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Prospects of Implementing Geospatial Information to Revolutionize Sudan`s Mining Investment

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***Abstract**—In the Sudan, the mining industry sector is considered a cornerstone of the Sudan economy, constantly seeking optimization to remain competitive and sustainable in the investment market. In the context of mining, geospatial information plays a key role in all phases of the mining life cycle, from exploration and surveying to site selection and planning to resource evaluation, mineral extraction and production optimization. Recent advancements in geospatial technologies, such as Geographic Information Systems (GIS), aerial bone photogrammetric and Lidar, and remote sensing satellite imagery, have made it possible to collect, analyze, and visualize geospatial data in competitive ways undiscoverable a few decades ago. These technologies enable mining entities and companies to make informed decisions based on accurate, real-time information, minimizing risks and maximizing benefits and efficiency. Sudan has introduced the implementation of geospatial information technologies and made significant progress in developing and transforming government institutions to enhance their geospatial information product, so that, the development plans and investment opportunities have been focused on achieving national goals in various investment sectors. This paper aims to highlight the path ahead and provide geospatial data and information to create the Sudan investment map to be integrated with the mining sector databases, and to bridge the development gap between the states of Sudan. The paper also, emphasizes that implementing and integrating geospatial data can revolutionize the mining industry by providing valuable insights that benefit the decision-making process throughout the mining business.*

***Keywords**— MIIC, SSA, AI, ML, UNGGIM, GGRF, IGIF, SVMs, GNSS, SNBS.*

I. INTRODUCTION

The Ministry of Investment and International Corporation will activate Geospatial Information for Sudan's Sustainable Investment with the participation of its stakeholders for the preparation and implementation of the Sudan investment map, based on the directives and objectives of the government of Sudan and the Ministry of Investment and International Corporation (MIIC). The Sudan Survey Authority (SSA) has maintained the Sudan base map covering the entire country and developed systems related to geospatial data and information [1, 2]. In recent years, the Ministry of Mining has made a strategic partnership with the Ministry of Investment & International Corporation to activate Mining Geospatial Information for Sudan's Sustainable Investment.

This paper comes within the framework of activating the efforts of the Ministry of Investment & International Corporation to develop investment services through the application of approved geospatial technologies and applications adopted by the Ministry of Investment and the mining industry sector as a priority for the advancement of mining investment operations in Sudan. This type of geospatial work is usually carried out by the Ministry of Investment, through cooperation, which aims to raise the country's geospatial standing in line with the United Nations Global Geospatial Information Management (UNGGIM) Initiative [14]. The SSA will provide the Ministry of Investment & International Corporation and the Ministry of Mining with basic information and The national digital base map of Sudan used as the basis for all spatial data provided by the two ministries and their public and private strategic partners.

Today's geospatial systems require the use of accurate geodetic references and integrated geospatial information frameworks [11, 13] in Sudan. These frames are essential for geospatial data sharing, integration, and data exchange. This will help every Institution in Sudan, including the Ministry of Mining, to expand its capabilities to enhance data collection and management, raise the level of support for geospatial data activities, and provide solutions that enable the effective implementation of mining operations. Contributions from Sudan Federal Departments and state government Spatial Data Infrastructure (SDI) are to be used to define the matrix of technologies, policies [8, 9], and institutional arrangements that will facilitate the availability and access of geospatial data at all levels of government, the private sector, and academic organizations.

Geospatial/ spatial Data in Mining is a data technique used to extract information from the data that belongs to a particular mining location. Geospatial data contains information about the boundaries, location, area characteristics, topography, environments, population, etc. This information can be extracted from geographic coordinates, satellite imagery data, line maps, GNSS coordinates, etc. For example, by considering the context of the geographical locations in the analysis, geospatial data mining allows for better investigation, exploration, and decision-making in the areas related to urban planning, transportation, public health, environmental management, and production.

