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FIRST EXPERIENCE IN USING SATELLITE DATA FOR MONITORING THE HYDRO-FLUID REGIME OF LOKBATAN VOLCANO IN THE ASSESSMENT OF SEISMIC EVENT RISKS IN THE REGION

(Представлено членом редакційної колегії д-ром геол. наук, ст. наук. співроб. О.Л. Шевченком та д-ром геогр. наук, проф. Д.О. Ляшенком)

Background. ***Mud volcanoes are unique natural structures affecting the environment by continuous emissions of gas-liquid fluids, mud breccia and mudflows. Despite extensive research and a substantial dataset on mud volcanism, the understanding of the fluid dynamics and hydrogeological processes associated with these systems remains a subject of ongoing debate. Globally, there are more than 2,500 mud volcanoes distributed across 42 countries (Aliyev et al., 2015), highlighting their widespread occurrence.***

Azerbaijan represents a unique region for the study of contemporary mud volcanism, hosting more than 350 mud volcanoes within a relatively small territory. Among them, the Lokbatan mud volcano is the most active, with 28 recorded eruptions. In this context, a comprehensive approach to studying the activity of mud volcanoes, including satellite monitoring, is highly relevant.

Methods. ***The study employed remote sensing techniques to analyze the hydro-fluid regime of the Lokbatan mud volcano. Specifically, satellite imagery was used to calculate a moisture index for the volcano field. For the first time, this index was remotely measured, enabling assessment of surface moisture dynamics as a proxy for fluid migration and subsurface activity.***

Results. ***The satellite-derived moisture index showed clear correlations with mud volcanic activity. Observations indicate that variations in the moisture index correspond to shifts in the fluid regime of the volcano, reflecting possible underground fluid migration or pressure changes prior to eruptions.***

Conclusions. ***The study demonstrates the potential of satellite-based monitoring in assessing the hydro-fluid regime of active mud volcanoes. The approach provides an effective, low-cost alternative to field-based observations and can support early warning systems for seismic or eruptive events. These findings contribute to the development of preventive strategies for managing geological hazards in seismically active regions.***

Keywords: ***Mud volcano, satellite images, fluids, NDWI, monitoring.***

Background

In the modern world, an integrated approach to solving challenges in Earth sciences is highly demanded and widely applicable. Today, satellite imagery, drone surveys, and other remote sensing technologies are increasingly used for data collection, analysis, and interpretation. By using modern technologies, the time and effort required to obtain such data are significantly reduced, making previously inaccessible research sites available without excessive risks or additional costs. In this study, satellite monitoring was applied for the first time to measure the moisture index at Lokbatan mud volcano.

The object of the research is the Lokbatan mud volcano, located 17 km southwest of Baku (Fig. 1). This choice is justified by the specific geological structure of the volcano, its eruption activity, proximity to the urban agglomeration, and spatial connection with the oil field.

Analysis of Previous Studies

Mud volcanoes of the Absheron Peninsula in Azerbaijan have a long history of study. The main research efforts have been conducted in connection with oil and gas exploration. Significant contributions in this field have been made by F. Dadashev, A. Yakubov, Ad. Aliyev, I. Guliyev, A. Feyzullayev, D. Guseynov, A. Mazzini, M. Schmidt, G. Etiope, and others. Their publications have examined in detail the morphology and genesis of mud volcanoes, the relationship between mud volcanism and hydrocarbon occurrences, the estimation of combustible gas volumes released during eruptions, and the physical-mathematical modeling of mud volcanoes.

In recent years, some researchers have begun to consider mud volcanoes as one of the major natural sources of greenhouse gas emissions into the atmosphere. Accordingly, several studies have focused on the role of mud volcanism in climate change processes. It is also worth noting that one of the modern and promising directions today is the use of satellite technologies, particularly data from the Sentinel mission, for remote monitoring of mud volcano activity. For example, NDWI was effectively used to analyze the spread of the Sidoarjo mudflow (Indonesia) (Wicaksono and Isa, 2022). Additionally, a number of monographs and color atlases have been published aimed at popularizing knowledge about mud volcanoes and promoting geological tourism in the country (Aliyev et al., 2015; Aliyev, Guliyev, & Rahmanov, 2019; hnyukov, 2006).

Objective of the Study

The aim of this study is to explore the potential of using satellite data for monitoring mud volcanic activity on the Absheron Peninsula of Azerbaijan, using the most active volcano, Lokbatan, as a case study.

Fig. 1. (a, b) Location of the Lokbatan mud volcano (a, b)? (source: Google Maps); (c) aerial photograph of the general view (c) ? (photo by A.R. Huseynov); (d) view of the crater field (d)? (photo by V. Shukyurov)

