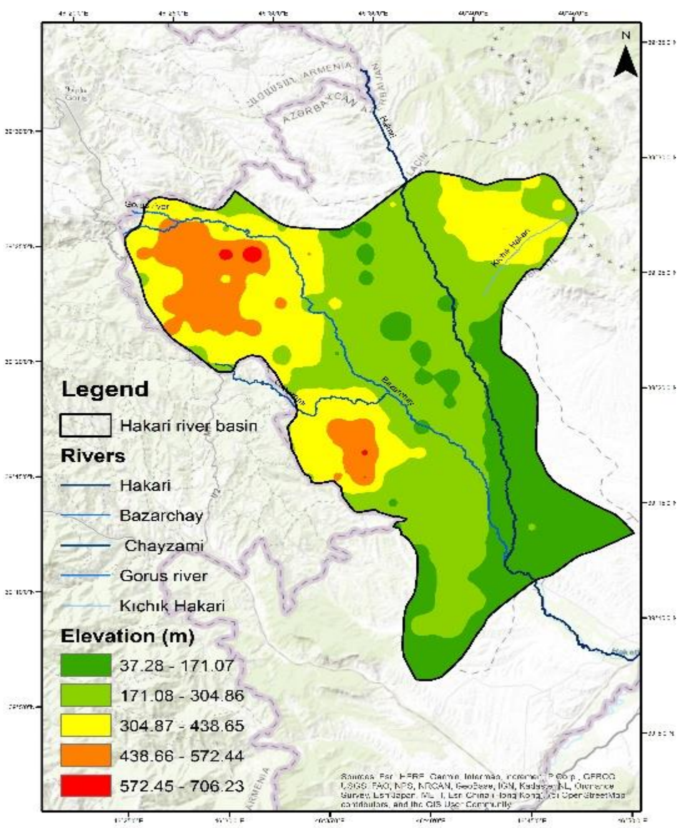

Figure 2. Hypsometric map of the Hakari River basin

The materials utilized in this study include Digital Elevation Model (DEM) data with a spatial resolution of 20 × 20 meters from the ALOS-PALSAR satellite, along with additional DEM data with a linear unit of 1 meter, stored in FGDBR format and referenced to the WGS_1984_UTM_Zone_39N coordinate system. DEMs are widely employed datasets for hydrological modeling and river network generation; however, they require preprocessing to ensure compatibility with hydrological analyses [4]. To enhance data accuracy, void pixels within the DEM were corrected using GIS-based interpolation techniques, making them suitable for hydrological assessments. The dataset was analysed in ArcGIS 10.4.1, where the delineation of basins and sub-basins was performed, and the drainage network was extracted. Basin parameters, including area, perimeter, and length, were automatically computed using the software's geoprocessing toolbox, while additional parameters were derived using standard morphometric formulas [6]. ArcGIS 10.4.1 was chosen for its capability to facilitate precise and systematic data analysis, ensure structured storage, and enable seamless sharing of results within a geospatial database. Other maps and numerical datasets generated throughout the study were compiled in accordance with the sequence presented in Figure 3.