In the meantime, the mining industry sector is considered a cornerstone of the Sudan economy, and currently, has cartridges with six types of metals including Gold, Iron, copper, fluorite, Black Sand Stone, agricultural metals, and other minerals. The Ministry of Mining constantly seeks optimization to remain competitive and sustainable in the

Sudan investment market. A critical part of this optimization accurately understands and managing the vast complexities involved in mineral concession areas, exploration, extraction, processing, and production. In the context of mining, geospatial data plays a key role in all stages of mining, from exploration and survey to site selection and planning to resource evaluation, mineral extraction and production optimization. It also has vital applications in geotechnical and environmental monitoring, ensuring mining operations completely with environmental regulations, and maintains sustainability and community development.

Recent advancements in geospatial technologies, such as Geographic Information Systems (GIS), aerial bone photogrammetric and Lidar, and remote sensing satellite imagery, have made it possible to collect, analyze, and visualize geospatial data in competitive ways undiscoverable a few decades ago. These technologies enable mining entities and companies to make informed decisions based on accurate, real-time information, minimizing risks and maximizing benefits and efficiency. Geospatial information is a treasure map of mining operations to detect anomalies, predict trends, and optimize processes to increase profitability and reduce environmental impact, strategically, leading to Sudan's sustainable future mining.

In mining, geospatial data is extremely important because it provides critical information about the geographic distribution, characteristics, topography and other environmental characteristics of mineral deposits. By leveraging this data, mining companies can make informed decisions about where to explore, where to dig, and how to manage their operations most efficiently and sustainably. Thus, Geospatial data can come from variety of sources, including Satellite Imagery, Aerial photogrammetric, Drone or Unmanned Aerial Vehicles (UAV) imagery, Traditional ground surveys, mobile Lidar scanning, and GIS technology.

Geospatial data, with its accurate capturing of the Earth's features and spatial relationships, provides the information needed to optimize every stage of the mining process, from planning and exploration to extraction, which can be considered the foundation on which successful, sustainable mining operations are built. Mining challenges and opportunities; continually evolve in response to global trends, economic factors, regulatory changes, societal demands, and technological advancements. Understanding these dynamics is crucial for mining companies to survive in an ever-changing environment and address their significant challenges. In addition to these operational challenges, geotechnical and environmental monitoring are vital for mining companies that face mounting pressure to minimize the environmental impact, and effectively adhere to increasingly stringent regulatory standards.

II. Geospatial Data and Optimization of Mining Processes

Mine surveying can be defined as a branch of surveying science, related to linear measurements, measuring dimensions, determining coordinates, and preparing mine maps and plans. It is also considered an essential part of mining science and technology and includes all measurements, mathematical work, and preparing mine maps. Geospatial data is used as basic data in all stages of mining, starting from the exploration stage and ending with the production stage [6, 9].

The Ministry of Mining is considered the primary source of information and data regarding mine operations and a source for providing data for other fields related to mining science, such as geology and geophysics. The mine Survey documents illustrate the mining work, through which; it is possible to develop work plans for all stages and identify the quantity of metal, reserves, layers, and locations of the metal. It also helps to manage and plan sites and their relationship with the environment surrounding the mine. Thus, measuring and recording area data in the mine is considered a basis for planning and controlling the mine work, and ensuring the economics, feasibility, and safety of operating the mine. Mine survey work is essential in all stages of mine development, as the success and development of mining work depend on it.

The mine survey aims to achieve many goals and tasks, including:

1. Representation of mine works in the form of plans, sections, maps, and geospatial information. This is done through drawings that show the geometric distribution of mineral properties and their locations, the topography of the surface above the mineral layers, and buildings and structures on the surface.
2. Mine studies, planning, exploration, implementation, and production.
3. Solving the various problems resulting from the mine exploration, construction, and mining works.
4. Study the movement of layers and surfaces resulting from mining work otherwise, by estimating the amount and type of movements, find the means to protect the mine and its facilities.