Methods

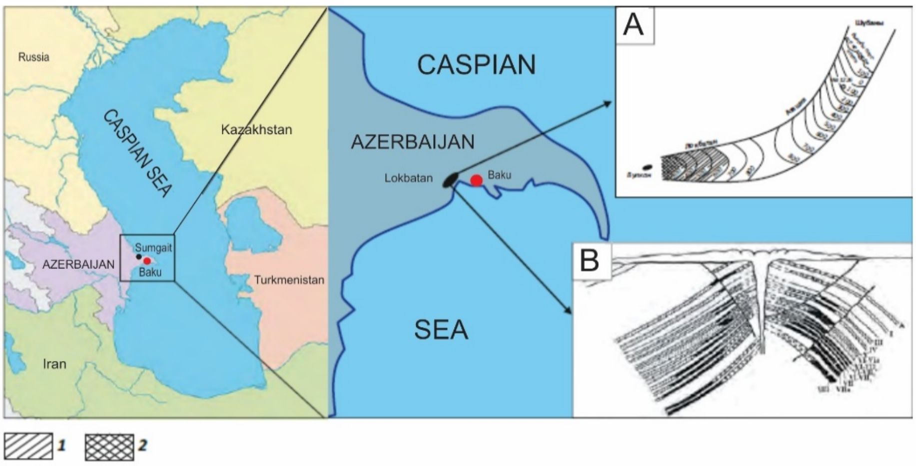
To study the fluid regime of the Lokbatan volcano, satellite monitoring was applied using the Normalized Difference Water Index (NDWI) based on Sentinel-2 satellite data. The methodology consisted of several stages: collection and calibration of satellite images, calculation of NDWI for assessing water bodies and soil moisture, analysis of time series from 2017 to 2023, mapping of changes (using Google Earth), and data interpretation. NDWI values greater than 0 indicate wet soil, while values below 0 represent dry areas. The resulting data were presented in KMZ format and used for analyzing the dynamics of fluid processes on the volcano. The extracted NDWI values for the volcano were plotted on a graph, which allowed for the visualization of changes in the water regime.

Main Material Presentation and Its Analysis

The Lokbatan mud volcano in relief represents a small dome with two peaks and an absolute elevation of 86 meters. The base of the mud volcano structure measures 2.5 km by 2.3 km, covering an area of 5.75 km². Structurally, the mud volcano is situated on the crest of an asymmetrical brachyanticline of latitudinal orientation, which extends and connects with the Akhtarma-Puta and Gushkhana brachyanticlines, forming a unified Lokbatan–Puta–Gushkhana anticline zone Besides Lokbatan, the mud volcanoes of Akhtarma-Puta and Gushkhana are also located here (Yakubov, Kastryulin, & Dzhavadov, 1976a; Yakubov, Aliyev, & Rakhmanov, 1976b).

In 1927, the Lokbatan hydrocarbon field was discovered near the mud volcano, and by 1933, it began development with an initial oil production rate of about 20,000 tons per day. The exploration well No. 45, drilled 1.5 km from the volcano's crater in the mudfield, proved the feasibility of drilling in areas complicated by mud volcanism.

The field contains several productive horizons, which is penetrated by a central channel. At present, the Lokbatan oil field is in the final stage of development.



A — structure in VI Horizon Top; accumulation in VI–VIa horizons, B — field cross-section: scheme of flat sheet pools broken into blocks.
1 — oil; *2* — gas

Fig. 2. The schematic map of the Lokbatan oil field location (Zhemeriev, 1958, Martynova et al., 2022)

The Lokbatan anticline is composed of Pliocene-Quaternary deposits and is associated with a major longitudinal fault, which displaces strata of the same age by 300–350 meters. On the outside, the volcano is protected from erosion by a ridge of Absheron limestone and sandstones of the productive strata.

A particularly interesting fact about the Lokbatan mud volcano is the absence of a typical mud cone field, as well as the lack of small gryphons and salsas within its crater area, which are commonly observed at other mud volcanoes. In most volcanoes, during the inactive stage, water, liquid mud, and gas are usually released through these gryphons and salsas. However, in the case of Lokbatan, the volcano's surface remains dry. A similar phenomenon is observed in only one other known case – the largest volcano of the Kerch Peninsula, Dzhau-Tepe – which also lacks a gryphon-salsa developmental stage (Shnyukov, 2006).

The main crater of the Lokbatan volcano formed after the eruption of 1887 and represents a subsidence caldera of oval shape with a diameter of 25 meters. The area covered by mud-volcanic material is about 424 hectares, and the average thickness of the erupted deposits reaches 60 meters. The elongated flow of mud-volcanic deposits, observed in Fig. 1, extends 700 meters and has a western direction.

According to seismic studies, the Lokbatan mud volcano has a two-chamber structure (Kadirov, & Mukhtarov, 2004; Aliyev et al., 2013; Rashidov, Khasaeva, & Guseynov, 2016). The first, upper chamber is located at a depth of 1.5–2 km and lies within the deposits of the Quaternary system, while the second chamber is located in Neogene deposits at a depth of 4–6 km. The second chamber has periodic connections with productive oil-bearing horizons (Fig. 3) (Rashidov, Khasaeva, & Huseynov, 2016; Alizade, 2007).

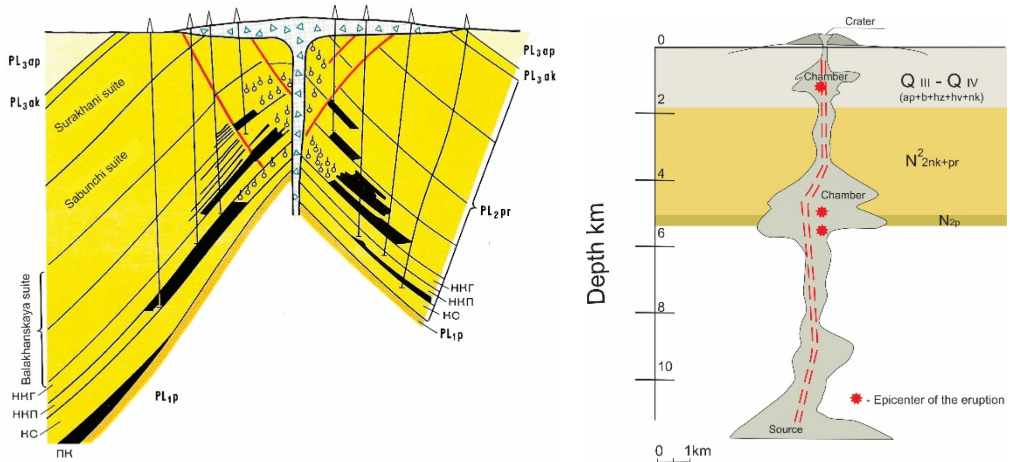


Fig. 3. Geological cross-section (a) (Aliyev et al., 2015) and conceptual model of the internal structure (b) of the Lokbatan mud volcano (Rashidov, Khasayeva, & Huseynov, 2016)

