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Research Article

IDENTIFICATION AND ANALYSIS OF TECTONIC DISLOCATIONS ON THE LEFT BANK OF THE AKHANGARAN RIVER USING SATELLITE IMAGERY AND GIS TECHNOLOGIES

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ABSTRACT
The paper presents the results of cosmogeological investigations aimed at identifying tectonic dislocations within the left-bank area of the Akhangaran River using remote sensing data and geoinformation technologies.

The relevance of this study lies in the construction of a tectonic dislocation density map, since such zones, characterized by increased permeability and geodynamic activity, play an important role in the migration, accumulation, and redistribution of pollutants and, under conditions of intensive industrial development, may contribute to the formation of concealed contamination zones.

The purpose of the study is the interpretation of multispectral and radar satellite imagery for the identification of lineaments and circular structures, followed by the compilation of tectonic dislocation and tectonic dislocation density maps.

The research was carried out using the ArcGIS and ERDAS Imagine software packages based on the analysis of Landsat imagery and the SRTM digital elevation model. To improve the reliability of interpretation, automated image-processing methods were applied, including matrix transformations and analysis of transformed spectral and thermal bands.

As a result of the interpretation, 197 lineaments corresponding to known faults and 724 lineaments of uncertain morphology with a total length exceeding 2,800 km were identified. Spatial heterogeneity in the distribution of tectonic dislocations was established, and zones of increased tectonic dislocation density were delineated. It was determined that lineaments detected in the thermal range predominantly correspond to active or buried faults.

The obtained results refine the tectonic structure of the investigated territory and may be applied to solving problems in hydrogeology, geoecology, and engineering geology. The study demonstrates the high efficiency of integrating remote sensing data and GIS technologies for the identification and analysis of tectonic structures.

Keywords: *tectonic dislocations, lineaments, remote sensing, Landsat, SRTM, geographic information systems, tectonic dislocation density, Akhangaran River.*

INTRODUCTION
The purpose of the present study is the interpretation of satellite imagery for the identification of tectonic dislocations within the right-bank area of the Akhangaran River and the compilation of the corresponding tectonic map, which may serve as a basis for subsequent geoecological, hydrogeological, and engineering-geological investigations. The relevance of this research is determined by the significant role of tectonic dislocations as zones of increased permeability and geodynamic activity controlling the processes of migration and redistribution of pollutants, particularly under conditions of intensive industrial development of the territory.

Within the framework of this study, satellite image interpretation was carried out by the authors using the ArcGIS 10.8 and ERDAS Imagine geoinformation systems at a scale of 1:100,000 (left-bank territory of the Akhangaran River, Fig. 1). The application of GIS technologies ensures integrated processing of multispectral and radar satellite data, enabling the creation of thematic maps based on remote sensing data and ground-based observations.

