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Mining mapping and exploration using remote sensing data in Kazakhstan: a review

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Abstract. Effective and sustainable resource management is critical to the mining industry, which plays a significant role in the Kazakhstan economy. To achieve this goal, the use of remote sensing technologies has become necessary. These advanced tools are now integral to activities such as mineral mapping, research and environmental monitoring. Therefore, the purpose of this comprehensive review article is to scrutinize how remote sensing data is used specifically in the context of mining in Kazakhstan. The comprehensive review covers a wide range of aspects, including the use of remote sensing for mapping and mineral resource studies. Key findings highlight the growing importance of remote sensing technologies in Kazakhstan's mining industry as they facilitate the precise delineation of ore deposits, enable effective monitoring of environmental impacts and promote optimal use of natural resources. The article discusses the difficulties and limitations encountered in the application of remote sensing data. Particular attention is paid to the need to improve methods of data processing, correction of atmospheric influences and spectral analysis. The overview presented in this paper is of great importance to those involved in research, policy development and industrial sectors who are interested in using remote sensing data to enhance mining activities and promote environmental sustainability in Kazakhstan. By providing a comprehensive analysis of the subject, this review offers valuable information that can help researchers deepen their understanding of the topic and guide them toward more effective strategies.

Keywords: *mining industry, remote sensing, ore deposits, GIS, exploration studies.*

1. Introduction

The mining industry plays a vital role in the worldwide economy by providing essential resources to key sectors like construction, manufacturing, and energy. In order to maintain the long-term prosperity of this sector and effectively oversee mining operations, it has become imperative to have accurate mapping and monitoring of mine sites. In recent years, experts and professionals in this field have increasingly turned to advanced remote sensing techniques that incorporate innovative hyperspectral and multispectral technologies. This integration of state-of-the-art tools enables a more extensive comprehension of the terrain, equipping decision-makers with valuable insights to make informed choices. The utilization of these cutting-edge methods ensures that the mining industry continues to thrive while promoting efficient management practices.

Hyperspectral data is an invaluable tool that allows us to delve into the distinct spectral characteristics of the Earth's surface across numerous narrow bands. By delving deeper into these specialized bands, hyperspectral data unveils intricate details and reveals distinctions that cannot be achieved solely with multispectral data. On the other hand, multispectral data encompasses a wide range of wavelengths, enabling it to effectively adapt in various fields. With its comprehensive coverage of the electromagnetic spectrum, multispectral data finds practical applications in a diverse set of tasks. These advanced technologies provide us with valuable insights into mineral composition, distribution patterns, and how these patterns evolve over time. This knowledge becomes crucial when identifying potential mining sites and enhancing mining processes. Furthermore, both hyperspectral and multispectral remote sensing techniques possess the capacity to detect changes in mineralogy over time, thereby allowing for more accurate assessments of environmental impacts caused by mining activities.

The primary goal of this paper is to thoroughly investigate the benefits obtained from merging hyperspectral and multispectral data in order to accurately map mining sites and closely observe mining procedures. Moreover, this examination will tackle the obstacles encountered by researchers and engineers when deploying these approaches. The objective of this article is to offer an in-depth examination of current literature on the topic, while also showcasing practical examples that illustrate how the combination of hyperspectral and multispectral data substantially improves the effectiveness and precision of mining mapping and monitoring methods.

The use of spectral methods for geological research is developing in several directions: geological mapping, the search for ore deposits of minerals by hydrothermal changes, the search for deposits of non-metallic raw materials.

An example of using ASTER data to map the lithological composition of rocks using spectral information from ther-

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mal channels is related to the study of the composition of rocks in the area of Mountain Pass, California, USA [1], another example is related to the mapping of rocks in the area of Bodie, California, USA [2], where they were discovered gold and silver deposits associated with hydrothermal changes in volcanic complexes.

Attempts have been made to quantify the SiO_2 content in rocks based on spectral analysis of satellite images. The research was conducted in Hiller Mountains, Nevada, USA and Virgens-La Reforma, Baja California Sur, Mexico [3]. As a result of the work on spectral data, maps of the quantitative content of SiO_2 in rocks were constructed.