Mine survey work covers all stages of mine development, starting from the exploration and construction stages, and ending with the mining production stage. During the exploration phase, future locations for well drilling are determined. Trenches and tables, test pits, and boreholes were placed in the exploration plan. The exploration plan surveying will be carried out before, during, and after the progress of excavation, where data is represented in charts, sections, or maps. It is prepared by the surveying engineer in cooperation with the mining geologist. These drawings show the type and quantity of materials that show the presence of the mineral, the nature of the layers, and the geometric distribution of the mineral's properties. They are also used for calculating the quantity and reserve of the minerals. In the construction phase, all engineering elements of the required facilities and related works, review of construction progress, surveying and drawing of the site map, and longitudinal and transverse sectors. The mine surveying work and the responsibility of the surveying engineer are as follows:

(a) Planning all engineering elements of the construction and works plan.
(b) Monitoring the planned elements during the implementation of surface constructions.
(c) Underground mine development.

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(d) Preparing, maintaining, and circulating survey plans and operating plans.

Surveying work is conducted during the mining stage, whether underground or open cast mines, to obtain data that helps in mining work and other information that explains the elements of the presence and condition of the mineral. The mine surveying engineer will participate in solving, many engineering problems that arise during mining work, as he carries out regular audit work to ensure the accuracy of the implementation of the mine and excavation works. Mining survey work helps in studying the movement of layers, estimating deviations, and identifying deformations, in addition to helping in setting outlines of indicators for preventive works to protect facilities from the effects of mining work. Mine survey work is regulated in many countries by issuing special laws and regulations that help in successful mining and exploration work. In Sudan, a mining survey executive regulation will be issued as part of the Sudan Survey Act that regulates all types of surveying works in Sudan [11]. The responsibility of the surveying engineer in the mining stage is as follows:

- Carrying out survey work and preparing maps to supply the mine with the necessary information on the ground's topography, underground survey work, and assistance in solving all engineering problems resulting from the effects of mining and other related works.
- Maintaining data and records of operating or existing mining wells Mineral reserves and losses were developed and estimated through mining operations.
- Planning lines and paths that show the boundaries of proper mining locations and monitoring the violations that may occur from time to time.
- Planning all planned works of mining works and construction. Supervising the mine work with specified slopes and directions according to approved maps and plans.
- Surveying supervision of mineral exploration and avoiding its loss during Mining works.
- Study and monitor the movement of the mine, the layers, and the surface to help develop means and establish procedures for protecting facilities, ensuring their implementation, and avoiding negative natural phenomena resulting from the effects of mining.
- Maintaining investigation records of mining output and quantity of work related to it.
- Participate in the preparation and follow-up of short, real-time, and long-lasting plans.
- Participation in the committees that approve or approve new mines to rebuild and develop the mine or close it.

The most important areas of mine surveying are as follows [3, 10]:

(a) Geodetic surveying: Concerned with the essential structure of the mine's work, by providing accurate information about the reference systems, coordinates of control points, and other necessary points on the horizontal and vertical levels, baselines, and determining heights and directions. It is also concerned with establishing geodetic networks and establishing precise reference points to which all other mine works are linked. Mine survey work at all stages requires geodetic work and measurements, especially those requiring high accuracy, as in studying ground movements and deviations in the mine or its facilities.

(b) Plane surveying: It is used in most stages of Mine surveying. It links planar area measurements to geodetic networks and control points and includes surveying work in which, the ground surface is usually considered flat.

(c)Photogrammetric: Aerial photography, UAVs, and airborne Lidar are considered as a means of obtaining geospatial information about natural and industrial targets and landmarks, which are carried out through measurements from aerial photographs using indirect methods. Photogrammetric is concerned with obtaining information about natural and industrial targets and landmarks by making measurements from aerial photographs in indirect ways. Aerial photogrammetric requires processes of, planning, collecting data about the photography site, carrying out aerial photography, and image processing. Ultimately, it is also used for producing topographical and thematic maps, as well as, obtaining ground coordinates, dimensions, and camera coordinates at the moment of filming, and using that in mine work for interpreting and processing aerial images, to obtain coordinates and topographical details and linear maps.

(d)Remote Sensing: Remote sensing is a means of obtaining information about natural and industrial targets and landmarks by making measurements and preparing maps from satellite images. Remote sensing is considered one of the most important sciences that has enabled the study of the Earth's natural resources, including minerals, in a broad and precise manner. Remote sensing can also be used in continuous, periodic monitoring and observation of the Earth's environment and the mine area.