Field observations have shown that during an active eruption, the volcano ejects a large volume of a gas mixture (methane, carbon dioxide), steam, water, liquid mud, and breccia, forming a distinctive fountain reaching several hundred meters in height (Aliyev et al., 2013). The photo (Fig. 6) shows several moments of the volcano's eruption in 2012. Initially, there was an emission of steam and gas, followed by spontaneous ignition, and then the eruption of mud and breccia. Methane was the main gas component released during the eruption – accounting for 90–95 %. The carbon dioxide content reached 3–5 %. Nitrogen and hydrogen sulfide were also recorded in small amounts (Fig. 4). The gas sampled during the eruption on September 20, 2012, for isotopic analysis indicated a thermogenic origin of methane ($\delta^{13}CCH_4$=~–48‰) (Farber, Schmidt, & Feyzullayev, 2015).

The erupted liquid mud contains rock fragments of various sizes. Together with clay, they form what is known as "mud breccia". Often, large rock fragments separate from the main mass during an eruption and scatter in different directions above the fountain, resembling volcanic "bombs". These fragments are composed of oil-bearing sandstones and combustible shales from the productive Eocene-Miocene age. The clay matrix of the erupted mud mainly consists of kaolinite and hydrosmectite. The smectite content in the mud does not exceed 5–15 %. The Eocene-age combustible shales are enriched with organic matter significantly more (31.7 %) compared to Miocene shales (16.9 %). These shales generate gaseous and liquid hydrocarbons. The sandstone fragments from the eruptions are heavily impregnated with oil (Fig. 5) (Guliyev et al., 2017).

The oil is heavy, naphthene-aromatic, with a high concentration of resins (up to 20 %) and asphaltenes (up to 10 %). The content of oil fractions is up to 50 % (Guliyev et al., 2017).

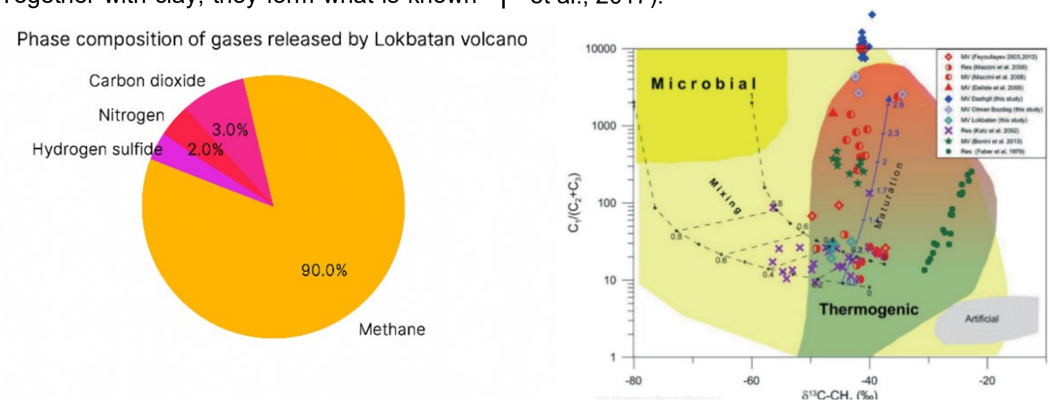


Fig. 4. Component composition of gases from the Lokbatan mud volcano (a); Gas data from hydrocarbon reservoirs collected from various fields and mud volcanoes in Azerbaijan (b) (Farber, Schmidt, & Feyzullayev, 2015)

Fig. 5 Oil-bearing sandstone and combustible shale in the mud breccia of the Lokbatan mud volcano (Aliyev et al., 2015)

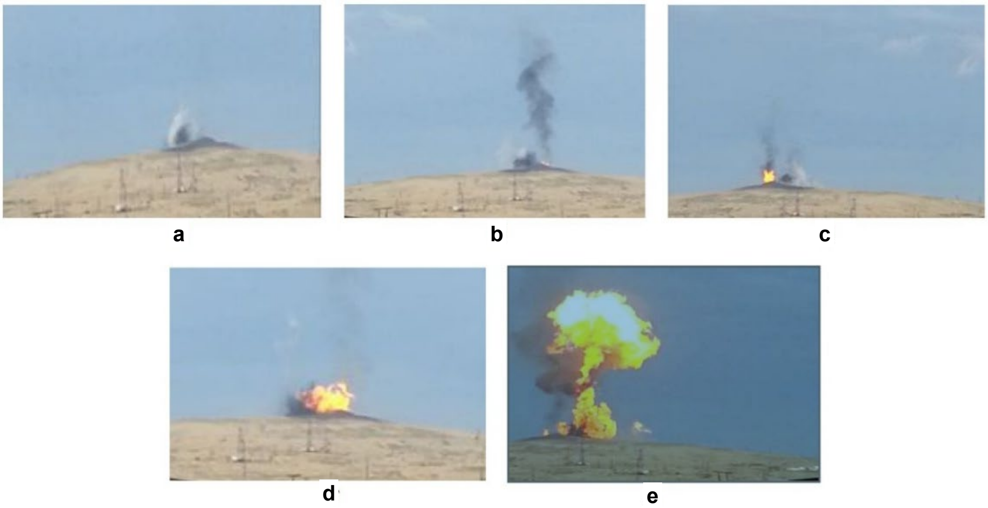


Fig. 6. Sequential moments of the Lokbatan mud volcano eruption in 2012 (Aliyev et al., 2013):
a) beginning of the eruption phase, eruption of breccia and steam; b) increase in intensity of breccia and steam eruption; c) ignition of the intermediate focus; d, e) ignition of the entire gas eruption column

The Lokbatan deposit is a multi-layered structure, with productive horizons that are significantly isolated from one another, which is reflected in the composition of hydrocarbon from different depths.

