International Journal of Engineering and Geosciences
https://dergipark.org.tr/en/pub/ijeg
e-ISSN 2548-0960

Study of the seismic activity of the Almalyk-Angren industrial zone based on lineament analysis

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Cite this study: Sichugova, L., & Faziova, D. (2024). Study of the seismic activity of the Almalyk-Angren industrial zone based on lineament analysis. International Journal of Engineering and Geosciences, 9 (1), 1-11

https://doi.org/10.26833/ijeg.1192118

Keywords
Lineaments
Earthquake
Density
Rose-diagram
Landsat 8

Research Article

Received:20.10.2022
Revised: 10.04.2023
Accepted:23.05.2023
Published:02.01.2024

Abstract

In this work, an automated lineament analysis was carried out to search for earthquake precursors for the territory of the Almalyk-Angren industrial zone in Uzbekistan. The seven events with a magnitude of about 3 were selected for analysis. The Landsat 8 satellite images were processed using the automated lineament detection method in the LEFA software. The processing steps included detecting line elements in raster images, calculating the characteristics of the spatial distribution of line elements, and combining collinear linear elements into lineaments. The analyses of the cyclicality of precursors before and after earthquakes were based on the study of the distribution of the lineament trend in the study area using rose diagrams and lineament density maps. The results showed a change in the dynamics of the lineament structure. The statistics of the number of lineaments showed that their increase begins almost 20 days before the event, reaches its maximum about 1 – 2 days before the earthquake, decreases starting from 14 days after the earthquake, and has a minimum value of 1 – 2 months. The main trends observed in the lineament map showed the dominant trend in NS, WE, NW-SE directions.

1. Introduction

Studying seismic activity in industrial areas is of great importance for understanding the impact of industrial activities on the environment and the possibility of predicting earthquakes in such zones. The understanding and prediction of earthquakes require diverse monitoring methods and data analysis. Specialists are developing and researching lineament systems in addition to alternative methods like satellite interferometry, GPS observations, heat flow tracking, and monitoring the environment, such as the ionosphere and ice cover of water bodies [1-3]. Lineament analysis identifies geological faults and cracks that may indicate seismic activity and potential earthquake sources, offering a means of earthquake prediction. Additionally, lineament analysis provides insights into other geological phenomena, such as geothermal and hydrothermal systems, which may also be associated with seismic activity [4-5]. Therefore, lineament analysis remains the main for understanding earthquakes and other geological phenomena [6-9].

Scientific studies have shown that there are observable anomalies associated with earthquakes that precede seismic activity. One such anomaly is an increased degree of lineament manifestation confirmed by several studies from various authors. This increase is attributed to the widening and elongation of linear tectonic structures, which merge into larger ones and result in a significantly larger number of lineaments being identified on satellite images than in normal conditions. However, the widespread use of this technique is hindered by technical limitations, such as the need for regular acquisition of images taken under identical conditions (including humidity, lighting, and vegetation cover) [10-13]. The data analysis has shown that there were more earthquakes registered in areas with the highest number of linear structures. The epicenters of earthquakes are not random, but rather associated with lineaments and their connecting segments. According to the modern understanding of seismic processes, high tectonic stresses that cause earthquakes usually concentrate at the intersections or bends of linear boundaries separating blocks of the Earth's crust [14-15]. Research on stress pattern changes around earthquake epicenters has shown significant changes in the lineaments and observable anomalies before impending earthquakes. In the absence of seismic activity, normal behavior is observed. The most important result of these studies is the high level of correlation between the ongoing maximum horizontal compressive stress that there is obtained from the lineament and the earthquake's focal mechanism. It was observed that a considerable number of lineaments emerged approximately a month or two before the earthquake and returned to their original configuration about a month after the event [10, 12, 16-18]. Busygin and Nikulin [19] reports that earthquake epicenters tend to be located closer to areas with more complex geological structures and specific azimuths of lineaments (22.5±12.5º, 67.5±12.5º, 112.5±12.5º, and 157.5±12.5º), which are not typical for the entire Earth's surface. The study found that almost 90% of earthquake epicenters are located within areas with high complexity values, based on the spatial relationship between earthquake epicenters and lineament networks identified from satellite imagery. The traditional method of identifying and mapping lineaments involved manual visual interpretation of satellite or aerial imagery. However, the increasing availability of high-resolution satellite imagery and the need for large-scale mapping has led to the development and implementation of automated methods for lineament analysis. The automated analysis enables the processing of large amounts of data quickly and accurately, making it a valuable tool for studying geological structures and tectonic features in various regions [7, 20-22]. Nonetheless, automated lineament analysis also has limitations, as it may not detect all visible lineaments and can produce false positives or negatives. Therefore, it is crucial to validate the results of automated lineament analysis with other data sources, such as geological maps.

This study aims to use an automated method for extracting lineaments from satellite images to investigate seismic activity in the Almalyk-Angren industrial zone of Uzbekistan. The scientific problem that we should be able to solve is to understand the patterns and characteristics of seismic activity in the region that there is caused by its complex tectonic structure. By using the automated lineament extraction method and comparing the results with geological maps, we hope to efficiently and accurately identify linear features that there is related to tectonic activity in a large dataset. It will contribute to a better understanding of the geological and tectonic features of the region. Specifically, we will examine the relationship between lineament density, orientation, and seismic activity in the region and assess the potential of automated lineament analysis as one of the tools for earthquake hazard assessment. Hypotheses can be formulated regarding the correlation between certain lineaments detected through automated analysis and tectonic lines where stress accumulation in the crust can lead to earthquakes. Additionally, certain lineaments can be associated with specific geological structures that could increase the likelihood of earthquakes in the region. These hypotheses will be tested by analyzing earthquake data and geological structures and comparing them to the distribution of lineaments. It will allow us a better understand the underlying geology and tectonic processes that contribute to earthquake activity in the area. In summary, this study seeks to investigate the dynamics of lineaments in the region, examine the localization of earthquake epicenters based on fault locations, compare the results with geological data, and identify zones of anthropogenic impact. The use of automated lineament analysis has the potential to enhance our understanding of seismic activity and its potential hazards in the region.

