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Advancing Geoscience at the Geological Survey of Namibia: Integrating AI, Big Data and Geospatial Technologies

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Abstract :- As available geoscientific data increase both in volume and in quality, and processing technologies evolve constantly, the Geological Survey of Namibia (GSN) needs to integrate innovative solutions to meet global standards and help attracting investment into the country. By implementing Artificial Intelligence (AI), GSN can further mineral exploration, make geological mapping more accurate, and better monitor the environment. Big data analytics can process large amounts of geological data for instance for mineral potential mapping, while advanced geospatial technologies provide real-time information on issues such as environmental and natural hazard monitoring to a variety of stakeholders. Challenges including technical skills required to handle complex data and the need for powerful computers, as well as ethical concerns must be addressed, but by adopting these new technologies GSN can contribute to Namibia's sustainable development.

Keywords :- Geoscience, Geological Survey of Namibia, Artificial intelligence, Big data analytics, Machine learning, Geospatial technology

Introduction

Geoscience plays a crucial role in tackling important global issues such as resource management, climate change and disaster prevention or mitigation (Frodeman, 2013). However, as technology advances and global challenges become more complex, traditional geoscience methods need to adapt by embracing new tools and approaches.

One major shift is the growing use of artificial intelligence and machine learning, which are transforming how scientists study and interpret the earth. These new technologies help create accurate models of complex systems, predict events like earthquakes or floods, and better understand long-term environmental changes (Bergen, 2019). Despite their obvious potential, however, there are challenges, such as data privacy, understanding the processes behind AI, and the need to make these intricate tools accessible and user-friendly (Karpatne *et al*., 2018).

Recent studies highlight the importance of collaboration across different disciplines to facilitate and improve decision-making and scientific research, and ensure a broad base for AI applications developed to meet specific geoscientific needs (Karpatne *et al*., 2018). As global challenges and competition grow, integrating tools like AI, machine learning, and big data analytics, will enable GSN to manage complex geological data, predict resource locations, assess risks like natural hazards, provide more accurate geological data for mineral exploration, land use planning and other fields, as well as to improve environmental monitoring. However, their successful implementation requires careful, long-term planning with respect to IT requirements, human resources and confidentiality issues. In the following, examples are given how GSN can profit from these new technologies.

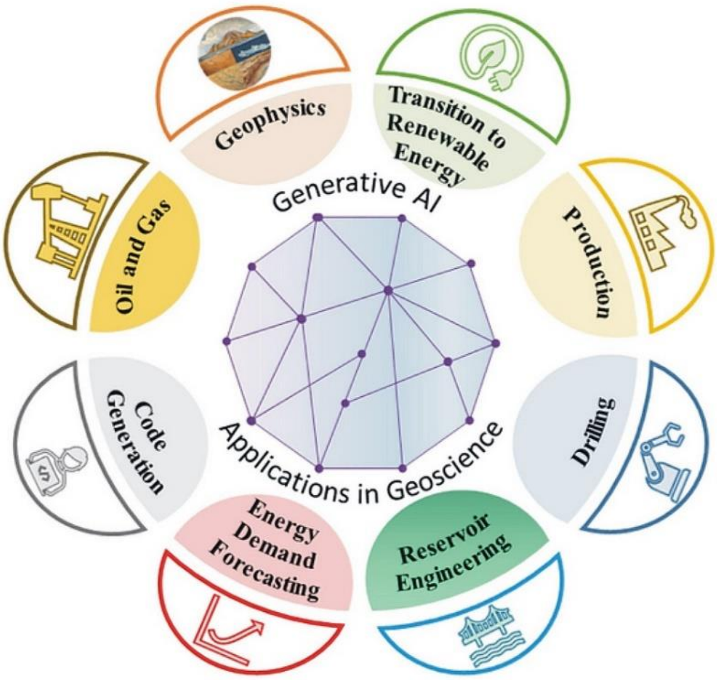
Geoscience Opportunities

Machine Learning and Artificial Intelligence in Geoscience

The Geological Survey of Namibia has been exploring ways to support mineral discovery by providing enhanced data. A current project on mineral prospectivity mapping of the Kunene Region can benefit from the application of AI models to integrate and analyse geophysical and geochemical survey data, drill hole information and satellite imagery to predict potential mineralisation (Köhler *et al*., 2021; Doyoro *et al*., 2025). Deep learning techniques applied to hyperspectral images can detect subtle mineral signatures in remote regions, such as north-western Namibia, thus reducing the need for extensive fieldwork

(Hajaj *et al*., 2024). AI also helps to identify geological features on maps, especially for non-geologists unfamiliar with them. The above examples show that AI is capable of making geological work faster, more accurate and, consequently, more cost-effective.