For a long time, it was believed that the central eruptive channel of the mud volcano, by piercing all the productive horizons from bottom to top, connected them into a single unit, averaged the composition of hydrocarbons, and contributed to the rapid depletion of reserves through this channel. However, this hypothesis has not been confirmed for this volcano. Hydrocarbon emissions occur only during the active phase of eruptions, and between eruptions, the volcano does not release hydrocarbons.

This suggests that the productive horizons, divided into two wings, become isolated from the eruptive channel after the active phase by impermeable clayey rocks that prevent the hydrocarbons from migrating. For the same reason, no water is emitted from the volcano between cycles of active eruption, meaning it remains "dry". When the pressure in the productive horizons reaches an anomalous value, the clay plug is breached, and the entire water-gas-mud-oil mixture rises through the central channel.

Seismic events in the region likely contribute to the creation of a brief impulse that increases the pressure on the reservoir.

The first documented eruption of the Lokbatan mud volcano was in 1828 (Gamba, 1828). Periods of increased activity include eruptions occurring with small intervals of 2 to 5 years, from 1915 to 1941, during which 8 eruptions were recorded. Periods of decreased activity included the period from 1828 to 1900, with only 5 eruptions (Aliyev, Guliyev, & Rahmanov, 2019). Currently, we are observing another period of increased mud volcanic activity. The most recent eruption was recorded in September 2024 (Fig. 7).

The water index of the Lokbatan volcano, like many others, had not been investigated before.

The idea occurred during the annual international summer school on *"Mud Volcanism and Hydrocarbon Systems"*, which has been held since 2018 in Baku. We noticed the observable "dryness" of the mud flow and the absence of salsas emmisions, which made the Lokbatan volcano stand out among others.

For satellite monitoring of the fluid (water) regime of the volcano, the Sentinel-2 satellite was selected in combination with the NDWI (Normalized Difference Water Index). This index was first proposed by McFeeters in 1996 to detect surface water in wetland environments and measure the area of open water surfaces (McFeeters, 1996). Thus, the NDWI is used to identify water bodies and assess soil moisture based on multispectral satellite imagery (Gao, 1996).

Recent studies have expanded the application of NDWI in mud volcano research, demonstrating its effectiveness for surface water and fluid regime monitoring. For example, investigated land cover characteristics of the Kesongo Mud Volcano Complex on Java Island, Indonesia, using harmonized Sentinel-2A MSI imagery to analyze surface features and provide visual interpretation of the fluid regime (Harbowo, & Sitinjak, 2025). Similarly, NDWI was successfully applied to predict the extent of the Sidoarjo mud flow, highlighting the method's potential for monitoring mud volcanic activity and associated hazards (Wicaksono, & Isa, 2022).

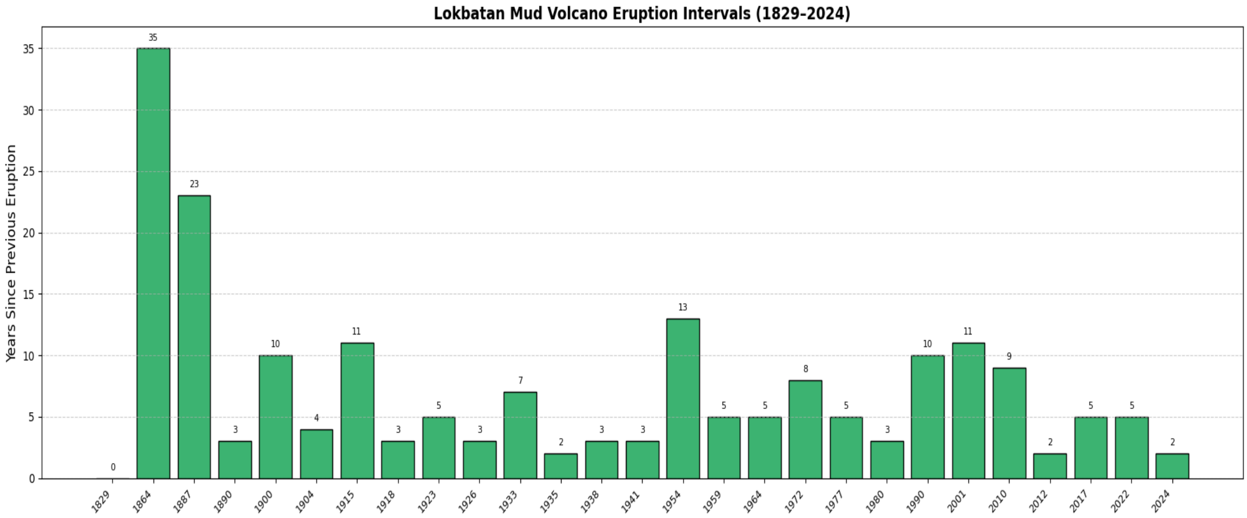


Fig. 7. Dynamics of Eruptions of Lokbatan Mud Volcano (Aliyev, Guliyev, & Rahmanov, 2019)