2. Method

2.1. Study Area

The Angren-Almalyk region is located in the northeast of Uzbekistan and is one of the richest mineral regions in the country. There are the Angren coal mine up to 300 m deep, the Djigiristan quarry, and the Naugarzan and Apartak coal pits. The Almalyk Mining and Metallurgical Complex (AMMC) is the base production of non-ferrous metals in Uzbekistan (Figure 1). The region is located within the Chatkal-Kuramin block, and there are parts of the Tien Shan geological region. One of the most fundamental geological structures in this region is a magmatic formation that covers around 85% of the region with an age range from Proterozoic to Mesozoic. The formation of structures within the Kuramin part Beltau-Kuramin zone occurred during the Caledonian, Hercynian and Alpine tectonic cycles. The modern relief of the Angren Zone was formed in the Neogene. The North and the South of the Angren zone are characterized by tectonic disturbances superimposed by the Chatkal and the Kuramin horst. The tectonics of the region is represented by a complex combination of various structural elements, including folds, troughs, faults, intrusions, and volcanic rocks (Figure 2). The primary deposit in the region is the Almalyk ore belt, which stretches for over 40 km and is rich in copper, gold, silver, and other minerals. Minerals were found in carbonated rocks, and volcanic deposits were formed due to volcanic activity and magmatic processes during the Mesozoic era [23].

The region is located within the Chatkal-Kuramin block, there is a crystalline rock mass, and it was formed due to ancient geological processes that occurred over 2 billion years ago. The block contains a variety of granite, gneisses, shale and quartzite rocks, that have undergone a strong tectonic deformation, leading to the formation of various structural elements, including folds, faults, and fractures. The most intense tectonic processes in this area occurred during the Mesozoic and Cenozoic eras when subduction and collision of lithospheric plates led to the formation of mountain folds, including the Pamir and Tien Shan ranges. As a result of this formation, various mountainous rocks were formed in the Angren and Almalyk regions, including granite, gneisses, shale and sandstone.

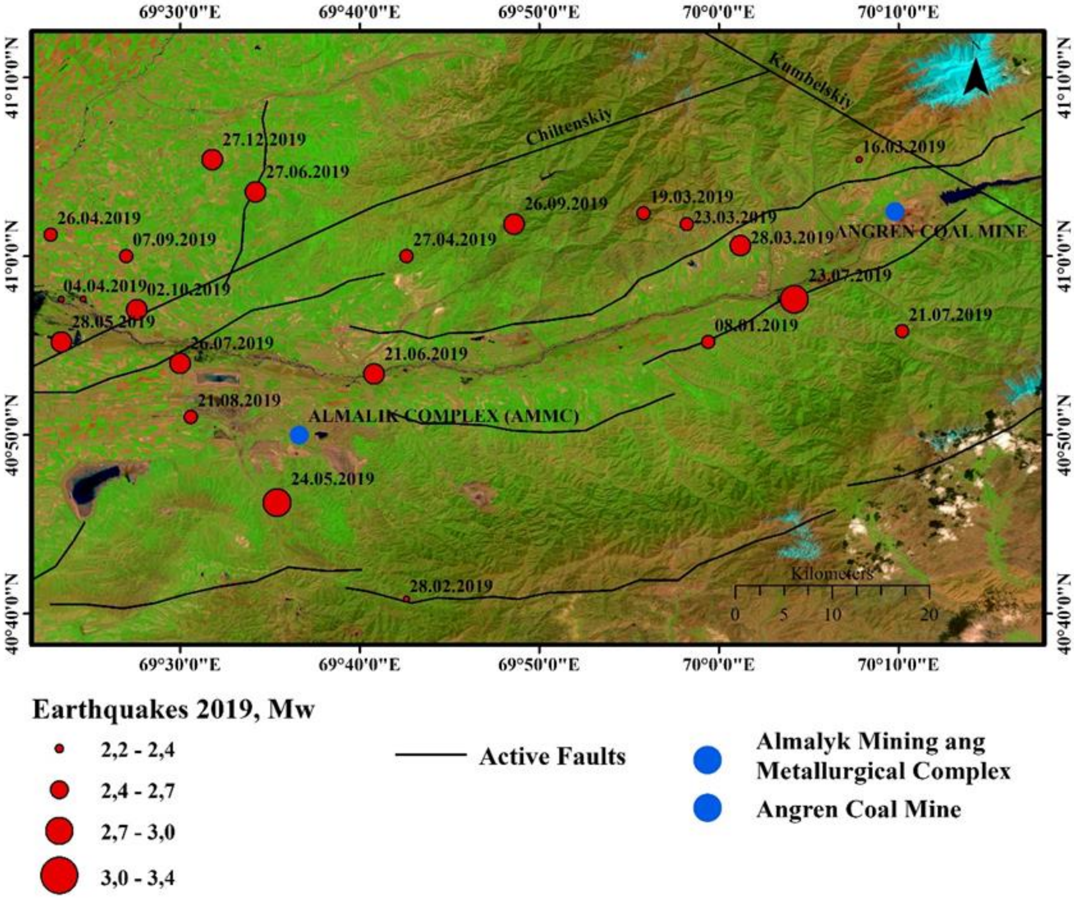

Figure 1. Study area, tectonic faults, and location of the earthquake's epicentres [24] (Landsat 8) [25].