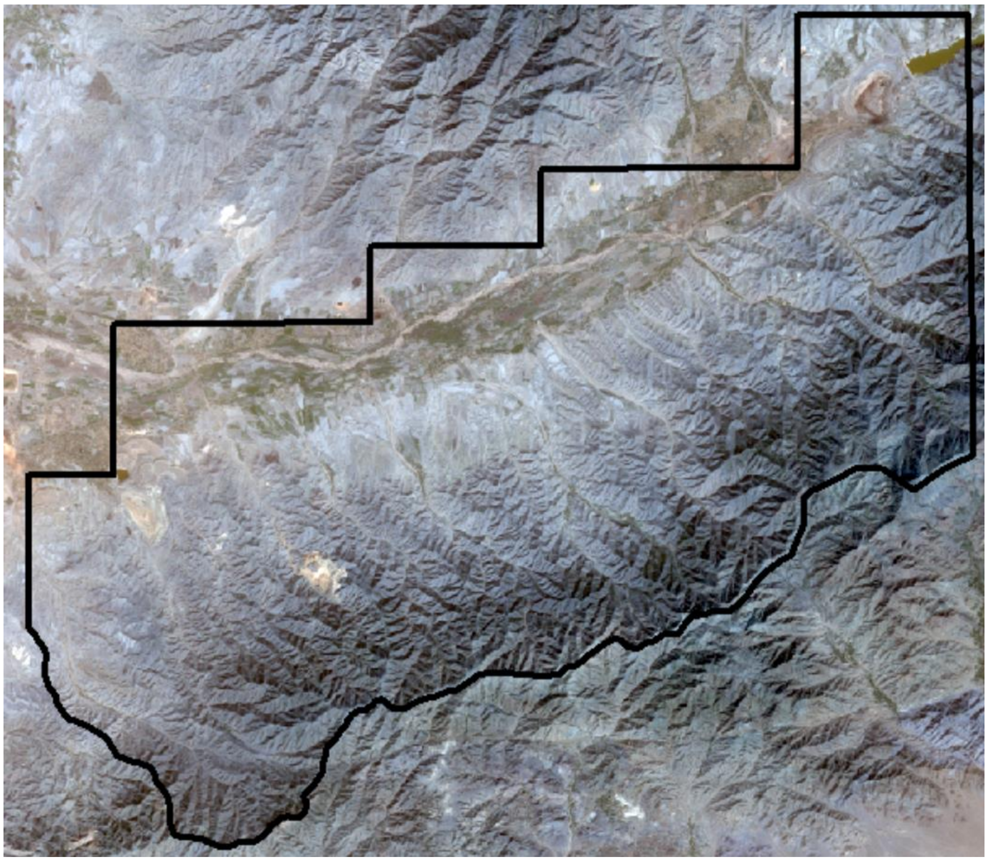

Fig. 1. Satellite image of the left-bank territory of the Akhangaran River.

Multispectral Landsat imagery and the SRTM digital elevation model (DEM), generated from radar survey data, were used as the initial dataset.

Multispectral Landsat imagery is widely applied in cartography, environmental monitoring, and various applied studies, including structural-geological, geoecological, and engineering-geological investigations [2, 4]. Their application, combined with automated image-processing methods, makes it possible to effectively identify tectonic dislocations, including lineaments and circular structures.

The Landsat imaging system, developed by the United States Geological Survey (USGS), is currently considered one of the most advanced Earth observation systems. The imagery includes 11 spectral bands, a spatial resolution of 30 m/pixel, and a radiometric resolution of 16 bits. A significant advantage is the open access to Landsat data available since 2009 [5].

The SRTM digital elevation model with a spatial resolution of 90 m represents a 16-bit raster image in which each pixel value corresponds to absolute elevation [6]. Based on the DEM and using automated interpretation methods, it is possible to generate maps of lineaments, tectonic dislocation density, slopes, surface curvature, slope aspect, hydrographic networks, and landscape structure.

The information potential of transformed radar data is considerably broader. The use of ArcGIS tools makes it possible to perform additional DEM transformations and analyze tectonic movements using structural-geomorphological methods.

Each spectral band of a satellite image represents a matrix of reflectance values, allowing it to be treated as a local database. For Landsat imagery, a grid with a spacing of 30 × 30 m (cell area of 900 m²) is generated, providing a high level of detail for subsequent analysis. The maps obtained during cosmogeological investigations can be effectively used for the integrated interpretation of geological, geoecological, and engineering-geological data.

METHODS

Methodology for Constructing Tectonic Dislocation Density Maps

The construction of the tectonic dislocation density map is based on the statistical analysis of lineament maps (faults and circular structures) obtained through satellite image interpretation [1, 7].

Modern multispectral and radar satellite data, after appropriate transformations, enable automated lineament interpretation. In comparison with the visual interpretation method, this approach significantly increases both the number of identified structures and the reliability of their detection. The use of imagery acquired during different seasons and under varying illumination and moisture conditions further improves the completeness of the interpretation.

A major advantage of Landsat data is their high synoptic coverage (swath width up to 180 km), which ensures complete coverage of the study area, unlike smaller-format aerospace imagery.

Radar data and their transformed derivatives make it possible to identify the most pronounced lineaments, including those not detectable in the optical range. Of particular importance are thermal-band transformations, which allow the identification of active faults and groundwater filtration zones [9].

The automated lineament extraction method is based on matrix image transformations using filters of different sizes (3 × 3, 5 × 5, and 7 × 7), which enables the detection of structures of various orientations and scales [8].