The possibility of quantifying the concentrations of light micas in the Pilbara greenstone belt, Western Australia, has been shown [4]. The assessment of the content of these minerals in the composition of rocks was carried out based on the calculation of spectral indices.

In Nevada (USA), the possibility of mapping minerals and rocks containing ammonium has been shown using spectral methods [5].

One of the most common objects for research are porphyry copper deposits, which are characterized by a regularly changing contrast in their mineral composition of the zonality of hydrothermal changes. Spectral mapping of porphyry deposits was performed for the Silver Belt region, Arizona, USA [6], Collahuasi, Northern Chile [7] and some others [8]. As a result of the study, propylite, argillite and phyllite zones of hydrothermal-metasomatic changes in the host rocks were identified.

Quartz-vein epithermal gold deposits have been investigated in the Goldfield Mountain District, Nevada, USA [9]. TIMS spectral data are used in the thermal range to study the hydrothermal gold deposits of Carlin, USA [10]. Gold deposits of various genesis: hydrothermal, scarn, epithermal vein, bonanza type, granite and porphyritic mineralization, and sedimentary type were studied in Santa Teresa County, Sonora, Mexico using Landsat satellite data [11]. ASTER radiometer data were used to search for altered rocks in the Chocolate Mountains (California, USA) to localize gold ore manifestations in quartz-biotite gneisses and muscovite shales of the Precambrian basement [12].

In Spain, complex geochemical and spectrometric work was carried out in the old ore region (gold, silver, lead) to study the spectral properties of soils in connection with concentrations of elements such as lead, zinc, arsenic [13]. According to the data of the HyMAP spectrometer and the results of geochemical analyses, correlations of some spectral relations with heavy metal contents were revealed.

Using the example of [14] a part of the territory of the East African Rift zone, a forecast of ore objects was made based on the use of materials from the lineament analysis of Landsat 8 and SRTM satellite images. In this work, it is shown that the density of lineaments serves as an indicator of zones of discontinuous faults and can be used in geological forecasting of ore deposits.

In Kazakhstan, using the example of well-known deposits and copper ore fields of Zhezkazgan, Aktogay, Kounrad, Sayak, Taysogan and other ore regions, metasomatic zonality mapping was performed using the ASTER spectroradiometer, which serves as an important criterion in the technology of predictive prospecting aimed at the discovery of new deposits of the geological and industrial type «copper-sandstones» [15].

The extended spectral coverage and high spatial resolution make it possible to obtain reflection spectra in the far infrared range with high detail: it becomes possible to more accurately diagnose the mineral composition and detect anomalies of a small area that previously could not be localized due to technical limitations. Thus, in [16], hyperspectral data from UAVs are used for geological research in the Czech Republic, Sokolov. As a result, several types of deposits can be distinguished based on differences in the content and types of iron minerals, which cause different reflectivity of the slope in the near infrared range (800-900 nm).

In [17], a study on geological mapping and geophysical surveying using unmanned aerial systems is described in detail. The research is conducted in Siilinjärvi, Finland, and includes ground-based spectroscopy, orthophotography, geological and magnetic exploration. The results demonstrated the effectiveness of using UAVs for the purposes of geological mapping and mineral prospecting through controlled image classification using the SVM classifier with an overall accuracy of >90%.

In the works of J. Robinson [18], R. Jackish [19] hyperspectral sensors based on unmanned aerial vehicles were used to determine the distribution of ore in the studied areas with verification of the data obtained by magnetic exploration, geochemical and field studies. The integrated exploration strategy made it possible to map ore occurrences.

In [20], using various hyperspectral cameras such as Specim FX10, FX17, Telops Hyper-Cam, etc., as well as machine learning methods for data processing, the types of minerals were determined. The work also showed the difference in the use of the obtained data in VNIR, SWIR and LWIR ranges. In the Dolomites (Italy), calcite, dolomite carbonate formations, clay and mica minerals were distinguished using hyperspectral data from UAVs during mineralogical mapping [21].