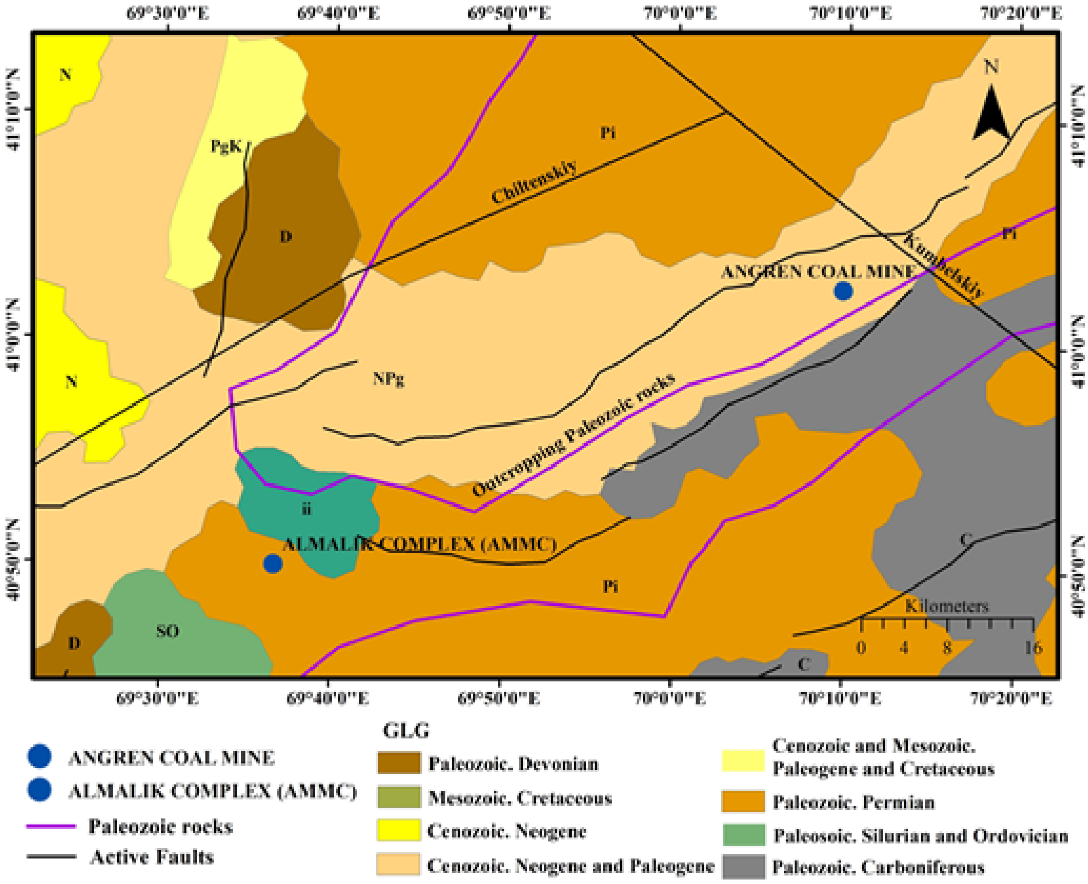

Figure 2. Geology map of the study area [26].

Currently, tectonic processes continue in this area. There are several main faults around the Angren-Almalyk region, which determine the tectonic structure of this region. One of the longest faults is the Chiltensky fault, which runs west of the Angren massif. It is an active fault and can cause earthquakes. Another significant fault is the Almalyk fault, which passes through the Almalyk massif to the north of the city of Almalyk. This fault is also active and can cause strong earthquakes. According to the study of stress distribution and zoning of the western Tien Shan and the adjacent territory based on the excess shear stress calculated by mathematical modelling, compared with data from instrumental measurements in deep wells, this region is identified as an area with the highest values of excess shear stress (>2 MPa) [27].

The Kumbel fault, which runs along the southern edge of the Angren-Almalyk zone, is less active but can still cause earthquakes. The Kumbel fault is a complex thrust fault with north-eastern dipping fault plane angles of 60°-90°, and the south-western block is uplifted. In recent times, there have strike-slip movements with an amplitude of up to 5 km along this fault [28-30]. The main faults are accompanied by numerous small supporting and accompanying fractures. Due to intensive mining operations and special geological and tectonic conditions, the Almalyk-Angren industrial zone is the region with a high level of seismic activity. The mining industry, which can cause dangerous tremors in the region, is a problem for nearby urban areas. Seismic hazard assessment in mining areas is important for the nearby urban region since local events are located directly underground and show a high frequency of repeatability.

2.2. Method

The processing of images in the lineament extraction system using various algorithms (Hough transform, Canny, PCI, LESSA, TecLines) allows for obtaining information on the dynamics of the Earth's crust even at depths of tens of kilometers below the surface. Images with lower resolution are required to detect deeper events that spread over large areas. Images with a resolution of 10-30 m are useful for studying earthquakes, as they can integrate information about the presence of faults at depths of tens of kilometers. Although such images cannot detect individual cracks, they can track changes related to the accumulation or weakening of strength caused by the movement of tectonic plates [10]. In our research, we used Landsat 8 OLI images with 30 m resolution of the pre-and post-earthquake that were downloaded from the United States Geological Survey (USGS) Earth Explorer website [31]. Archive images included from May 06, June 23, July 09 and 25, August 10, September 11 and 27, 2019. The catalog of the earthquakes in the region of the Republican Center for Seismic Predictive Monitoring of the Ministry of Emergency Situations of the Republic of Uzbekistan was used for analysis [24]. Data became available in 2018. During 2019, 29 earthquakes (2.2 < Mw < 4.2) occurred in Almalyk-Angren industrial zone. In Table 1 are the dates that were selected for analysis (2.5 < Mw < 3.2) (Table 1).

Table 1. Catalog of earthquakes in 2019 on the territory of the Almalyk-Angren industrial zone.

№	Date	Depth (km)	Magnitude (Mb)	Epicenter region
1	21.06.2019	5	3	Center Uzbekistan
2	27.06.2019	14	3	Center Uzbekistan
3	21.07.2019	5	2,5	Eastern Uzbekistan
4	23.07.2019	15	3,2	Center Uzbekistan
5	26.07.2019	7	2,9	Center Uzbekistan
6	07.09.2019	5	2,6	Center Uzbekistan
7	26.09.2019	30	2,9	Center Uzbekistan

The method of image processing consisted of several stages: selection of suitable satellite images (free of cloud and with the earthquakes), image preprocessing (spatial resolution improvement, brightening satellite image, contour and texture enhancement, resampling), lineament extraction, calculation of the density of lines, estimation their directions. In this analysis, we used the synthesized images of the Landsat 8, which consists of 7 channels (Coastal aerosol, Blue, Green, Red, NIR, SWIR1,2) with a 30 m pixel size [32]. The synthesized image can be useful for studying the Earth's surface. The synthesized images were merged with a higher quality panchromatic channel with a 15 m pixel size using the Create Pan-sharpened tool in ArcGIS ver. 10.8.