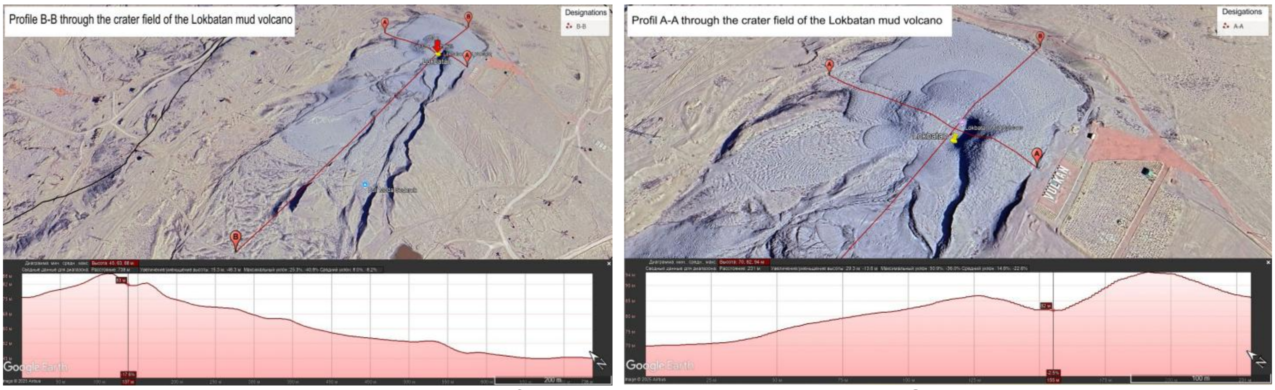


Fig. 8. Morphological Features of the Lokbatan Mud Volcano Based on Google Earth Data:
a) – Across the Crater Field and b) – Along the "Tongues" of Breccia Outflows

In light of these developments, the current study not only utilizes Sentinel-2 data combined with NDWI but also aims to synthesize previous research experiences, emphasizing the novelty and applicability of this integrated methodology for assessing the fluid dynamics of mud volcanoes in the Absheron region. This approach offers a promising tool for enhanced remote monitoring, risk assessment, and early warning of mud volcanic and seismic hazards.

Despite the fact that initially for NDWI calculations it was supposed to use images obtained only from the Landsat Multispectral Scanner (MSS) satellite, it is worth noting that this method also worked well when using images from other satellites when there was a need for such an assessment (McFeeters, 1996; Chowdary et al., 2008; Environmental Protection Agency, 2005; Murray, 2012; Panigrahy, 2012; US Geological Survey…, 2013).

The NDWI is calculated using the following formula (1):

$$NDWI = \frac{(Band\ 2 - Band\ 4)}{(Band\ 2 + Band\ 4)}, \quad (1)$$

where Band 2 represents green light reflectance at the TOA (Top of Atmosphere) level, and Band 4 corresponds to near-infrared (NIR) reflectance. According to McFeeters (1996), NDWI values greater than zero are assumed to indicate the presence of water surfaces, while values less than or equal to zero generally correspond to non-water surfaces.

Thus, NDWI values range from -1 to 1, where higher index values are typically associated with water bodies or, in our case, areas with moist soil, whereas lower values indicate dry, non-water surfaces. It should be noted that data obtained from the Sentinel-2 satellite in open access reflect the spectral characteristics of the Earth's surface and require additional analytical processing, as well as integration with other data sources for comprehensive interpretation.

To analyze the dynamics of the fluid (water) regime of the Lokbatan mud volcano during the 2017–2023 period, which included two recorded eruptions, a satellite monitoring approach was applied. The use of satellite data enabled a detailed investigation of surface changes in the volcano area. The action algorithm included several key steps: 1) collection of satellite images and their calibration; 2) identification of fluid processes; 3) time series analysis; 4) mapping of changes; 5) interpretation of the obtained data and formulation of conclusions.

During processing, the NDWI formula was applied to the acquired multispectral satellite images. As a result, a KMZ file was generated, representing NDWI values for the researched area (Fig. 9). Then, NDWI values were extracted from image pixels along profile A-A (through the crater). These values were then plotted on a time-series graph showing the distribution of NDWI over time (Fig. 10).

