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Geodynamic Monitoring of the Lopushne-Rososh Main Gas Pipeline Using Remote Sensing Data

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SUMMARY

The primary method of studying the Earth's crust using remote sensing data in geodynamic studies is lineament analysis. Disjunctive tectonic structures associated with lineaments determine the mobility of crustal blocks, the physical and mechanical properties of soils, and the features of groundwater circulation, and also affect the activity of exogenous geological processes. Areas where the pipeline route crosses geodynamic active zones require special attention and the implementation of additional measures for the engineering protection of the pipeline and its infrastructure. Thus, an integrated map of geomorphological risks within the Lopushne-Rososh gas pipeline section has been created, allowing us to identify areas of most significant risk.

Introduction

The sustainable development of Ukraine's economy and the national security of the state are significantly determined by the condition of transport infrastructure, particularly pipeline transport. The pipeline network represents a complex spatial object, encompassing main pipelines and branches with crossings over natural and artificial obstacles, protective structures, gas distribution stations, access roads, and other features, located in areas characterized by diverse engineering-geological conditions. The stability of these structures is primarily determined by modern geodynamics – processes and phenomena that cause deformations in rock strata and changes in the Earth's relief.
The term "lineament" was introduced into science by American geologist William Hobbs in 1911. According to his definition, a lineament is an elementary line of abrupt change in the parameters of geographical, geological, and geophysical environments (Ahmadi, Kalkan, 2021). Over the past several decades, domestic and foreign scientists have conducted studies on lineament structures. Based on their genesis, lineaments are classified as follows: 1) lineaments of the geographical environment: topo-, bathy-, photo-, and cosmo-lineaments; 2) lineaments of geological structure: geo-, tectono-, metallo-, and hydro-lineaments; 3) lineaments of geophysical and other fields: magneto-, gravi-, seismo-, and thermo-lineaments (Verkhovtsev et al., 2014). In the 1980s, the study of lineaments based on the interpretation of space imagery gained popularity. In space photographs, lineaments (from Latin lineamentum – line) are linear image elements corresponding to rectilinear or slightly curved objects in the Earth's crust, reflecting its multi-scale, multi-temporal, and multi-depth heterogeneities (Bairak, 2014; Khodorovsky et al., 2024). As a result of various studies conducted in previous years, classifications of lineaments have been developed based on their size, extent, depth of occurrence, and relationship with structural elements (Adhab, 2019; Elmahdy, 2019; Zhumabek et al., 2017). Differences in lineament zones were identified based on their density, degree of ordering, dominant and suppressed orientations, spatial arrangement of individual elements, and interrelationships of lineaments (Busygin & Nikulin, 2016; Azimov, 2010; Abdelkareem et al., 2021). V. Verkhovtsev carried out known constructions of lineament systems for specific regions using remote sensing data for the Ukrainian Crystalline Shield, O. Azimov and B. Busygin for the Dnieper-Donets Basin, O. Gintov for Volhynia-Podillia, M. Aristov for Podillia, A. Bubniak and R. Hnatiuk for Roztochchia, and A. Mychak for the Pre-Carpathian region and the Carpathians.

Methods

Various methods are used to remotely monitor the activation of dangerous natural processes (Orlenko et al., 2024). The primary method for studying the Earth's crust based on remote sensing data in geodynamic research is lineament analysis. As previously noted, lineaments are linear relief anomalies that are clearly visible in Earth remote sensing (ERS) imagery and are genetically associated with faults and fractures in the Earth's crust, active during the neotectonic stage. Disjunctive tectonic structures related to lineaments determine the mobility of crustal blocks, the physical-mechanical properties of soils, the characteristics of groundwater circulation, and the influence of the activity of exogenous geological processes. The following phenomena are associated with lineament zones:

1. Increased fragmentation of rock masses, systems of fractures, and loosening of sediments.
2. Lineament zones are significantly saturated with water, with intensive groundwater circulation within their boundaries.
3. Elevated heat flow values and gas emanations are associated with lineament zones, sometimes accompanied by electrical anomalies.
4. Earthquake epicenters are concentrated along lineament zones and at their intersection nodes.
5. Weakened, fractured zones are commonly associated with sections of river valleys, gullies, and ravines, necessitating the installation of additional engineering structures along pipeline routes.

Modern aerospace remote sensing data enable the study of geodynamic processes and the assessment of their impact on the stability of engineering structures, particularly linear ones, through lineament analysis.