To investigate surface variations on Earth, the Lineament Extraction and Fracture Analysis (LEFA) algorithm was selected for this research. It is based on factor analysis and designed for the automatic extraction of the linear features on images, such as a fault or fold boundaries, which are associated with geological structures. The LEFA algorithm produces more accurate and high-quality results than traditional methods such as Hough processing or Gabor filtering. Additionally, it can automatically adapt to different types of images, including multi-channel and multi-spectral images. The LEFA algorithm uses mathematical morphology and image processing methods to extract linear features from the image. It is based on the observation that linear features on the image usually appear as bright lines on a dark background or vice versa. The algorithm first applies image filtering to reduce noise and improve contrast. Then, it uses the morphological gradient operator to extract edges on the image. LEFA subsequently identifies potential linear features using the skeletonization algorithm. The image skeleton is the thinnest structure representing the central line connecting all object pixels in the image. Finally, the LEFA algorithm conducts feature analysis to identify linear elements. It analyzes the geometric properties of potential linear elements, such as their length, orientation, and shape, as well as the properties of neighboring pixels to determine whether they are actual linear features or not [22]. The Canny edge detection algorithm with a Gaussian noise filter was selected to study a linear network [21]. To identify and detect the edges of the images needs to reduce the noise of the images, and then the images become smooth. The Canny edge detector uses two filtering thresholds: if the value of the pixel is higher than the upper edge, then it will be in maximum value (the edge is considered reliable), and if the value of the pixel is lower, the pixel is suppressed. Points with a value falling between the thresholds take a fixed average value [33].

The next step of lineament extraction was applying Hough Transform. The most common case is Hough Line Transform. Based on the theory, Hough Transform is any point of a binary image that can be part of some set of possible lines. The Hough Transform is based on the notion that the desired object is in the form of a parametric equation. The parameters of that equation represent the Hough phase space. Then, a binary image is taken (for example, the result of the Canny edge detector). All the points of the edge are sorted through, and a hypothesis is made that point belongs to a line of the desired object. The final step is to traverse the Hough space and selects the maximum values for which the most pixels of the image "voted", which gives us the parameters for the equations of the desired object [34].

3. Results

As we noted earlier, the study area belongs to a seismic zone, but most of the events here have a medium magnitude [Ребецкий]. Therefore, only seven events with a magnitude of about 3, that can be felt, were selected for the study, as indicated in Table 1. In the first stage, the dynamics of the lineaments during these events were investigated based on a statistical analysis of changes in their density. As can be seen from Figure 3, there is a clear trend of an increase in the number of lineaments in the interval before and after 1-3 days from the moment of the earthquake (June 23, July 25, September 11, and September 27). Moreover, the total number of lineaments sharply decreases 20 days before and approximately 14 days after the earthquake (May 6, July 9, and August 10). It is worth noting that the minimum and maximum length of the lineaments is practically the same for all the events. However, the maximum length of the lineaments of 6 km is observed only on May 6, 2019 (Table 2).

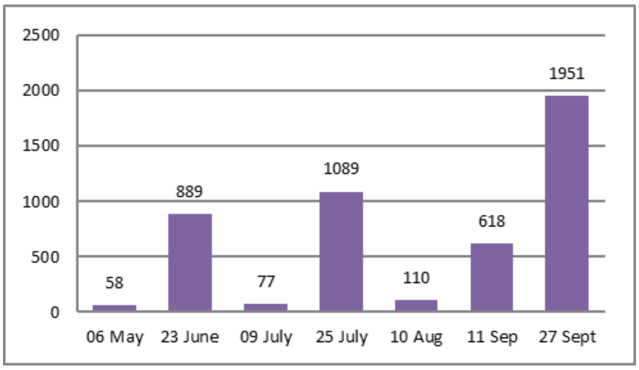

Figure 3. The total number of lineaments.

One of the main statistical indicators used to predict changes in lineaments was rose diagrams and density maps, as shown in Figure 4-10 (right column). The dominant directions obtained were NW, WE, and NW-SE. It was found, that with an increase in the number of lineaments, the length of the north direction also increased. Density maps (Figure 4-10, left column) showed a high density of lineaments near the epicentre of earthquakes that occurred on June 23, 2019, and June 27, 2019. The density of lineaments decreased on May 9, July 9, and August, as indicated by the results with the lowest density observed on July 9, 2019, which was 0.33. A high density of lineaments near the epicentre of the earthquake that occurred on July 26, 2019, was observed on July 25, 2019, with lineaments reaching their maximum one day before the event. The maximum number of lineaments was observed on September 27, 2019, with a density of 1.11.

Table 2. Statistics of lineaments length.

Value	06 May	23 June	09 July	25 July	10 Aug	11 Sep	27 Sept
Minimum, km	1,5	0,75	1,2	0,75	1,35	0,9	0,6
Maximum, km	6,0	2,7	3,0	2,6	3,0	3,7	2,9
Standard Deviation, km	0,7	0,2	0,3	0,2	0,3	0,3	0,2

4. Discussion

The results of the statistical analysis of lineament density during earthquakes are an important contribution to understanding the tectonic processes taking place in the studied region. Changes in the dynamics of lineaments can indicate the influence of complex tectonics on geological processes. A comparison of the geological map and the map of lineament densities shows that the highest density and, therefore, the most stressed and deformed state, even during periods between earthquakes, is observed in the zones around the Chiltin and southern Almalyk faults, particularly in the northwestern part of the territory. At the same time, the zone around the Kumbel fault can be considered relatively "quiet." These results may indicate the possibility of predicting earthquakes in the future. However, it is worth noting that the results only apply to earthquakes with a magnitude of about 3 and are concentrated in zones near Paleozoic rocks that outcrop on the surface. This can indicate the influence of human activities on the stressed state of the earth's surface in areas of mineral extraction or excavation. Further research can expand this work, including the analysis of earthquakes of higher magnitude and for other geological regions, as well as studying the influence of human activity on tectonic processes. It's also clear from the analysis that there is a tendency for earthquake epicentres can be located along faults. Regarding the earthquake on September 26th, it is worth noting that it was the deepest of all the events considered, with a depth of about 30 km (Table 1). Despite this, the study shows that it had a significant impact on the lineament dynamics in the region, which indicates that earthquakes with greater depth can influence the geological processes in the region. The results obtained from the analysis of lineament density during this event were particularly clear and accurate, providing valuable insight into the tectonic processes taking place in the region. The lineaments observed during this event showed a clear correlation with the active faults in the region, highlighting the importance of such studies for understanding the geological and tectonic processes in seismic zones.