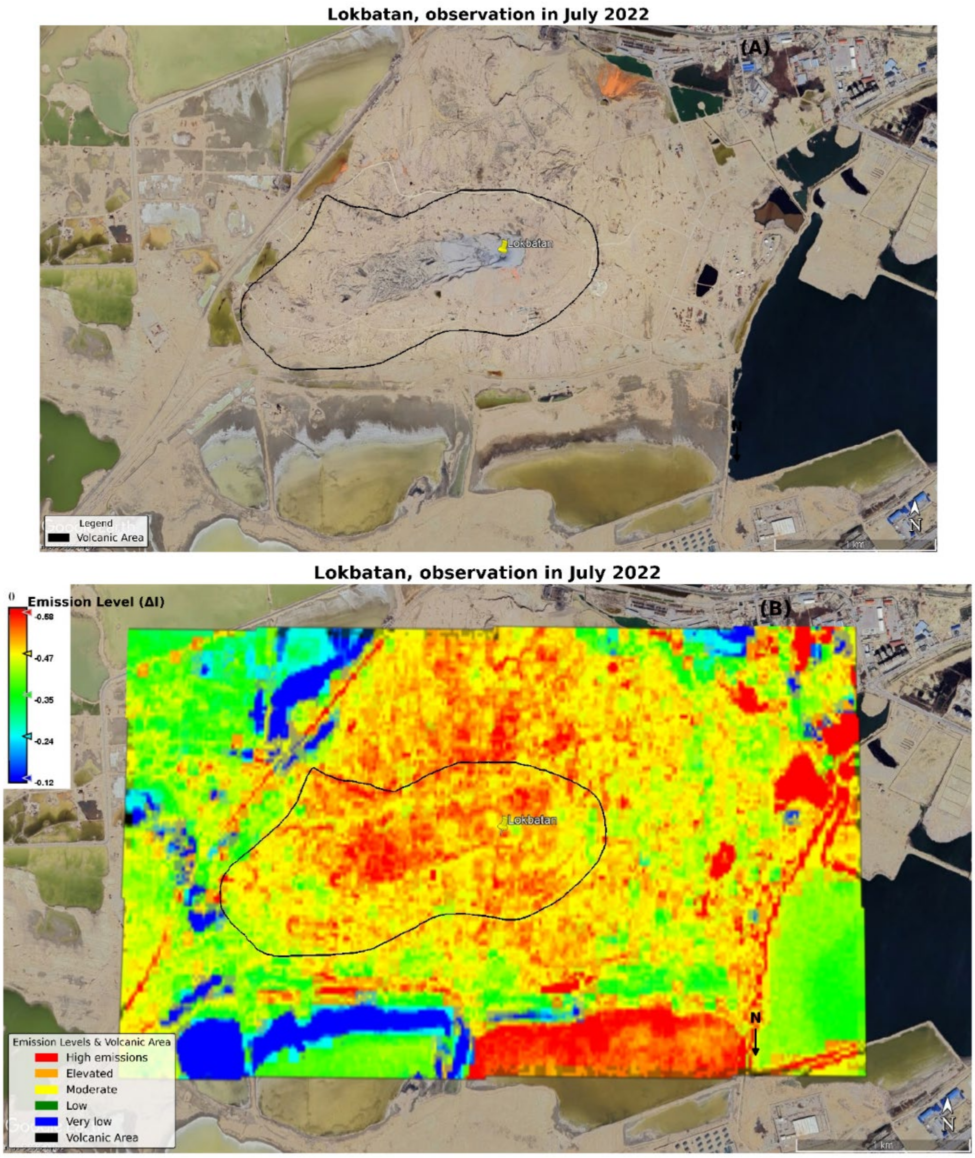


Fig. 9. Map of the Moisture Index Distribution at the Lokbatan Mud Volcano for the 2022:
a) Satellite image of the Lokbatan mud volcano, b) map of moisture Index (NDWI) distribution for the Lokbatan area

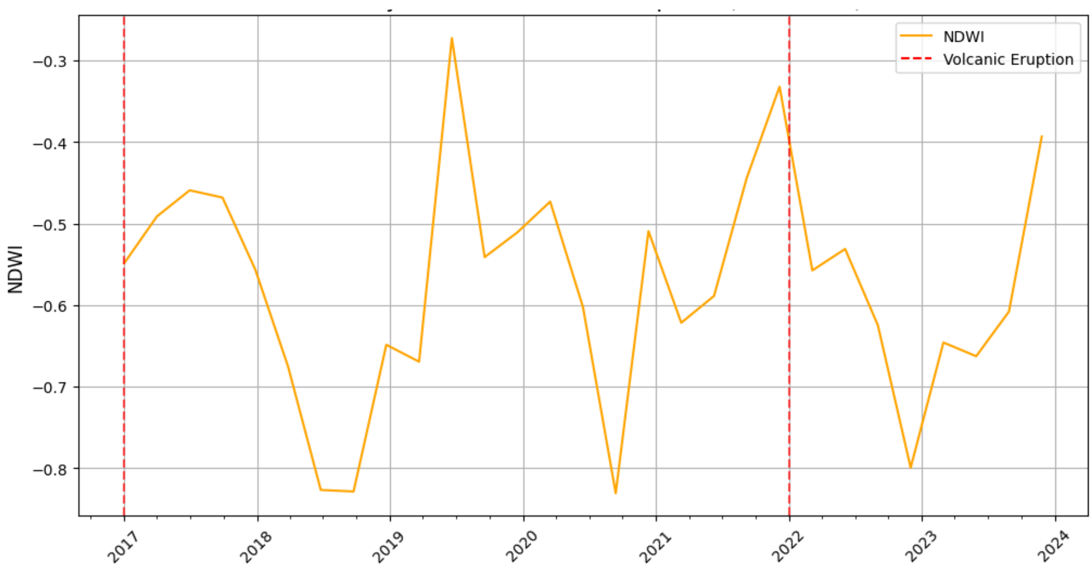


Fig. 10. Plot of NDWI and Eruption variation on the Lokbatan mud volcano from 2017 to 2023

Results

During the aforementioned period, a comprehensive set of monitoring activities was carried out for the Lokbatan mud volcano. According to satellite data, the analysis of the moisture index of the mud volcanic cover, influenced by various factors including geological activity and climate changes, revealed the following trends and factors:

- ***Climate factor*** – the moisture of the mud volcanic cover positively correlates with seasonal and climatic changes.
- ***Earthquakes and geodynamic activity*** – recorded earthquakes, especially in 2020, 2021 and 2022, probably have an influence on moisture and may be predictors of changes in the geodynamic conditions, as well as sometimes preceding volcanic activity.
- ***Anomalies in the moisture index*** – sudden changes in moisture, anomalous peaks, and stable values during certain periods can serve as indicators of potential risks of volcanic activity.
- ***Forecasting volcanic activity*** – before the eruption in August 2022, anomalies in the water regime of the mud volcano were observed in February. This could serve as an indicator for predicting paroxysmal events.

In ***2017***, the NDWI values in the Lokbatan mud volcano and its surroundings had significant fluctuations, from minimum to maximum values. In 2017, the humidity index values in the volcano and its surroundings had significant fluctuations, from minimum to maximum values, which was the result of several factors at once – seasonal fluctuations, which were most pronounced in the summer, and volcanic activity, which manifested itself in the form of the 25th eruption, which led to a sharp increase in the moisture index. By autumn, NDWI values reached a minimum value. However, by the end of the year, a gradual increase in NDWI values was observed, especially in the central (crater) part of the Lokbatan mud volcano.