The following datasets were used for map compilation:

seven Landsat spectral bands (including the thermal band);

transformed derivatives of the digital elevation model (hypsometry and surface curvature).

Each image was transformed using diagonal filters of both right- and left-oriented directions. As a result, linear features interpreted as faults were generated in the images and represented as contrasting (black or white) linear segments.

Surface curvature was calculated as the second derivative of the relief using the ArcGIS tool *Spatial Analyst → Surface → Curvature*. This parameter reflects morphodynamic processes: negative values correspond to runoff zones, whereas positive values indicate erosion zones. Zero values characterize relatively stable areas.

Curvature analysis makes it possible to assess:

the direction and intensity of surface runoff;

erosion and accumulation processes;

zones of flow divergence and convergence.

Each transformed satellite image contains unique information on the geological structure and tectonic features of the study area.

Figures 2 and 3 demonstrate the advantages of transformed imagery compared to the original data for lineament interpretation. The main stages of image processing are presented in Figs. 3–7.

Interpretation was carried out within a GIS environment with the creation of a local database (LDB) containing the parameters of the identified lineaments and circular structures.

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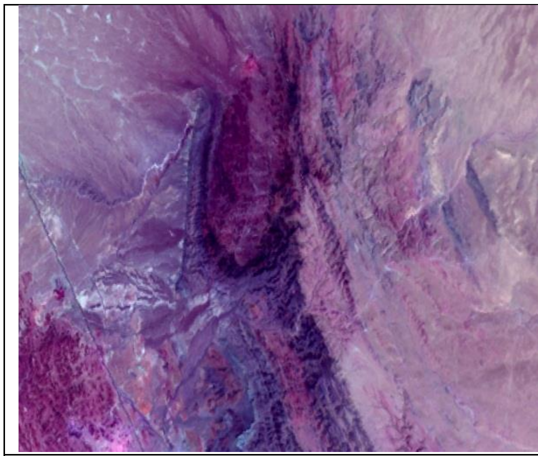

Fig. 2. Fragment of a multispectral Landsat 7 satellite image.

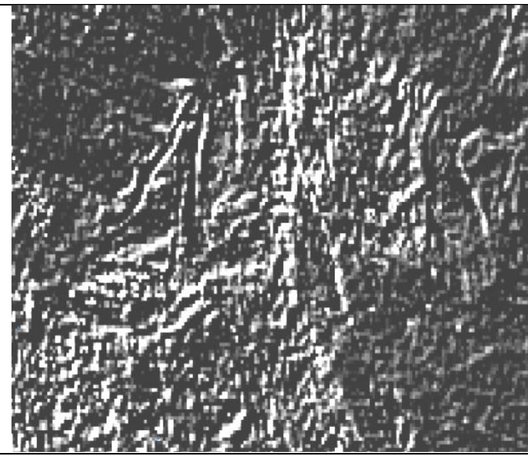

Fig. 3. Transformation of the 4th spectral band of the satellite image with extraction of the right-diagonal matrix direction.

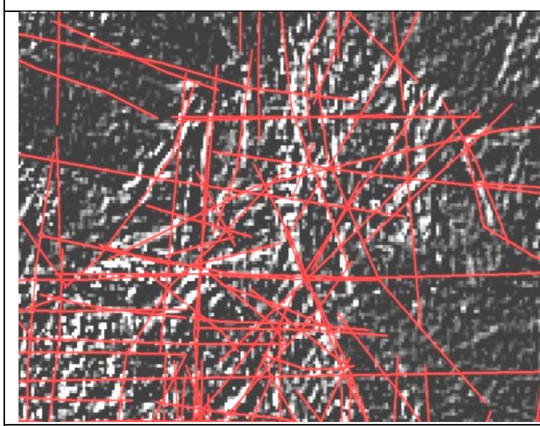

Fig. 4. Fault vectorization.

Fig. 5. Identified lineaments.