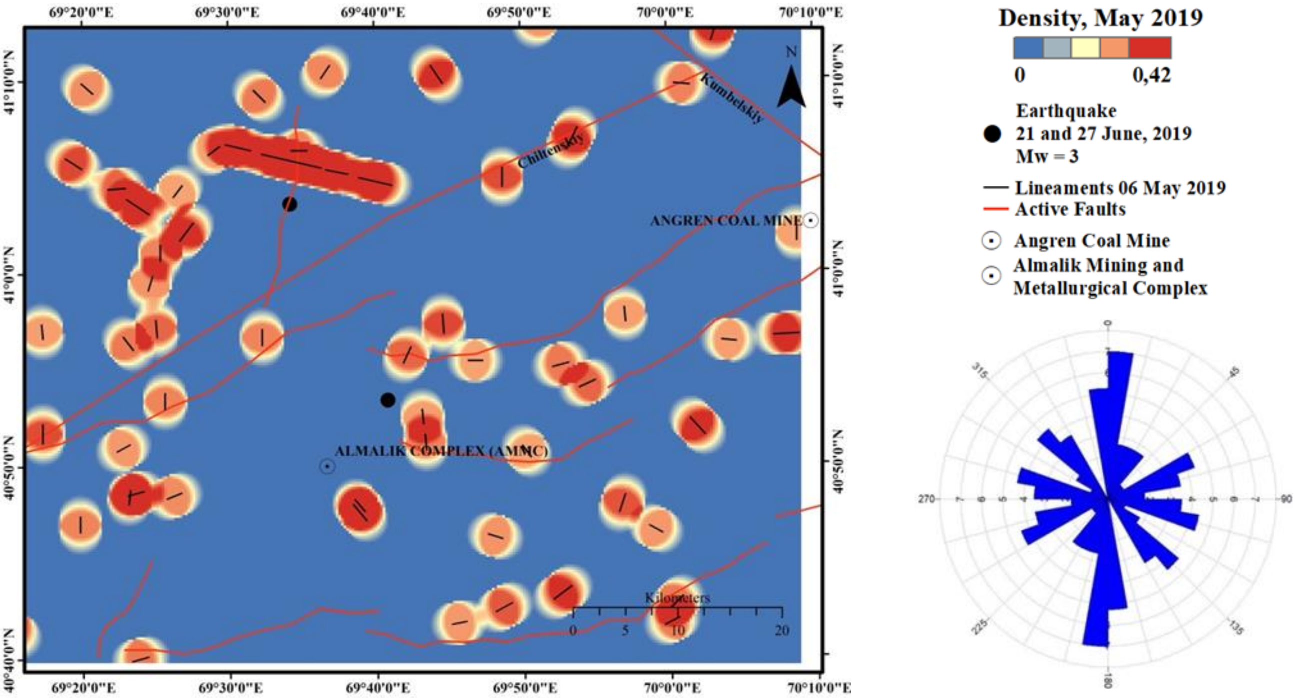

Figure 4. Density map and rose diagrams of lineaments (May 06, 2019).

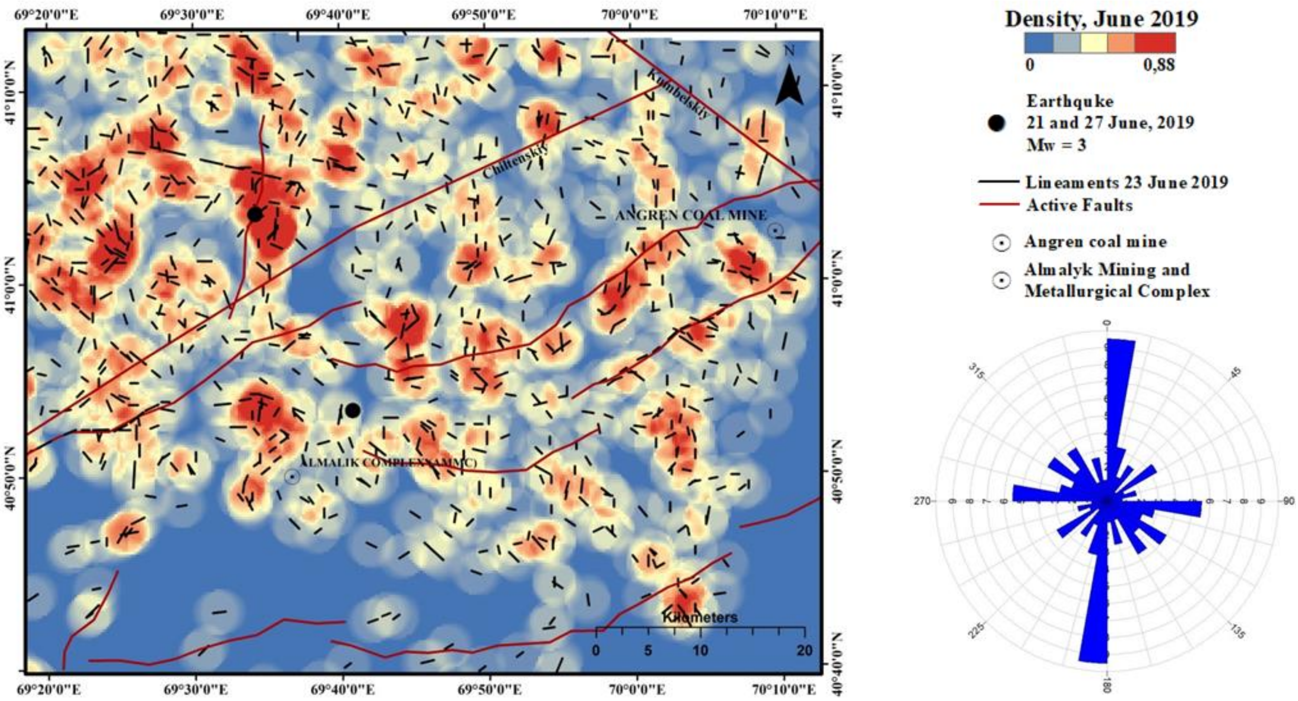

Figure 5. Density map and rose diagrams of lineaments (June 23, 2019).