In ***2018***, the humidity index values also showed considerable fluctuations; however, the overall trend indicated a gradual increase, most likely due to climatic factors (seasonal variations) as well as hydrogeological processes.

At the beginning of ***2019***, NDWI values remained relatively stable, but in May, a sharp drop to -1 was recorded. By summer, the index had risen slightly to -0.78, only to decline again in winter, reaching a minimum value of -0.96.

At the beginning of ***2020***, an increase in NDWI values was observed, followed by a decline during the spring period. The summer season was characterized by relatively stable NDWI values. However, by October, a sharp increase to -1 was recorded, followed by a return to minimum values in December. It is also worth noting that on February 15, an earthquake with a magnitude of 4.6 was recorded near the mud volcano at a depth of approximately 30 km, which may have influenced the overall NDWI trend for 2020.

Throughout ***2021***, fluctuations in NDWI values were recorded at the Lokbatan mud volcano. In early February, the NDWI value was -0.45, but from March to May, it dropped to -0.65. Additionally, earthquakes with magnitudes of 4.1 and 5.0 were recorded in August and November, respectively, which undoubtedly affected the geodynamic activity in the region.

It is noteworthy that in December, NDWI values in the southwestern part of the Lokbatan mud volcano reached -0.94, in the central (crater) part -1, and in the mudflow "tongue" area -0.55.

In ***2022***, on August 11, the Republican Seismological Service Center recorded an eruption of the Lokbatan mud volcano that lasted 5 minutes and 12 seconds ($E=0.6\times10^7$), along with two earthquakes: one in February with a magnitude of 4.2 at a depth of 56 km, and another in August with the same magnitude at a depth of 62 km. These events, to some extent, were reflected in the NDWI values. The NDWI values for the first half of 2022 remained relatively stable at -0.76. However, a sharp spike in NDWI values was observed in the crater area in February, reaching -1.

The year ***2023*** was characterized by relatively stable NDWI values. However, an increase in NDWI values up to -1 was observed in the crater area at the beginning of the year.

The anomalies in NDWI values observed in the middle and end of the year in the crater area may be due to some volcanic activity or seasonal environmental changes. According to the data collected for 2023, the average NDWI value for the crater area was -0.81, with a maximum value of -1 and a minimum of -0.57.

Based on the accumulated satellite data on NDWI for the Lokbatan mud volcano, its variations, and observed trends during the 2017–2023 period, a statistical forecast can be made regarding the expected behavior of NDWI values for the coming years. Using linear variation, we attempted to make such a forecast for the period from 2024 to 2030 (Fig. 11).

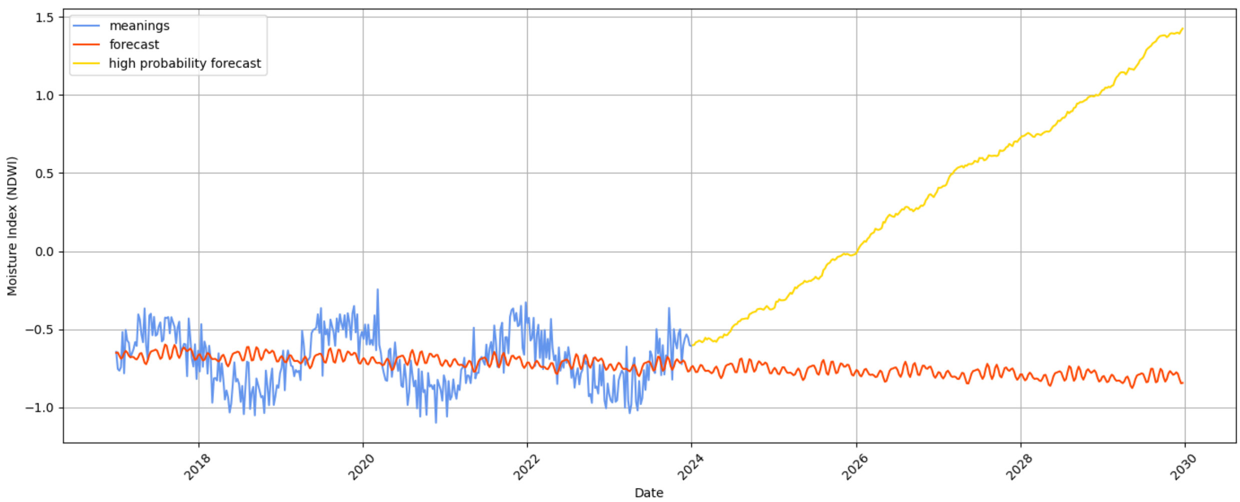


Fig. 11. Assessment of probable variations in the moisture index until 2030

The accuracy of the estimated data can be judged by the calculations for 2024, where the actual values almost coincide with the predicted ones. At the beginning of 2024, the high-probability trend shows fluctuations, then begins to rise in June, reaching a peak by the end of the year. An anomaly stands out in late June – early July, where a sharp increase in value occurs. The average value rises sharply from -0.39 to 0.07. In 2025, the high-probability trend fluctuates between 0.26 and 0.77 from January to June, with a sharp increase in June–July. An anomaly in October–November, expressed by growth, also stands out.

The graph titled "Assessment of probable changes in the moisture index until 2030" presents two main forecast components:

◍ The blue line represents the historical values of the moisture index, collected over the period from 2017 to 2024.