(e) Global Navigation Satellite Systems positioning mine Surveying: There arean unlimited number of global location system applications in mine surveying and mining work, which can be summarized in the following applications:

Ground applications for surveying and mapping work: including surveying data and information that can be used in the following surveying works: -

(i) Obtaining the coordinates of mine control points and mining areas.
(ii) Detailed surveying and engineering surveying work by specifying coordinates, dimensions, and directions.
(iii) Geodetic control works and establishment of geodetic networks.
(iv) Monitoring of local and continental movements.
(v) Determination of locations of wells and key points in the mine.
(vi) Applications in transportation: movement monitoring work by specifying coordinates and real-time transmission and reception of data and measurements such as coordinates, distances, and directions.
(vii) The Global Position System is useful in mining work, which takes place under deep water bodies, as is the case of sea mining and marine geodesy works.

(viii) Marine geodesy, oil sites, and marine gravity positioning.

2.1 Sources of geospatial data in mining

Mining geospatial data, with its diverse sources and types, forms the cornerstone of mining operations. Accurately capturing ground features and spatial relationships provides the information needed to optimize every stage of the mining process, starting with Planning, exploration, extraction, and production. Therefore, geospatial information for mining is the foundation on which successful and sustainable mining operations will be built. There are many sources of mining geospatial data and information, and these sources may include but are not limited to: -

(a) Satellite images: Satellites orbiting the Earth constantly capture images that provide a wealth of geospatial data. These images can reveal differences in the composition and structure of the Earth's surface, indicating the presence of mineral deposits. Satellite images can cover large areas and are particularly useful for preliminary exploration and large-scale environmental monitoring.

(b) Aerial photographs: Aerial photographs taken from aircraft can provide high-resolution geospatial data. These images are often used in later stages of exploration when a more detailed view of the potential mining area is needed. They can also be of great value in planning mining operations and monitoring their environmental impacts.

(c) Drone imagery: Drones, or unmanned aerial vehicles (UAVs), can capture extremely high-resolution images that are ideal for detailed site inspections and close monitoring of mining activities. It can fly at low altitudes and reach areas that are difficult or dangerous for humans to reach, making it a valuable tool in mining.

(d) Ground Surveys: Traditional geophysical and geomatic ground surveys, including terrain, geophysical and geological surveys and soil sampling, provide localized and highly detailed geospatial data. They are often used with remote sensing data to validate results and gain a more comprehensive understanding of the site.

(e) GIS is a technology that manages, analyzes and visualizes geospatial data. The data stored in a GIS can come from various sources, including those mentioned above, and can be used to create detailed maps and models of the mining area.

Geospatial data types for mining can be divided into multiple categories based on their properties and representation. Different types of data are used in geospatial data mining. This data includes geospatial mining point data, linear, polygon, raster, and image data, which can be defined as follows: -

(i) Point data: Point data represents a single location or a group of locations on a map or geospatial layer. Each point is identified by geographic coordinates (latitude and longitude) or UTM projection coordinates in the form of, easting's E and northing's, N locations in geographic space. Point data is commonly used to represent geographic features such as cities, landmarks, or specific points of interest such as mining features.

(ii) Line data: Line data contains a series of points in the form, of lines or curves. It is used, to represent linear entities, such as rivers, pipelines, and roads on a map or geospatial layer.

(iii) Polygon Data: Polygon data consists of regions in space that represents closed shapes, a region on the map, or a geospatial layer. Each polygon is defined by a set of vertices that join to form a closed boundary. Polygon data are commonly used to represent administrative boundaries, concession areas, land use, pass zones, plots of land, lakes or forests, and reservoirs.

(iv) Raster Data: Raster data refers to space as a grid of pixels, where each cell in the grid represents some feature. It is used to represent phenomena such as remote sensing images etc.

(v) Image Data: Image data, as the name suggests, consists of spatial data in the form of images. It is often used for object detection, capturing visual information about the Earth, land cover classification, etc.