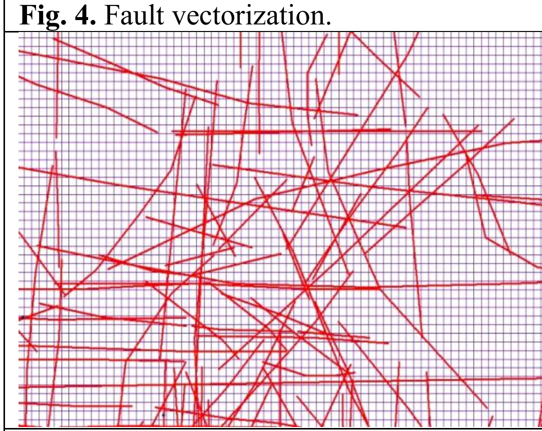

Fig. 6. Segmentation of lineaments using a 250 × 250 m grid followed by calculation of the total lineament length for each cell.

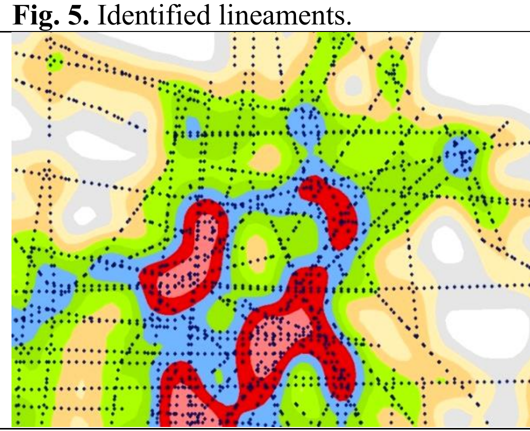

Fig. 7. Calculated tectonic dislocation density field.

The use of the LDB enables statistical data processing and the construction of tectonic dislocation density maps using the "moving window" method (for example, 250 × 250 m), within which the cumulative length of lineaments is calculated.

This approach provides the possibility to:
vary the analysis parameters (window size);
identify directional fault systems;
determine prevailing orientations (for example, northeastern, northwestern, or meridional trends).

RESULTS

As a result of the conducted investigations, a tectonic dislocation map and a tectonic dislocation density map were compiled for the left-bank territory of the Akhangaran River at a scale of 1:100,000.

Tectonic Dislocation Map

The identification of lineaments and circular structures was carried out based on the analysis of seven spectral bands of the Landsat 8 satellite image (acquisition date: August 27, 2013) and two transformed derivatives of the SRTM digital elevation model (hypsometry and surface curvature). All initial datasets were transformed using the CONVOLUTION method with left- and right-diagonal matrices of size 3 × 3.
In total, 18 transformed satellite images were used for interpretation. On their basis, preliminary schemes of lineaments and circular structures were compiled and subsequently generalized into the final map. During interpretation, all transformed datasets (spectral bands, hypsometry, and surface curvature) were analyzed comprehensively, which significantly increased the reliability of tectonic feature identification.
In addition, transformed thermal spectral bands were used, making it possible to identify faults and fracture zones exhibiting present-day activity or associated with groundwater circulation.
The attribute table of lineaments (Fig. 8) contains information on the length of each object, its orientation, strike azimuth, and the inferred genetic type of tectonic dislocation. The final map of lineaments and circular structures is presented in Fig. 9.

Tectonic lineaments identified by satellite imagery

FID	Lineament type	Angle	Length, km	Orientation
0	Lineaments identified by spectral and thermal channels	-59.466	6.3385	Northeast
1	Lineaments identified by spectral and thermal channels	12.7252	5.2563	Latitudinal
2	Lineaments identified by spectral and thermal channels	-0.1866	5.3007	Latitudinal
3	Lineaments identified by spectral and thermal channels	-7.8583	1.285	Latitudinal
4	Lineaments identified by spectral and thermal channels	-13.4912	7.6691	Latitudinal
5	Lineaments identified by spectral and thermal channels	16.0073	8.3152	Northwest
6	Lineaments identified by spectral and thermal channels	21.6675	16.1093	Northwest
7	Lineaments identified by spectral and thermal channels	23.5565	6.6826	Northwest
8	Lineaments identified by spectral and thermal channels	19.393	10.0258	Northwest
9	Lineaments identified by spectral channels	68.9903	3.1364	Submeridional
10	Lineaments identified by spectral channels	24.9864	2.4089	Northwest
11	Lineaments identified by spectral and thermal channels	-87.9881	1.8926	Meridional
12	Lineaments identified by spectral and thermal channels	-82.9593	8.1167	Meridional

Fig. 8. Fragment of the attribute table of lineaments used for compiling tectonic dislocation maps.