Historical geological reports, which are stored in the GSN's Earth Data Namibia database, hold a wealth of information invaluable to resource exploration; however, extracting this information can be a lengthy process. Another useful tool - Natural Language Processing (NLP) - analyses geological reports to find relevant information for mineral exploration, assessing environmental impacts or other purposes (Luccioni *et al*., 2020). In addition, geospatial tools are capable of supporting mineral exploration by identifying potential deposit locations based on historical geological data and spectral imaging analysis. Expanding the use of such technologies will enable GSN to improve its services to stakeholders by creating a variety of enhanced map products, such as mineral potential maps.



AI in Geoscience - Source: https://onlinelibrary.wiley.com/doi/10.1111/exsy.13654

Real-Time Insights through Advanced Computing

The integration of cloud-based geospatial platforms, edge computing, and GIS-based analytics is changing the processing and interpretation of geological data (Huang *et al*., 2018). The implementation of real-time monitoring systems using remotely sensed data, such as satellite imagery and drone-based surveys, allows tracking groundwater depletion, land use changes, soil erosion and seismic activity, to name but a few of many potential applications. At GSN, seismic hazard assessment can benefit from AI-driven early warning systems that analyse real-time ground motion in conjunction with historical seismic trends to predict earthquake risks more accurately.

Harnessing Big Data for Predictive Capabilities

As geoscience enters the era of big data, the use of large datasets for predictive modelling is a powerful opportunity. Machine learning techniques, such as deep learning and neural networks, excel at identifying patterns and relationships within such complex datasets (Zhao *et al*., 2024). Apart from mineral potential mapping, these technologies can also be employed to advantage in the prediction of natural hazards and environmental trends (Zhao *et al*., 2024). Last but not least, big data analytics can elevate the role of geoscience in addressing pressing global challenges (e. g. climate change) by integrating and evaluating data from a large variety of sources.

GSN manages and provides extensive geoscientific datasets, including geological, geophysical and geochemical data, drill hole and mineral deposit records, as well as a large variety of remotely sensed imagery. By applying big data analytics to this varied information, economic geologists can identify mineralisation trends, optimise exploration strategies, and improve resource extraction. Indeed, the use of predictive models in mineral exploration has already shown some promise in Namibia's uranium and copper mining sectors, although mineral exploration is by far not the only application for this powerful new tool.

Geoscience Challenges

Data Complexity and Integration

Geological data are inherently complex, consisting of multi-source datasets with varying spatial and temporal resolutions. Integrating historical geological maps with modern digital datasets remains a challenge not only at GSN. To address this, standardised data processing routines that merge old geological records with modern geodatabases have been developed and successfully applied, while AI-driven automated data cleaning methods further enhance the value of the resulting large, diverse datasets.

Ethical and Technological Challenges in AI

While AI-driven tools enhance geological research, they also introduce concerns regarding data privacy, model interpretability and algorithmic bias. AI applications in resource exploration and other fields must be transparent and capable of being reproduced to ensure responsible decision-making (Tucker, 2018). Ethical guidelines, emphasising the need for explainable AI models which provide geologists with clear reasoning behind predictions, are therefore a prerequisite for everyone planning to employ AI applications.

Computational Demands and Infrastructure

Handling large geoscience datasets requires substantial computational power, often exceeding the capabilities of traditional computing infrastructure (Diviacco, 2005). Cloud computing and high-performance computers offer solutions, but they require considerable investment in expertise and resources. This may constitute a major difficulty at present, which could be overcome by collaboration with local and international universities and research institutions. By forming such alliances, GSN could gain access to advanced computing facilities, while building local capacity in AI and data science, and developing a long-term plan to invest in these technologies, which will ensure its remaining at the forefront of geoscience.

Requirements and concerns of AI - Source: https://onlinelibrary.wiley.com/doi/10.1111/exsy.13654

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