Geospatial mining data is usually an interactive process of determining what data will be used in mines and what technologies will be used to obtain meaningful results. Once the mining process for a particular application is completed, automation can be implemented via geospatial processing in a reasonable pattern. On the one hand, it can be useful to consider each stage of the mining process – from exploratory analysis through the processing pipeline—providing the infrastructure and supporting tools to move applications from exploration to production. On the other hand, automating some parts of geospatial data in the mining process can be very useful in improving the accessibility and usability of geospatial information. For a given application, many common, processes can be automated based on database specifications, loading data into databases, linking the database to analysis/mining packages, some recursive queries and statistical analysis, and sending data or results back to databases or to investment visualization packages.

Before dealing with geospatial data applications in mining, it is necessary to understand what it is and where it comes from. At its simplest, geospatial data, also known as spatial data or geographic information, refers to data associated with a specific mining location on the Earth's surface. This data can be either vector (points, lines, and polygons) or raster (grid cells), and represents physical locations and features, as well as their relationships and spatial attributes.

(a) In mining, geospatial data is of utmost importance, it provides critical insights into the geographical distribution of mineral deposits, their characteristics, topography, and other environmental features. By leveraging this data, mining companies can make informed decisions about where to mine, where to explore, where to drill, and how to manage their operations more efficiently and sustainably. Geospatial data mining is essential to today's mining industry, as it has a wide range of applications and all stages of mining inclusive: -

(b) Exploration and Mining Surveys Geospatial data is like a treasure map that points the way to potential mineral deposits. Advanced geospatial technologies, such as satellite images and drones, allow detailed data to be collected on a large scale, revealing the Earth's secrets. Innovative techniques such as spectroscopy can help identify potential targets by identifying

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anomalies or specific mineral properties. Furthermore, geospatial data can aid risk assessment by providing insight into factors, such as terrain difficulty and environmental sensitivities.

(c) Site selection and planning: Geospatial data can transform the site selection and planning process. Providing detailed information on time about the geographical and geological characteristics of potential mining sites, allows decisions to be made effectively. Geospatial data can help assess potential environmental impacts, and help companies mitigate risks before become problems. Geospatial data also increases safety and reduces costs by enabling accurate planning of mining operations and infrastructure.

(d) Predictive Modeling and Resource Estimation: Using geospatial data, mining companies can create predictive models to guide exploration and improve resource estimation. Technologies such as geostatistical analysis and machine learning algorithms can analyze patterns in geospatial data, predict where mineral deposits are likely to be located and estimate their size and value. This can significantly reduce the risks and costs associated with exploration and increase the chances of successful mining.

(e) Extraction and production: Once mining begins, geospatial data continues to play a vital role. It provides important insights that can improve mineral extraction, such as the most efficient paths for drilling or blasting. *Real-time monitoring* of production processes using geospatial data *can improve efficiency, productivity, and resource allocation*, which leads to increased profitability.

(f) Geotechnical monitoring is essential to maintain stability and mine safety in the workforce. Geospatial technologies such as LiDAR and radar can monitor mine slope stability and ground movement, providing real-time alerts appropriate regarding potential risks. This enables mining companies to take preventive measures and mitigate risks before they materialize.

For environmental monitoring and compliance, geospatial data is considered crucial, in monitoring the environmental impact of mining operations and ensuring compliance with regulatory requirements. It can track changes in the local ecosystem, and assess, the impact of mining activities can be mitigated and reduced with the help of geospatial data. This not only aids mining companies in complying with regulations but also contributes to sustainable mining practices that balance mineral extraction with environmental stewardship. Geospatial data will continue to play a fundamental role in shaping the mining industry. Advances in geospatial technologies and their integration with other emerging technologies, such as satellite imagery, digital aerial surveying, drones, airborne and mobile lidars, artificial intelligence (AI), and machine learning (ML), are creating in the future, mining operations will be safer, more efficient, and sustainable. The integration of geospatial technologies, such as high-resolution satellite imaging, hyper spectral imaging, and advanced drone technology, promises detailed insights into the Earth's interior. These techniques can detect subtle variations in the Earth's surface and provide more accurate data for exploration, prospecting, monitoring, and control in mines. Moreover, integrating geospatial data with artificial intelligence, machine learning, and Internet of Things (IoT) technologies opens new possibilities in mining optimization. AI can analyze vast amounts of geospatial data, identify patterns, and make predictions that may be beyond the reach of human analysis. This could be valuable for resource estimation, predictive modeling, and risk assessment in mining operations. Similarly, IoT devices, such as sensors installed on mining equipment or throughout a mining site, can instantly generate geospatial data about various operational aspects. This data can be used to monitor and improve production processes, enhance safety, and reduce environmental impact. In the future, fully autonomous mining operations can be seen, guided by real-time geospatial data or advanced visualization techniques that enable miners to visualize underground deposits and geological structures in three dimensions. Advanced environmental monitoring systems that use geospatial information to predict and mitigate environmental impacts before they occur.