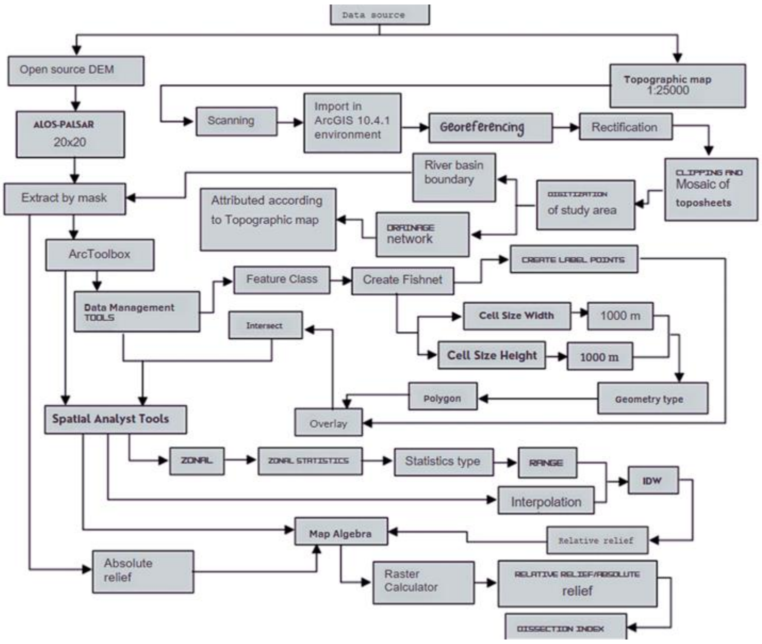

Figure 3. Flow chart depicting methodology

The calculation of morphometric parameters using classical methods is typically time-consuming, and if computational errors are not mitigated during the process, the final results may lack accuracy and reliability [8]. Although the relief fragmentation index (RI) holds significant theoretical and practical importance in geomorphological studies, no fully automated method currently exists for its computation based on the two morphometric variables proposed by D. Nir—relative and absolute relief. Consequently, this study introduces a methodology that systematically and transparently outlines the derivation of this parameter. The RI can be calculated using the following formula, as proposed by Nir (1957) [9]:

$$D_{\mathrm{i}} = \frac{R_h}{R_a} \qquad (1)$$

here: DI - fragmentation index of the relief,;

R_h - relative height of the relief;

R_a - absolute height of the relief;

Utilizing Geographic Information System (GIS) techniques, the relative height of the land surface was computed through the point interpolation method, leading to the generation of square pixels measuring 2 km by 2 km (Figure 4). The relative height of the land surface (Rh) was derived using the "Zonal Statistics" tool in ArcGIS. Upon selecting this tool, a dialog box appears where specific parameters must be defined. Among the available parameters, this study focuses on the "Range" parameter, which calculates the difference between the maximum and minimum values within each cell. Following the computation of the relative elevation of the relief (Rh), the next step involves point interpolation. Due to its computational efficiency and accuracy, the "Inverse Distance Weighted" (IDW) method was employed for interpolation. IDW is a widely used interpolation technique in ArcGIS, particularly effective when interpolation points are densely distributed and distance plays a crucial role in the spatial prediction process [10,12]. This method estimates values at unknown locations by assigning greater influence to nearby known points, adhering to the following mathematical formulation:

$$Z\,(x)=\frac{\sum_{i=1}^{n} w_i z_i}{\sum_{i=1}^{n} w_i} \tag{2}$$

$$w_i = d_i^{-u} \tag{3}$$

here: Z (x) - the estimated value at an interpolated point;

z_i - the value at a known points;

n - the number of known points that are used in interpolation;

d_i - the distance between point i and the prediction point;

w_i - the weight given to point i.

Larger weighting values are given to those points which are near the interpolated points. As the distance increases, the weight decreases and u is the weighting power that impose the amount of weight decrease with respect to the increase in distance [11].