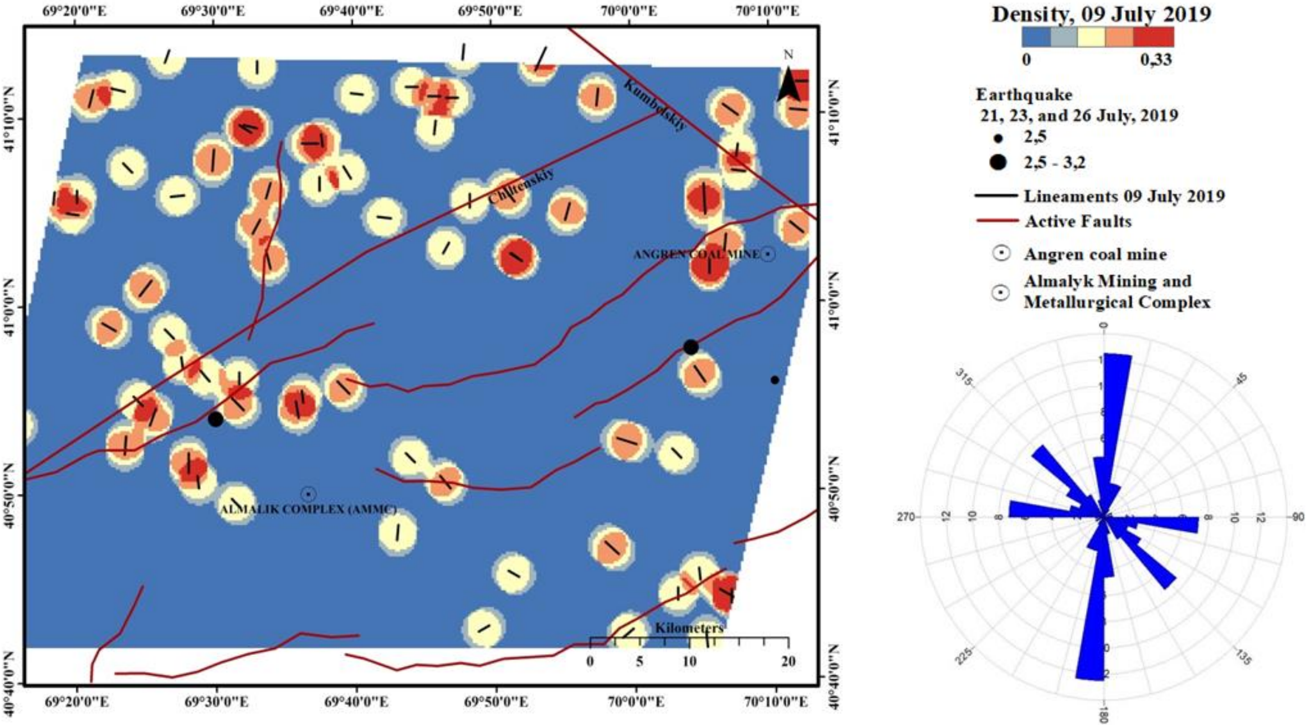

Figure 6. Density map and rose diagrams of lineaments (July 09, 2019).

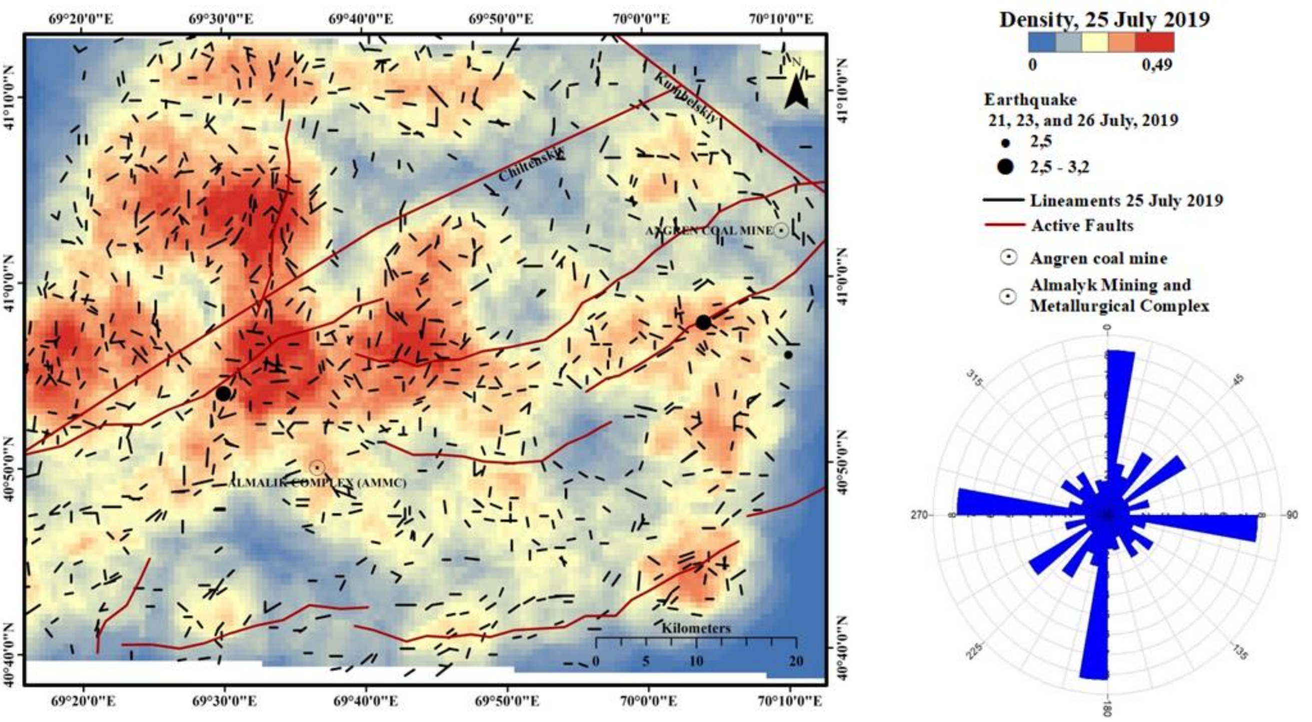

Figure 7. Density map and rose diagrams of lineaments (July 25, 2019).