The results of shooting in the visible, as well as near, short- and long-wave infrared (IR) range were used as a combination of channels, and the images were processed using machine learning algorithms to create 2.5D maps [22]. In British Columbia, the results of hyperspectral surveys were used to predict the content of organic carbon and SiO_2, Al_2O_3, K_2O and CaO in surface formations, and in Texas to determine the chemical and mineral (quartz, clay and carbonate) composition of shales. The results obtained can be used both for individual samples up to collector volumes [23].

A number of scientific studies use a combination of multi- and hyperspectral data, which allows us to obtain extensive data on the composition of formations on the Earth's surface. Multispectral images are used to create maps of geological structures, identify various cracks, faults and others, monitor changes in land cover, vegetation, etc., and hyperspectral images are used to diagnose the predominant mineral species in surface formations based on spectral characteristics, indices.

The use of field spectroscopy in geological exploration preceded aerial spectrometry, since it is important to obtain accurate ground-based data on spectral reflectivity/radiation. The results of satellite sensing – spectral anomalies – can be verified by field spectrometers. Modern field-based spectroradiometers have a large spectral range, high resolutions and improved signal-to-noise ratios. Measurements of the reflec-

tion and radiation spectra of rocks in situ can be carried out in the wavelength range from 0.35 to 14.00 microns [24].

From a geological point of view, field spectroscopy can be used in two different modes. Firstly, it can be used as an independent method for diagnosing the mineral composition of formations on a deposit scale. Ramakrishnan et al. [25] used this method to determine the boundaries of the development of Pb-Cu-Zn mineralization and associated zones of hydrothermal-metasomatic changes. They used field spectrometers, a library of spectra, and separation algorithms to identify ore zones and rock types in the deposit. Kurtz applied hyperspectral imaging and lidar to map diagenetic carbonates and clastic carbonates in the field. Secondly, it can be used to assess the quality of ore; mining mapping.

2. Materials and methods

The analysis of existing literature delves into research papers that have been published in the English language from the years 2013 to 2023. This comprehensive examination was conducted through a systematic approach, which entailed five distinct phases (Figure 1):

1. Formulation of the research question. In order to embark on a comprehensive and organized examination of existing literature, it is of utmost importance to first identify the specific research question or topic that will be investigated. This inquiry might involve delving into a highly specialized field of study or selecting a more wide-ranging approach, depending on the desired objective of the analysis. The research question is the following:

RG1 - Which hyperspectral and optical images are used for geological research?

RG2 - What data is used together with the images for geological research and mapping?

RG3 - What data processing and analysis algorithms have been used in the literature for mapping and exploring mining sites using a combination of optical and hyperspectral remote sensing data?

RG4 - What challenges and difficulties arise in the field of mapping and exploration of mining sites using a combination of optical and hyperspectral remote sensing data?

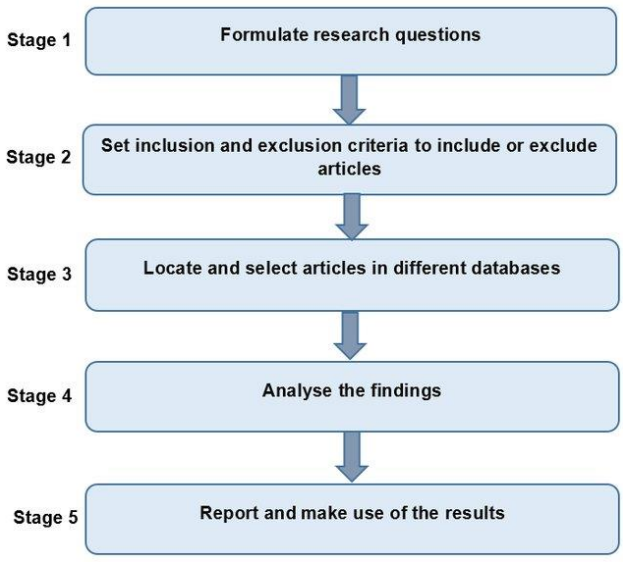

Figure 1. Stages of Literature Analysis

2. Search and selection of literature. The following databases were used to search the literature: Scopus, Web of Science, Google Scholar, Science Direct. Next, articles were selected that met the specified criteria. The following exclusion criteria were selected:

– the publication is not written in English;

– duplicate publication or has already been received from another database;

– the full text of the article is not available;

– the publication is a review article, a book chapter, or a conference abstract;

– the publication was published before 2013.