Results

The research was conducted in the area of the Lopushne-Rososh main gas pipeline, which consists of two lines (pipes with diameters of 800 mm and 1400 mm). The climate of this region is transitional, ranging from the temperate-warm Western European to the continental Eastern European type. Climatic conditions are determined by geographic location (latitude and elevation above sea level). The area is characterized by a dense hydrographic network, with all-mountain rivers fed by atmospheric moisture and groundwater. The hydrogeological regime of the region is quite complex.

Alluvial-diluvial deposits found here were formed by the washout of weathered rock products downslope by rainwater and snowmelt. These deposits consist of a greyish-yellow mass composed of fine soil particles and coarse, fragmented material. In river valleys, soddy soils have formed, with alluvial deposits serving as the parent material. The landscape characteristics of the area, particularly its relief, shape the features observed in satellite imagery. In this study, Landsat-8 space images and SRTM were analyzed. These features are determined by gradual and impulsive vertical and horizontal movements of the Earth's crust in this region. Components of natural-territorial complexes of various ranks distinctly respond to changes in physical fields, mechanical displacement of tectonic blocks, and geochemical transformations, which are governed by local and regional patterns of material and energy transfer in the subsurface. By solving the inverse problem – i.e., analyzing the characteristics of natural-territorial complexes – it is possible to reconstruct the geodynamic model of the region under study.

The result of interpreting and formally processing satellite imagery, which involves identifying linear image elements, is an initial lineament scheme that serves as the structural framework (model) of the area. Lineaments were released interactively manually. The arrangement of lineaments in the initial scheme, particularly in platform regions, does not allow for unambiguous identification of tectonic dislocations. Therefore, the initial lineament scheme requires further processing. The objective of transforming the initial lineament scheme is to transition to a continuous field of lineament density, which reflects spatial heterogeneities in tectonic stresses. The primary task of the analysis remains the identification of faults and geodynamic zones. Derived lineament maps are designed to highlight heterogeneities in the lineament field and identify its anomalies. Using the proposed methodology with GIS tools, derived lineament maps were constructed (Fig. 1): maps of overall lineament density, lineament frequency, and density of lineaments in specific directions.

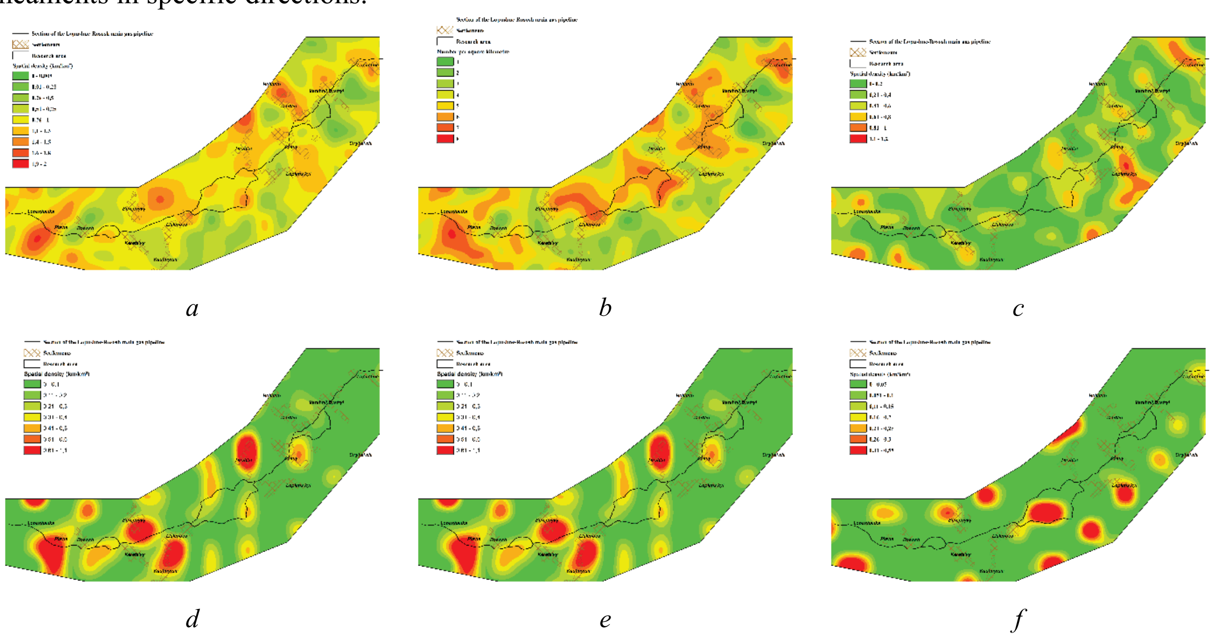

Figure 1. *Lineaments (Spatial Density: a – Total, b – Quantitative, c – Western, d – Eastern, e – Longitudinal, f – Latitudinal Directions)*

Based on the obtained results, an integrated map (Fig. 2) of geomorphological risks within the Lopushne-Rososh main gas pipeline area was created, focusing on the operational reliability of the gas transportation system using remote sensing methods of the Earth's crust.