5. Conclusion

In this work, an automated lineament analysis was carried out to search for earthquake precursors for the territory of the Almalyk-Angren industrial zone. The study area is tectonically and seismically active, but earthquakes typically occur with earthquakes of moderate magnitude. Automatic lineament analysis based on remote sensing data showed high efficiency. The seven events with a magnitude of about 3 were selected for analysis. The statistical analysis was performed to investigate changes in lineament density before and after the events. The results showed a clear trend of an increase in the number of lineaments in the interval before and after the earthquake, with a sharp decrease in the total number of lineaments 20 days before and approximately 14 days after the earthquake. The rose diagrams and density maps showed dominant directions of NS, WE, and NW-SE, with a high density of lineaments near the epicenter of the earthquakes that occurred on June 23, 2019, June 27, 2019, and September 26, 2019. The results of the statistical analysis of lineament density during earthquakes provide important insights into the tectonic processes taking place in the studied region and may indicate the possibility of predicting earthquakes in the future. However, the results only apply to earthquakes with a magnitude of about 3 and are concentrated in zones near Paleozoic rocks that outcrop on the surface, indicating the influence of human activities on the stressed state of the earth's surface in areas of mineral extraction or excavation. Further research can expand this work by including the analysis of earthquakes of higher magnitude and in other geological regions, as well as studying the influence of human activity on tectonic processes. It is also clear from the analysis that there is a tendency for earthquake epicenters to be located along faults.

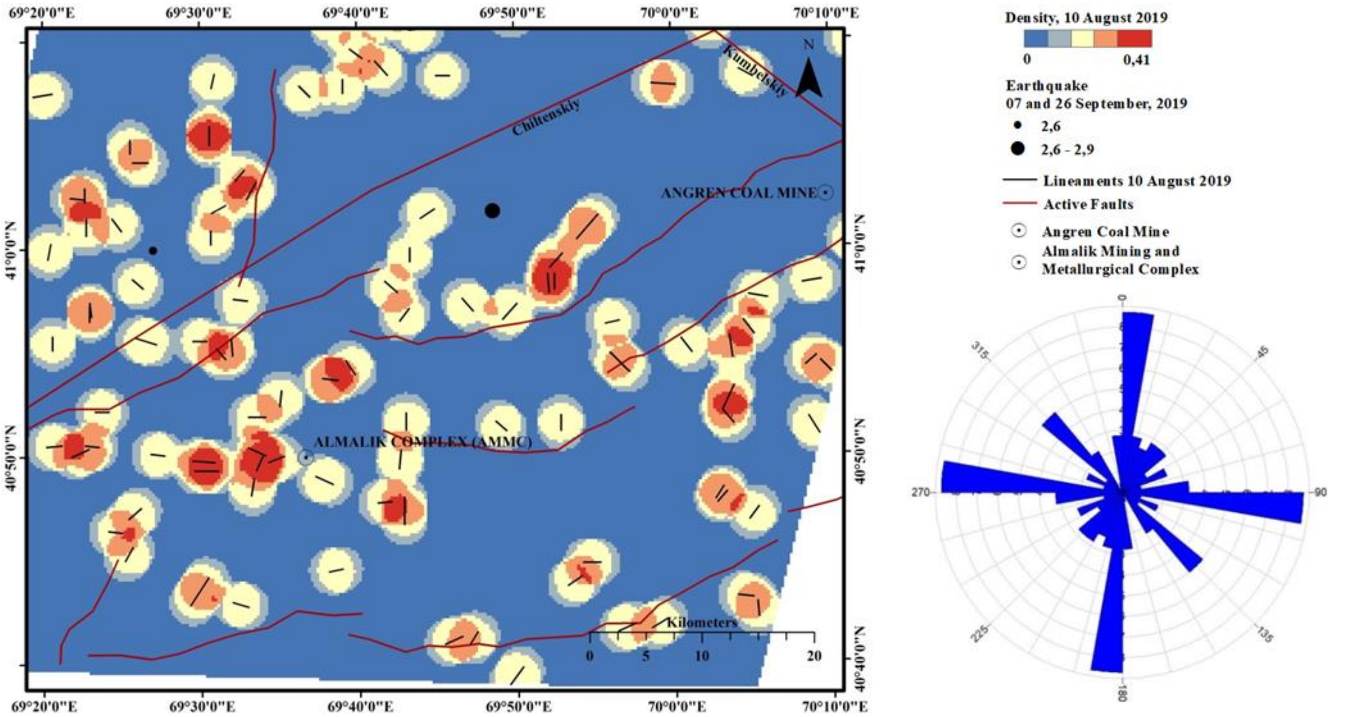

Figure 8. Density map and rose diagrams of lineaments (August 10, 2019).