2.2 The role of geospatial data in improving mining operations

Today, the mining industry is the cornerstone of the Sudan government economy, and the Ministry of Mining is constantly striving to improve mining to remain competitive and sustainable in a rapidly developing world. An important part of this improvement is the ability to accurately understand and manage the enormous complexities involved in prospecting, extracting, and processing minerals. Here, the geospatial information can represent the basic foundation, which will improve the complexities of mining in Sudan today and in the future.

Recent advances in geospatial technologies, with the use of GNSS, Geographic Information Systems (GIS), remote sensing satellite imagery, digital aerial photography and drones, artificial intelligence, and machine learning, have made it possible to collect, analyze, and visualize geospatial data in non-traditional ways. These technologies enable mining companies to make informed decisions based on accurate and timely information required, which reduces mining risks and maximizes efficiency. The power of geospatial data lies in its ability to transform raw, often vast, amounts of information into actionable insights. Through it, mining operations can reveal hidden patterns, detect anomalies, predict trends, and improve operations – all of which contribute to increased profitability and reduced environmental impacts. It is also well known that the mining industry is not static; it is constantly evolving in response to local natural and global trends, economic factors, regulatory changes, requirements and technological advances. Understanding these dynamics is essential for mining companies to thrive in an ever-changing environment and to meet the significant challenges they face. One of the major challenges in mining is the increasingly difficult task of exploration and prospecting. Often, high-quality, easily accessible mineral deposits are becoming more scarce, forcing companies to search in remote and difficult-to-reach places. This not only increases the cost of exploration, but also presents a range of logistical and environmental challenges that need decisions based on geospatial information analysis.

Once viable mineral deposits are found, accurate resource estimation represents another major hurdle. Incorrect estimates can lead to significant financial risks and possible project failure. Furthermore, the actual process of mineral extraction is fraught with operational complexities and risks, requiring careful planning and continuous monitoring to ensure safety and efficiency. In addition to these operational challenges, mining companies also face increasing pressure to reduce their environmental impact and adhere to increasingly stringent regulatory standards. Geotechnical and environmental monitoring is crucial in this regard, but can be resource intensive and difficult to manage effectively. Despite these challenges, the evolving landscape also offers number of opportunities, especially in technology, in which emerging technologies, including geospatial technologies, offer innovative solutions to many of the mining industry's most pressing problems. For example, advanced geospatial technologies, including geographic information systems (GIS), remote sensing, and drone technology, can significantly improve exploration and prospecting by providing detailed real-time information, required above and below the Earth's surface. This can significantly varied from risks associated with exploration and increasing the chances of finding viable mineral deposits. Moreover, these technologies can help estimate resources more accurately, thus mitigating financial risks. They can also improve the planning and execution of mining operations, enhancing productivity and efficiency. Mining geospatial data offers excellent capabilities; it also comes with its own set of challenges. One of the main challenges is the complexity and volume of geospatial data. Spatial data sets can be large and heterogeneous, making them difficult to process and analyze. In addition, mining spatial data often come with inherent uncertainties and errors, which can affect the accuracy of the analysis. Another challenge is the need for specialized skills and experience in mining and geographic information systems. Organizations need professionals who can effectively integrate these two areas and apply appropriate techniques and algorithms. Finally, privacy and ethical concerns also arise when dealing with location-based data. Organizations must ensure that they handle and analyze geospatial data responsibly and securely.