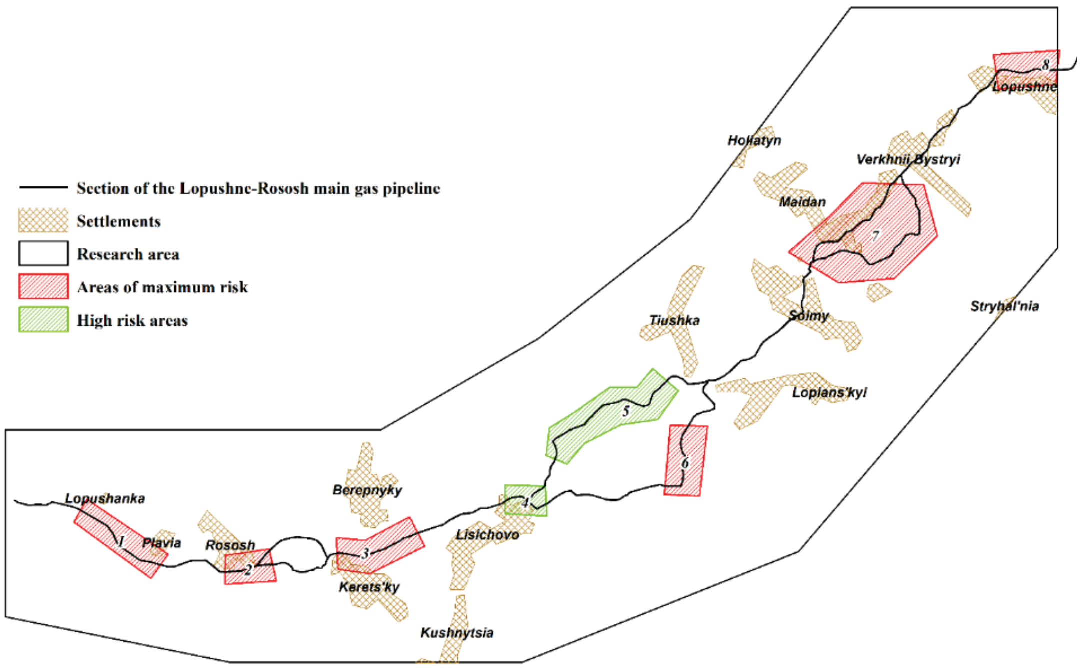

Figure 2. *Map of High-Risk Sections of the Lopushne-Rososh Main Gas Pipeline*

The map identifies eight hazardous sections (6 sections of maximum risk and 2 of significant risk). The most pronounced development of erosional processes in the mountainous part of the Carpathians is observed along the Lopushne-Rososh main gas pipeline section between the settlements of Soymy and Lopushanka. The development of erosional processes is facilitated by the activity of neotectonic and modern crustal movements, which increase slope angles, causing initial erosion forms (such as furrows and potholes, most commonly found on non-vegetated slopes) to deepen significantly. The depth of these incisions reaches 0.5-0.7 m, with widths of 1-3 m and lengths of 10-100-150 m. Steep slopes contribute to the widespread development of gullies, particularly on easily erodible deluvial loams. Field observations indicate that the most common features here are various types of gullies: bottom, bank, and slope gullies, as well as roadside gullies and washouts. All these geoindicators are evidence of the development of geodynamic active zones.

Conclusions

Thus, sections where the pipeline route intersects geodynamic active zones require special attention, including the implementation of additional engineering protection measures for the pipeline and its infrastructure (bridge and underwater crossings, compressor stations).
It is considered that further research and interpretation of remote sensing data along main pipelines should focus on:

- Forecasting pipeline damage sections;
- Identifying the location of potentially hazardous sections, taking into account the specifics of recent geodynamics;
- Monitoring exogenous processes along pipeline routes and determining the conditions for their activation;

- Measures to reduce the negative environmental impact of pipelines;
- Selecting optimal routes for gas and oil pipelines.

Comprehensive studies of lineaments in areas along main pipelines will contribute to the development of effective preventive measures, reduce operational risks, and enhance the state's energy security.

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