Within the study area, 57 circular structures were identified, a significant proportion of which are interpreted as formations associated with ancient volcanic activity.
Lineaments interpreted as zones of crushing and fracturing are predominantly concentrated in the western part of the study area, indicating spatial heterogeneity in tectonic dissection.
According to the interpretation results, the following structures were identified:
197 lineaments (or their fragments) coinciding with known geological faults, with a total length of 872.4 km;
724 lineaments of uncertain morphology with a total length of 2,891.1 km, including:
475 lineaments identified from spectral bands (1,522.6 km);
191 lineaments identified from thermal bands (1,172.4 km);
58 lineaments simultaneously detected in both spectral and thermal ranges (196 km).

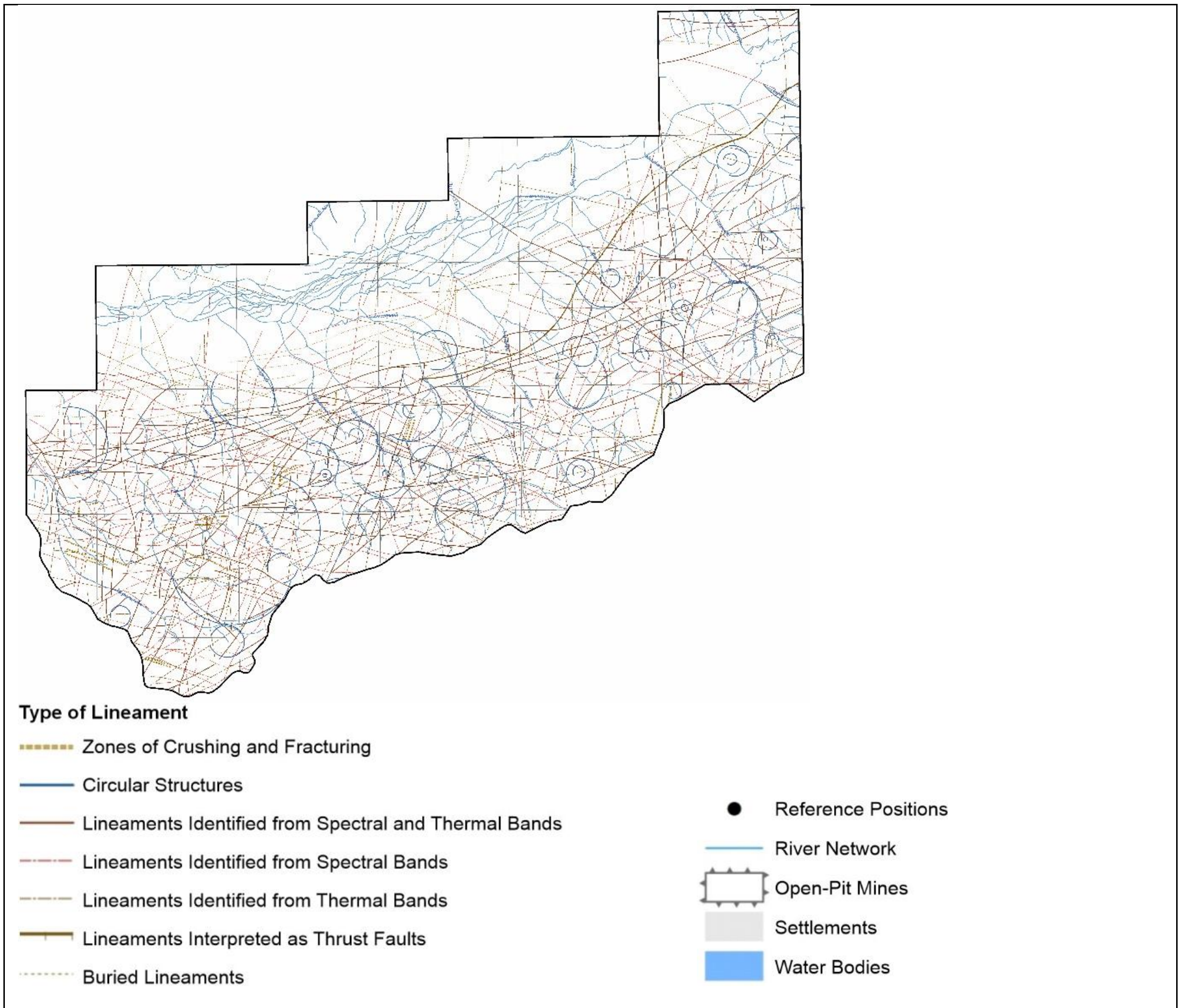

Fig. 9. Tectonic dislocation map of the Akhangaran River territory at a scale of 1:100,000.

Lineaments identified from spectral bands are characterized by diverse genesis and may reflect tectonic, lithological, or morphostructural features. At the same time, lineaments interpreted from thermal bands are predominantly associated with active or buried faults and fracture zones.

Tectonic Dislocation Density Maps

To quantitatively assess the spatial distribution of tectonic dislocations, a tectonic dislocation density map was compiled.

The calculations were performed using a regular grid with a cell size of 500 × 500 m. At the first stage, a polygonal network was generated, within each cell of which the cumulative length of lineaments and circular structures was calculated. The obtained values were then assigned to the corresponding polygons.

Subsequently, the coordinates of the cell centers were calculated and converted into a point layer. This layer served as the basis for the creation of a local database and the subsequent compilation of the tectonic dislocation density map (Fig. 10).