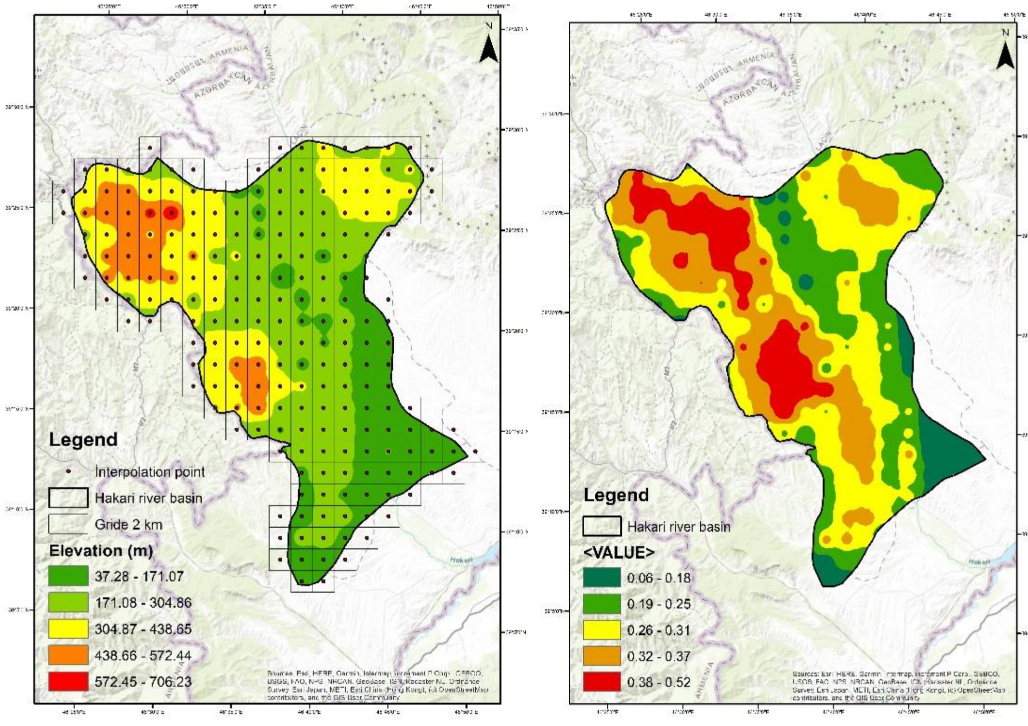

Figure 5. Dissection index of the Hakari River basin

CONCLUSION

The Dissection Index (DI) serves as a fundamental tool for assessing the developmental stages of relief forms within a given basin or physiographic region. By utilizing DI-based analyses, it is possible to generate geomorphological maps at various scales, facilitating a more comprehensive understanding of landscape evolution. In this study, 1:230,000 scale maps were developed to provide a detailed representation of the study area, based on 2 km² pixel resolution and interpolated points. Additionally, since the database is structured using a well-defined grid system, it minimizes data redundancy and enhances correlational analyses, thereby improving the integration of geospatial data for morphometric assessments . The hypsometric map of the Hakari River basin offers critical insights into the basin's topographic characteristics, elevation distribution, and potential geomorphological processes. Elevation values within the region range from approximately 37.28 meters to 706.23 meters, indicating moderate topographic variability with significant elevation contrasts (Figure 2). The observations derived from the hypsometric analysis, along with the spatial distribution of elevation classes and relief characteristics, are as follows:

The hypsometric analysis of the Hakari River basin reveals a complex topographic structure with significant implications for hydrology, erosion processes, and land management. The elevation distribution within the basin is categorized as follows:

- Low elevations (37.28–171.07 m): These areas predominantly occupy the southeastern and certain central parts of the basin. They are typically associated with floodplains and alluvial deposits, indicating regions prone to sediment accumulation and fluvial processes.

- Medium elevations (171.08–438.65 m): This elevation range is mainly found in the central and northeastern sections of the basin, representing foothills and low-gradient slopes. These areas serve as transitional zones between alluvial plains and higher-elevation ridges.

- Higher elevations (438.66–706.23 m): Marked in orange and red on the hypsometric map, these zones are concentrated in the western and southwestern parts of the basin. They are characterized by steep slopes, ridges, and eroded landforms, suggesting active geomorphological processes such as slope instability and river incision.

The presence of high-altitude zones, particularly in the western and southwestern regions, indicates that fluvial erosion and mass wasting processes may be influencing the basin’s geomorphic evolution. The hypsometric distribution suggests that the basin is in a mature stage of geomorphic development, where both erosion and accumulation are actively shaping the landscape [13]. Elevation gradients have direct implications for land use planning and environmental sustainability. Lower elevations, which are more suitable for agriculture and human settlements, are often subject to sediment deposition and seasonal flooding. In contrast, higher elevations are more susceptible to erosion, landslides, and deforestation, necessitating targeted conservation measures. Effective watershed management should focus on stabilizing slopes, controlling erosion, and promoting land-use practices that minimize environmental degradation. Overall, the hypsometric characteristics of the Hakari River basin underscore the need for sustainable management strategies that integrate slope stability assessment, erosion control measures, and land-use regulations. Implementing such strategies will enhance ecological resilience, mitigate hydrological risks, and ensure long-term watershed sustainability. The fragmentation index is a very important morphometric parameter of the relief and river basin. This parameter indicates the degree of vertical fragmentation and horizontal fragmentation and includes the stage of development of the relief forms. DI values vary between "0" and "1". If the DI value is 0, it indicates that there is vertical fragmentation in the relief and therefore the surface is flat or partially smooth. Therefore, the absence of fragmentation means a smooth topographic surface. If the DI value is 1, it indicates the presence of cliffs, which can be in hilly parts of the relief, on steep slopes or along the coastline. The Dissection Index (DI) values obtained from our calculations were assigned to each 2 km² grid cell and subsequently categorized into five distinct classes:

- very weak (0.06–0.18),
- weak (0.19–0.25),
- medium (0.26–0.31),
- high (0.32–0.37),
- very high (0.38–0.52).

To illustrate the spatial variability of DI across the Hakari River basin, a fragmentation map was generated (Figure 5).

- Very weak (0.06–0.18): Predominantly observed in the southeastern part of the basin, these areas are represented in dark green on the map. They exhibit minimal vertical dissection and are characterized by relatively stable surfaces with low topographic variability. Such regions primarily correspond to lowland areas, floodplains, or alluvial deposits where erosion processes are less pronounced.
- Weak, medium and high (0.19–0.37): These zones, represented by colors ranging from light green to yellow, indicate moderate levels of vertical dissection. They correspond to regions where fluvial erosion and tectonic influences have contributed to landscape development, shaping rounded hills, valleys, and transitional zones between lowlands and mountainous terrains. The fragmentation intensity in these areas suggests the presence of moderate geomorphic activity.
- Very high (0.38–0.52): The northwestern and central parts of the basin exhibit the highest fragmentation intensity, depicted in shades from orange to red. These areas are characterized by steep elevation gradients, active erosion processes, and potential tectonic influences. The prevalence of high DI values suggests significant landscape instability, possibly due to a combination of fluvial incision, mass wasting, and structural deformations.

Result:

The spatial distribution of DI highlights the basin's geomorphological complexity, with varying degrees of landscape dissection influenced by both natural and anthropogenic factors. Understanding these variations is critical for erosion control, watershed management, and sustainable land-use planning within the region. The Dissection Index (DI) within the Hakari River basin exhibits extreme values ranging from 0.06 to 0.52. Such relatively low values suggest minimal fluvial incision and the gradual expansion of smooth relief surfaces within the basin. Notably, the Yazı Plain and Inca Plain, situated between the Bazarchay and Hakari Rivers, exemplify regions with low DI values, indicating limited vertical dissection, reduced river erosion, and the predominance of relatively stable landforms. The presence of low DI values suggests that the basin is less fragmented, with geomorphic processes favoring the development of smoother surfaces over time. In contrast, high DI values, particularly in the central and northwestern parts of the basin, indicate areas subjected to significant fluvial incision and steep slopes. These regions likely experience intensified sediment transport, suggesting dynamic geomorphic activity. The irregular spatial distribution of DI values reflects the influence of tectonic uplift, differential erosion, and lithological heterogeneity on the basin's morphodynamics. Notably, the northwestern sector, adjacent to the Armenian border, appears to exhibit active deformation or variations in lithological resistance, contributing to higher DI values. Regions characterized by high DI values are often associated with increased surface runoff, enhancing susceptibility to geomorphic hazards such as landslides, gully formation, and fluvial sedimentation. Conversely, low DI zones in the southeastern portion of the basin correspond to depositional environments where accumulative sedimentation processes dominate. The Hakari River basin presents a complex morphometric structure, with considerable spatial variability in its fragmentation index. While the highly dissected areas in the northwest and central sections indicate active geomorphic and fluvial processes, the southeastern low DI zones suggest more stable landforms. These findings have significant implications for:

- Hydrological and sediment transport modeling
- Erosion risk assessment and mitigation strategies
- Environmental management and sustainable land-use planning

The integration of remote sensing data, field investigations, and digital terrain analysis can further enhance the understanding of the geomorphic evolution of the basin. Future research should focus on refining morphometric models, incorporating higher-resolution datasets, and evaluating long-term geomorphic changes to inform sustainable watershed management practices.

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