The literature search is carried out using the following keywords: «Optical and hyperspectral remote sensing for mining mapping and geological exploration in Kazakhstan» and «Remote sensing data for mining in Kazakhstan».

3. Analysis and synthesis. After collecting extensive literature related to the topic under consideration (Table 1). Each article is then analyzed in detail to identify and generate important implications, methodologies, associated research questions, and other elements. Rules combine these important findings through a data synthesis process to produce a comprehensive literature review that draws together key material from all sources.

Table 1. Distribution of papers based on the databases

Database	# of initially retrieved papers	# of papers after exclusion criteria
Google Scholar	576	1
Springer	217	0
Scopus	27	2
IEEE Xplore	0	0

4. Identification of gaps and directions of research. By conducting a thorough and comprehensive study of various literature sources, it becomes possible to pinpoint specific areas where research is inadequate or where there is a lack of sufficient research papers. Consequently, this allows us to suggest other avenues for further research that address these identified shortcomings.

5. Formulation of conclusions. After conducting an extensive and methodical literature review, a thorough evaluation is carried out to arrive at key ideas and comprehensive observations. These conclusions are based on a comprehensive review of existing research. The implications of these results are valuable not only for researchers, but also for specialists in the field who can apply this knowledge in their practical work.

3. Results and discussion

During the literature review, several articles were selected and analyzed. They have mostly been published in recent years. Based on data analysis, the following research questions can be answered:

RG1 – The selected works used optical images of Sentinel-2, Landsat-7 and radar images of RADARSAT, Sentinel-1. Hyperspectral images for geological research have not yet been used in scientific works where Kazakhstan was the object of study.

RG2 - Together with images for geological research, data on the chemical composition of the soil, which was obtained in a laboratory, is used.

RG3 – ArcGIS, ENVI, SPSS programs were used to process satellite images. The IDL and ENVI basic package included analysis of LIDAR, IDL, and ENVI data. In addition, SAR Scape, Photogrammetry, DEM Extraction, Atmocultural Correction, Feature Extraction and Crop Science modules were used as additional ENVI modules. Satellite images and data were downloaded from the USGS database. Subsequently, different ranges were selected in ENVI 5.2 software and the data format was converted to Geotiff.

RG4 – The following challenges and difficulties arise in the field of mapping and exploration of mining sites using remote sensing data:

– atmospheric conditions and atmospheric correction;

– comparison of data in different time periods;

– difficulties when working in inaccessible and remote areas;

– integration of data and other information sources.

As a result of the synthesis, several articles were selected for further work (Table 2). Many articles were excluded during the database search because the subject of the study was not Kazakhstan or they were conference abstracts.

Table 2. List of selected articles based on the results of analysis and synthesis

№	Article title
1	Felegari S. et al. Using Sentinel-2 data to estimate the concentration of heavy metals caused by industrial activities in Ust-Kamenogorsk, Northeastern Kazakhstan //Heliyon. – 2023. – T. 9. – №. 11.
2	S.S. Demessinova et al. Algorithm for control of remote sensing spacecraft for monitoring subsoil use objects // News of the National Academy of Sciences of the Republic of Kazakhstan, Series of geology and technical sciences. – 2022. - №6
3	Boris Zeylik et al. New technology for mineral deposits prediction to identify prospective areas in the Zhezkazgan ore region // Mining of Mineral Deposits. – 2021. – V. 15. – Issue 12

The following articles were analyzed and brief descriptions were given:

1. This study focuses on evaluating the levels of heavy metal pollution in Ust-Kamenogorsk, located in Northeastern Kazakhstan, using data obtained from the Sentinel-2 satellite mission. The researchers collected 60 soil samples from the region and conducted analysis using atomic absorption spectroscopy to measure the concentrations of lead, copper, and zinc.