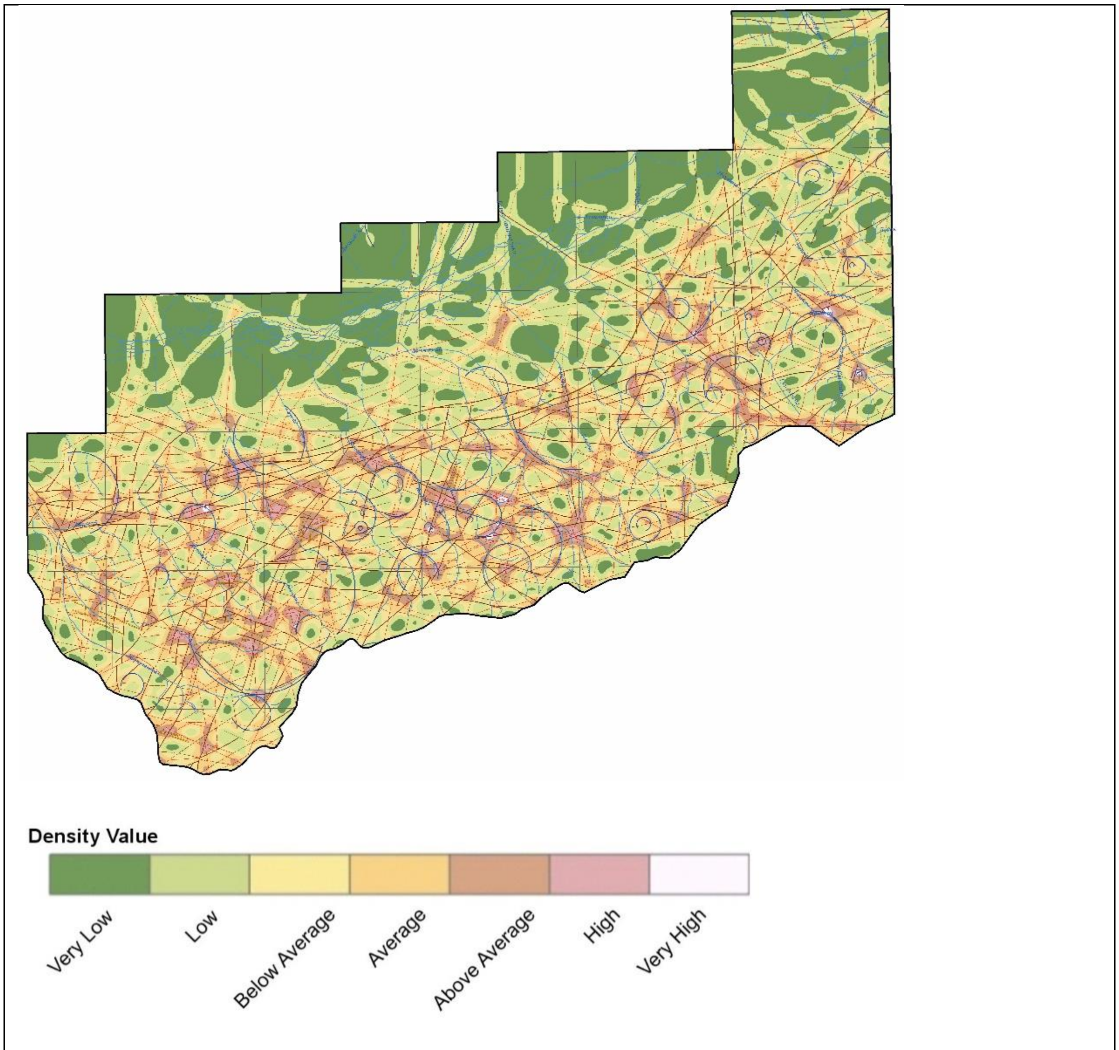

Fig. 10. Tectonic dislocation density field of the left-bank territory of the Akhangaran River.

Analysis of the obtained density field demonstrates pronounced spatial heterogeneity in the distribution of tectonic dislocations, reflecting different degrees of tectonic reworking of the territory. These results may serve as a basis for further geological-structural, hydrogeological, and geoecological interpretations.

DISCUSSION

The obtained results of satellite image interpretation and tectonic dislocation mapping significantly refine the understanding of the structural organization of the left-bank territory of the Akhangaran River.

One of the fundamentally important results is the identification of a considerable number of lineaments that do not coincide with previously mapped geological faults. This indicates the limitations of traditional geological mapping methods in the investigation of weakly expressed or concealed tectonic structures and confirms the high efficiency of automated interpretation of satellite data. Thus, the use of multispectral and radar imagery in combination with GIS technologies substantially increases the completeness and detail of structural analysis.

The spatial heterogeneity in the distribution of lineaments, expressed by their increased concentration in the western part of the study area, reflects the differentiated character of tectonic dislocation. These zones most likely correspond to areas of enhanced tectonic activity and may be associated with deep-seated fault structures or zones of stress redistribution within the Earth's crust. This makes it possible to consider the tectonic dislocation density map (Fig. 10) as an indicator of geodynamically active areas.