◍ The orange line shows the forecast, calculated using time series models such as Prophet, which take into account both trends and seasonal components. This forecast is based on historical data up to 2024 and extrapolates it into the future until 2030. The methodology assumes the continuation of current trends and seasonal patterns. The "forecast" has a broader uncertainty range, as it includes all possible scenarios – both favorable and unfavorable – without filtering by probability. This makes it suitable for assessing the overall range of moisture index fluctuations, assuming external factors remain unchanged.

◯ The yellow line represents the high probability forecast – the most likely scenario of future development, derived from a confidence interval (typically 95 %). It can be constructed using Bayesian or ensemble modeling methods, where the result reflects an average trajectory (e.g., the median) across multiple simulations. Unlike the full forecast, this component focuses on the statistically dominant scenario, excluding extreme variations. Thus, the "high probability forecast" reflects an optimistic yet realistic vector of potential changes in the moisture index, given the current trends.

Discussion and conclusions

Monitoring the Lokbatan mud volcanic activity using satellite data has shown positive results and can be effectively applied in future comprehensive studies of mud volcanism dynamics.

The fluid regime of the Lokbatan mud volcano during the study period was influenced by both geodynamic and climatic factors, which was reflected in variations of the moisture index.

The behavior of the moisture index under climatic influence differs from that caused by geodynamic factors by the "smoothness" of value changes and its clear seasonal dependence. In contrast, geodynamic factors tend to be associated with more abrupt "spikes" in the humidity index values, standing out against the general background – for example:

- Earthquakes can affect internal hydrodynamic processes within the mud volcano, leading to fluctuations in the moisture index (as observed with earthquakes in 2020, 2021, and 2022 within a 100 km radius of the Lokbatan mud volcano).
- Sudden changes in the moisture index on the mud volcano can be considered an additional mechanism for assessing potential upcoming volcanic activity (as demonstrated in the 2022 data analysis).

In conclusion, the interconnection between geological processes, climatic factors, and seismic activity represents a complex and demanding process that requires extensive data analysis and systematic monitoring. This approach is essential for effectively responding to both actual and potential risks associated with mud volcanoes.

Therefore, analyzing changes in the water regime of mud volcanoes based on satellite data – using the Lokbatan mud volcano as an example – can serve as an additional tool for anticipating future paroxysms. Satellite moisture analysis provides crucial insights into the dynamics of volcanic processes, contributing to the development of monitoring and forecasting systems for volcanic activity. However, further and more detailed studies are necessary.

Authors' contributions: Arif Huseynov – conceptualization, methodology, software, formal analysis, data validation, writing (original draft). Viktor Nesterovskyi – writing (review and editing); Ayten Huseynova – data validation, writing (original draft).

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ПЕРШИЙ ДОСВІД ВИКОРИСТАННЯ СУПУТНИКОВИХ ДАНИХ ДЛЯ МОНІТОРИНГУ ВОДНО-ФЛЮЇДНОГО РЕЖИМУ ВУЛКАНА ЛОКБАТАН ПРИ ОЦІНЦІ РИЗИКІВ СЕЙСМІЧНИХ ПОДІЙ У РЕГІОНІ

Вступ. ***Грязьові вулкани є активними природними структурами, що впливають на навколишнє середовище шляхом безперервних викидів газорідинних флюїдів, грязьової брекчії та грязьових потоків. Попри широкі дослідження та значний масив даних про грязьовий вулканізм, розуміння динаміки флюїдів та гідрогеологічних процесів, пов'язаних із цими системами, залишається предметом постійних дискусій. Нині налічується понад 2500 грязьових вулканів, розташованих у 42 країнах світу, що підкреслює їх глобальне поширення.***

Територія Азербайджану – унікальний регіон для дослідження сучасного грязьового вулканізму. На його порівняно невеликій території розташовано понад 350 грязьових вулканів. Грязьовий вулкан Локбатан серед них є найактивнішим. На ньому зареєстровано 28 активних подій з виверженням великої кількості матеріалу, з ним пов'язане нафтове родовище і сейсмічні події. У цьому контексті комплексний підхід до вивчення активності грязьових вулканів, включаючи супутниковий моніторинг, є надзвичайно актуальним.

Методи. ***У роботі використано методи дистанційного зондування для аналізу водно-флюїдного режиму грязьового вулкана Локбатан, фіксації активних фаз і пошуку кореляційних зв'язків. Зокрема, супутникові знімки застосовано для розрахунку індексу вологості у межах грязевулканічного поля, що періодично змінюється. Вперше цей індекс виміряно дистанційно, що дало змогу оцінити динаміку поверхневої вологи як показник міграції флюїдів та підповерхневої активності.***

Результати. ***Отриманий за допомогою супутника індекс вологості показав чіткі кореляції з активністю грязьового вулкана. Спостереження вказують на те, що варіації індексу вологості відповідають змінам у флюїдному режимі грязевулканічної структури, відображаючи можливу підземну міграцію флюїдів або зміни тиску перед фазою виверження.***

Висновки. ***Дослідження демонструє потенціал супутникового моніторингу в оцінці водно-флюїдного режиму інших активних грязьових вулканів. Цей підхід може забезпечити ефективну, недорогу альтернативу польовим спостереженням і лабораторним дослідженням і надає можливість підтримувати системи раннього попередження про сейсмічні події чи виверження. У подальшому отриманий досвід можна реалізувати при розробці превентивних стратегій управління геологічними процесами в сейсмічно активних регіонах.***

Ключові слова: ***грязьовий вулкан Локбатан, супутникові знімки, флюїди, NDWI, моніторинг.***

Автори заявляють про відсутність конфлікту інтересів. Спонсори не брали участі в розробленні дослідження; у зборі, аналізі чи інтерпретації даних; у написанні рукопису; в рішенні про публікацію результатів.

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