To establish a relationship between heavy metal concentrations and the spectral bands in Sentinel-2 images, the researchers employed regression analysis. They identified specific spectral bands that were most effective in monitoring the concentrations of each heavy metal. For example, the blue channel, the ratio of green to near-infrared-IV channels, and the ratio of short-wave infrared-III to near-infrared-II channels were found to be effective in monitoring lead. Similarly, different bands were identified for monitoring copper and zinc concentrations.

To assess pollution intensity, the researchers calculated Pollution Load Indices (PLI) and Geographical Accumulation Indices (Igeo). The analysis of Igeo values indicated that heavy metal concentrations in the region exceeded typical geochemical background levels. Copper, lead, and zinc concentrations were found to be at hazardous levels, suggesting a significant pollution problem.

Comparisons were made with other industrial regions globally, and the heavy metal concentrations in Ust-Kamenogorsk were found to be much higher than usual ranges observed in industrial areas. The study also highlighted that heavy metal concentrations exceeded permissible limits in recreational, institutional, and residential areas. Copper concentrations were approximately 95 mg/kg higher than the limit, while lead and zinc exceeded the limits by nearly 490 mg/kg.

The findings of this study emphasize the urgent need for remediation measures and further monitoring to mitigate the risks associated with heavy metal pollution in Ust-Kamenogorsk. The use of satellite data from the Sentinel-2 mission provides valuable insights into the extent and intensity of contamination, enabling targeted actions to address the pollution issue in the region.

2. This scientific article delves into the field of subsoil use and addresses several important issues related to geological research. It emphasizes the significance of remote sensing as the most effective method in modern geological studies. Remote sensing involves using aerial and satellite images to study the Earth's surface relief, including processes of recognition, interpretation, and tying obtained images to real conditions.

The article highlights different research methods employed depending on the specific object of study. It stresses the need for high-resolution images when compiling general geomorphological maps. These maps serve as the remote basis for geological content and are created based on remote sensing materials, formalized transformations, decoding, and interpretation.

One of the key focuses of the article is the monitoring and evaluation of subsoil use objects, which is identified as a strategic direction in Kazakhstan. The authors point out the insufficient scientific research in the development of new mineral deposits in recent decades and the decrease in control over existing subsoil use facilities by law enforcement organizations. To address these issues, the article proposes the establishment of a database for existing subsoil use objects and the implementation of research procedures for newly developed subsoil use objects.

Considering Kazakhstan's severe climatic conditions, such as wind, precipitation, floods, and sudden temperature changes, the article emphasizes the need for careful consideration in the development of new mineral deposits. Unfortunately, the operational geospatial information available on proposed subsoil use objects is still inadequate for decision-makers and does not meet modern environmental requirements.

To overcome this limitation, the article suggests utilizing satellite observations through remote sensing methods as one of the main sources of up-to-date, complete, and reliable data on conditions. The primary objective is to identify and assess risks that may arise during the development and further operation of proposed new subsoil use objects. The article also highlights the importance of optimizing errors in the spacecraft control system to obtain the most reliable information from the spacecraft.

In summary, this article provides insights into the use of remote sensing in subsoil research, highlighting the methods, challenges, and strategic directions in Kazakhstan. It emphasizes the significance of high-resolution images, the need for a comprehensive database, and the importance of

satellite observations in obtaining reliable data for decision-making and risk assessment in subsoil use.

3. The article proposes a new technology for predicting mineral deposits in the Zhezkazgan ore region of Kazakhstan. It employs an integrated methodology that combines remote sensing data analysis, geophysical data utilization, and analogy and actualism methods. The study focuses on identifying prospective areas for detailed exploration by analyzing ring structures identified through remote sensing data from satellite images.