Comparative analysis of lineaments identified from different spectral ranges is of considerable interpretative significance. Lineaments detected in the thermal range are highly likely to reflect active or buried faults associated with modern geodynamic processes and fluid circulation. In contrast, lineaments identified only from optical bands may have a more complex origin, including lithological and morphostructural boundaries. This emphasizes the necessity of integrated use of different types of remote sensing data in order to improve the reliability of geological interpretation.

The identified circular structures, interpreted as manifestations of ancient volcanism, indicate the complex geodynamic evolution of the region. Their spatial association with linear structures may suggest the presence of tectonic intersection nodes, which are of particular interest from the standpoint of ore localization and zones of increased permeability.

From a practical perspective, the obtained results are important for related fields of research. It has been established that zones of increased tectonic dislocation density may be regarded as areas of enhanced fracturing and permeability controlling the filtration properties of rocks. In hydrogeological terms, such zones may play a key role in the formation and redistribution of groundwater flow, as well as in determining groundwater protection conditions.

At the same time, it should be noted that the interpretation of lineaments based on remote sensing data has certain limitations associated with the ambiguity of their genesis. Some of the identified structures may be controlled not only by tectonic factors but also by lithological or geomorphological conditions. Therefore, the obtained results require subsequent verification using geological and geophysical data [3].

Thus, the present study demonstrates that the integration of multispectral, thermal, and radar data within a GIS environment is an effective tool for identifying tectonic dislocations. The resulting maps not only refine the tectonic structure of the territory but also provide a basis for further integrated geological-geophysical, hydrogeological, and engineering-geological investigations.

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