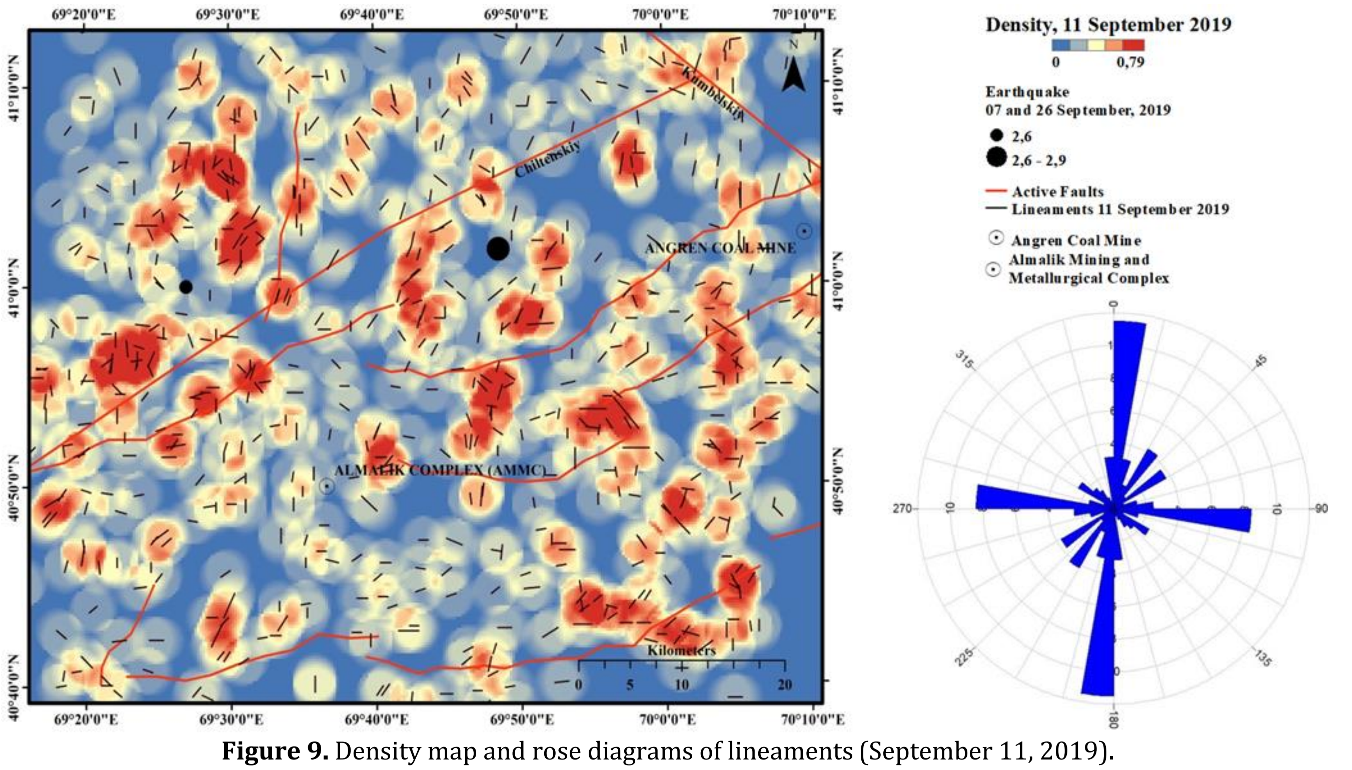

Figure 9. Density map and rose diagrams of lineaments (September 11, 2019).

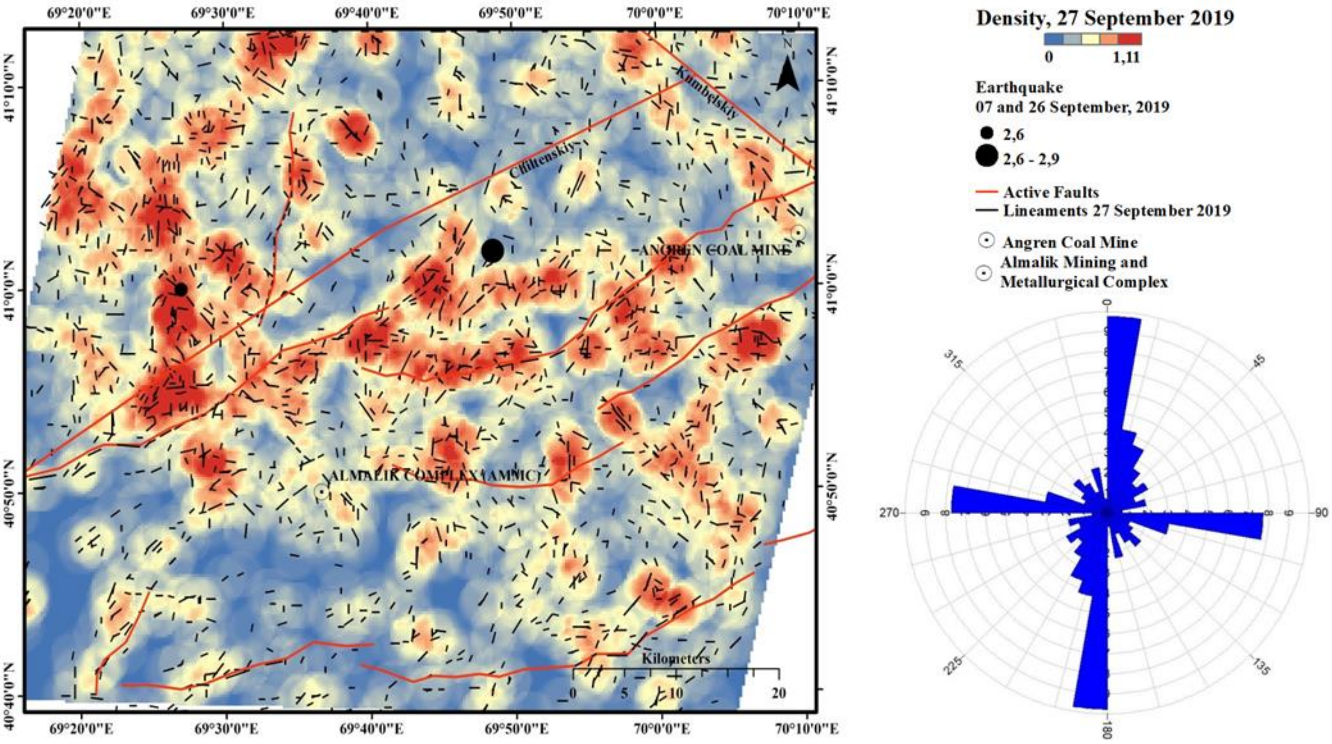

Figure 10. Density map and rose diagrams of lineaments (September 27, 2019).

Automatic lineament analysis based on remote sensing data can be one of the most effective methods with operativeness and effectiveness for geodynamic monitoring of seismically hazardous areas and also industrial zone. The results obtained have shown the possibility of the practical application of such an analysis, especially for the analysis of fracture tectonics, which are zones of high seismic activity and deformations of the earth's surface. The proposed method for studying the dynamics of lineament systems from satellite images, together with other methods, can be used for the operational monitoring of seismic hazards. It should be noted that the automatic method still needs to be improved by mathematical methods and algorithms to make it possible to apply it to territories with different geological conditions.

Acknowledgement

This work was carried out within the scientific project of the Astronomical Institute of Uzbekistan with the financial support of the Academy of Sciences of the Republic of Uzbekistan.

Author contributions

Lola Sichugova: Methodology, Validation, Investigation, Software, Writing-Original draft, Writing – Review and Editing. **Dilbarkhon Fazilova:** Conceptualization, Supervision, Writing-Original draft, Writing – Review and Editing, Project administration, Funding acquisition.

Conflicts of interest

The authors declare no conflicts of interest.

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