The research identifies six ring structures in the region and delineates tension and compression zones for the prominent structures. By superimposing these zones, blocks with increased permeability are distinguished. The study also highlights new prospective areas within gravity maxima, namely gravity maximum 1 (Near), gravity maximum 2 (Middle), gravity maximum 3 (Distant-Tabylga), and gravity maximum 6 (Central). Additionally, an area overlaid by loose sediments in the Terekty ring structure and an area near well Sh-2 containing a thick pyritized sandstone stratum are identified as potential areas for exploration.

The article proposes two prediction options based on different types of ring structures, one expressed in relief and indicating younger age, and the other based on older image-expressed structures. These predictions are combined by overlaying tension areas. The study also correlates gravity data with known deposit locations to support the identification of certain maxima.

Overall, the technology proposed in the article allows for the reduction of exploration areas and costs compared to traditional approaches. The integrated predictions and gravity data analysis improve the localization of prospective areas, while remote sensing data enhances the accuracy of identifying these areas. The findings of this study offer potential for cost-effective replenishment of the depleted ore base in the Zhezkazgan ore region of Kazakhstan.

4. Conclusions

After thoroughly examining various studies and literature, we have assimilated valuable insights into the utilization of a fusion of optical and hyperspectral remote sensing information for the purpose of mining site mapping and exploration. Our comprehensive analysis has led us to draw certain noteworthy conclusions, which are as follows:

The utilization of optical and hyperspectral data has been witnessing a notable upsurge in the mining industry. This type of remote sensing data holds immense significance as it aids in the meticulous creation of deposit maps, vigilant monitoring of alterations occurring within mining sites, and precise estimation of mineral resources.

The advantages of utilizing a fusion of optical and hyperspectral data are manifold. By integrating these two datasets, researchers and mappers can greatly enhance the precision and richness of their findings. This powerful combination not only amplifies the accuracy but also expands the informational capacity, enabling a more comprehensive identification of minerals, anomalies, as well as changes in rock formations with exceptional precision. The incorporation of such diverse data sources unlocks new possibilities for groundbreaking research and mapping endeavors.

In this particular field, the utilization of remote sensing data presents a myriad of challenges and difficulties that have been duly recognized. Atmospheric conditions, for instance, pose a significant obstacle to the accurate collection and interpretation of data. Additionally, ensuring proper instrument calibration is crucial in order to avoid any distortions or inaccuracies in the gathered information. Furthermore, the management of large volumes of data can be quite overwhelming and demands efficient strategies for storage and analysis. Nonetheless, advancements in modern technologies and data analysis methods offer promising solutions to overcome these obstacles successfully.

The future of the mining industry looks promising as there is immense potential in integrating optical and hyperspectral data. This integration opens up new avenues for advancement and progress. As we look ahead, it becomes evident that further research and development will play a crucial role in shaping the industry. The focus of these efforts should be on enhancing analysis techniques, refining data management strategies, and ensuring that decision-makers have access to a wealth of information. Through these endeavors, we can expect to witness significant growth and innovation in the mining sector.

The utilization of a combination of optical and hyperspectral remote sensing data offers immense potential in the field of mapping and exploring mining sites. Despite the obstacles that come with using these technologies, their integration can substantially enhance the precision, effectiveness, and sustainability of the mining industry. By conducting further research and fostering innovation in this domain, we can pave the way for sustainable and efficient approaches to resource extraction and environmental preservation.

However, in our country, compared to other countries, space data is currently rarely or not used at all for geological research. But in the future, there is potential for increased interest in these technologies and their wider application. This is due to several factors, such as the development of technology and equipment, the need for sustainability and efficiency, and the increasing importance of the mining industry for the economy.

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Қазақстанда қашықтықтан зондтау деректерін пайдалана отырып, тау-кен жұмыстарын картаға түсіру және барлау: шолу

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Аңдатпа. Ресурстарды тиімді және орнықты басқару Қазақстан экономикасында маңызды рөл атқаратын тау-кен өндіру өнеркәсібі үшін шешуші мәнге ие. Осы мақсатқа жету үшін қашықтықтан зондтау технологияларын қолдану қажет болды. Бұл озық құралдар қазір пайдалы қазбалар кен орындарын картаға түсіру, зерттеулер жүргізу және қоршаған ортаны бақылау сияқты қызметтердің ажырамас бөлігі болып табылады. Осылайша, осы жан-жақты шолу мақаласының мақсаты қашықтан зондтау деректерінің Қазақстанда пайдалы қазбаларды өндіру контекстінде нақты қалай пайдаланылатынын мұқият зерделеу болып табылады. Жан-жақты шолу картаға түсіру және минералды ресур-

старды зерттеу мақсатында қашықтықтан зондтауды қолдануды қоса алғанда, көптеген аспектілерді қамтиды. Негізгі тұжырымдар Қазақстанның тау-кен өнеркәсібінде қашықтықтан зондтау технологияларының өсіп келе жатқан маңыздылығын көрсетеді, өйткені олар кен кен орындарының шекараларын дәл айқындауды жеңілдетеді, қоршаған орта үшін салдарлардың тиімді мониторингін қамтамасыз етеді және табиғи ресурстарды оңтайлы пайдалануға ықпал етеді. Мақалада қашықтықтан зондтау деректерін қолдану кезінде туындайтын қиындықтар мен шектеулер қарастырылады. Деректерді өңдеу әдістерін жетілдіру, атмосфералық әсерді түзету және спектрлік талдау жүргізу қажеттілігіне ерекше назар аударылады. Осы құжатта ұсынылған шолу пайдалы қазбаларды өндіру жөніндегі қызметті кеңейту және Қазақстандағы экологиялық тұрақтылыққа жәрдемдесу үшін қашықтықтан зондтау деректерін пайдалануға мүдделі зерттеумен, саясатты әзірлеумен және өнеркәсіптік секторлармен айналысатын адамдар үшін үлкен маңызға ие. Тақырыпты жан-жақты талдауды қамтамасыз ете отырып, бұл шолу зерттеушілерге тақырып туралы түсініктерін тереңдетуге және оларды тиімдірек стратегияларға бағыттауға көмектесетін құнды ақпаратты ұсынады.

Негізгі сөздер: *тау-кен өнеркәсібі, қашықтықтан зондтау, кен орындары, ГАЖ, геологиялық барлау зерттеулері*.

Картографирование и разведка горных работ с использованием данных дистанционного зондирования в Казахстане: обзор

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Аннотация. Эффективное и устойчивое управление ресурсами имеет решающее значение для горнодобывающей промышленности, которая играет значительную роль в экономике Казахстана. Для достижения этой цели использование технологий дистанционного зондирования стало необходимым. Эти передовые инструменты теперь являются неотъемлемой частью таких видов деятельности, как картографирование месторождений полезных ископаемых, проведение исследований и мониторинг окружающей среды. Таким образом, целью данной всеобъемлющей обзорной статьи является тщательное изучение того, как данные дистанционного зондирования используются конкретно в контексте добычи полезных ископаемых в Казахстане. Всеобъемлющий обзор охватывает широкий спектр аспектов, включая использование дистанционного зондирования для целей картографирования и изучения минеральных ресурсов. Основные выводы подчеркивают растущее значение технологий дистанционного зондирования в горнодобывающей промышленности Казахстана, поскольку они облегчают точное определение границ рудных месторождений, обеспечивают эффективный мониторинг последствий для окружающей среды и способствуют оптимальному использованию природных ресурсов. В статье рассматриваются трудности и ограничения, возникающие при применении данных дистанционного зондирования. Особое внимание уделяется необходимости совершенствования методов обработки данных, коррекции атмосферных воздействий и проведения спектрального анализа. Обзор, представленный в этом документе, имеет большое значение для лиц, занимающихся исследованиями, разработкой политики и промышленными секторами, которые заинтересованы в использовании данных дистанционного зондирования для расширения деятельности по добыче полезных ископаемых и содействия экологической устойчивости в Казахстане. Предоставляя всесторонний анализ предмета, этот обзор предлагает ценную информацию, которая может помочь исследователям углубить их понимание темы и направить их к более эффективным стратегиям.

Ключевые слова: *горнодобывающая промышленность, дистанционное зондирование, рудные месторождения, ГИС, геологоразведочные исследования*.

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