III. Ministry of Investment & International Cooperation and Sudan Mining Industry

The Ministry of Investment in Sudan has outlined its commitment to leveraging the investment map as a framework (Figure 1) to boost investment in the country and develop executive regulations for technical services. This includes aligning with policies approved by the Government of Sudan and stakeholders, such as the Ministry of Mining, to enhance mining investment operations. The Sudanese Survey Authority (SSA) plays a crucial role in partnering with the Ministries of Investment and Mining to integrate cadastral data and geospatial information for activities like mining and investment into a national map framework. As a national leader in geospatial data and geographic information technology, the SSA is responsible for the National Base map and shaping the country's frame of reference. They are working on various initiatives to advance the geospatial landscape in Sudan and support the nation's digital development. Additionally, the SSA acts as the central regulatory body for implementing Geospatial Information Management, focusing on sustainable national development. They advocate for unified global reference frameworks and have established a system for federal and state governments to benefit from the Sudan National Base map System (SNBS). By collaborating with organizations and entities across Sudan, the SSA aims to improve access, sharing, and integration of geospatial information for informed decision-making processes. These efforts align with the United Nations Global Geospatial Information Management (GGIM) initiative, which seeks to improve global access to geospatial data for sustainable development. The initiative focuses on enhancing the use, accessibility, and quality of geospatial data worldwide by promoting best practices, standards, and policies. The United Nations Integrated Geospatial Information Framework (UN-IGIF) and the United Nations Global Geodetic Reference Framework (UN-GGRF) are central components of this initiative, aiming to bridge the geospatial digital divide and ensure global consistency and accuracy in measurements related to Earth's shape and position.

To find investment opportunities in the government sectors, it's important to identify areas with strong demand, potential for import substitution, and significant competitive advantages. This is especially true for expanding exports. The Ministry of Investment is considering the Investment Map approach developed by Harvard University and the Massachusetts Institute of Technology [16]. This approach involves analyzing the connections between manufactured and exported goods and exploring the possibility of shifting towards premium goods manufactured with high levels of local production, this requires a clear and precise scientific methodology tailored to the nature and objectives of the required, investment map, as well as its geographical and sectoral scope.

It's important to fully understand the investment process by examining its components and the surrounding environment. To successfully convert investment ideas into viable projects, it's crucial to have an attractive and cost-effective environment in place. This includes favorable working conditions, essential investment foundations like financing, infrastructure, logistical services, and easy access to production inputs. Furthermore, there should be, both local and external demand to ensure profitability for the projects outlined in the investment plan, analyzing value chains and supply chains to develop integrated industrial clusters forms the basis for examining potential sectors.

IV. Sudan national base and investment maps

The Sudan Survey Authority (SSA) offers effective solutions for collecting, editing, storing, and delivering geospatial data and information. Implementing an improved information management system will significantly enhance support for SSA activities and the Sudan geospatial

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community. The Sudan National Base Map System (SNBS) will ensure the delivery of the geospatial information management system at an acceptable level of confidentiality, availability, and performance. This will contribute to the effective management of geospatial information by maintaining acceptable levels of quality control procedures, confidentiality, secure service, and performance [1, 2, 5].

Figure 1: Base map interactions between the Sudan Survey Authority and the Clients

The investment map (Figure 2) is a document that outlines potential investment opportunities and serves as a comprehensive guide, providing investors with the necessary geographical, legislative, and procedural information to make informed investment decisions. It covers investment opportunities at both federal and state levels in Sudan and is an essential tool for highlighting specific projects. To create an effective investment map, collaboration between the Ministry of Investment and strategic partners such as the Ministry of Mining is essential. The geospatial information's development involves the collection, organization, and management of geospatial data and a clear process has been identified to determine its geographical scope, framework, objectives, and strategic plans.

The methodology for preparing the Sudan investment maps used in Sudan is based on several sequential and interconnected stages. It relies primarily on identifying the missing links in industrial clusters, value chains, and productive supply chains within the developing economies of Sudan. These missing links and activities directly impact investment and require comprehensive analysis [16].

Preparing investment maps involves gathering primary and secondary data, complete and partial, and requires cooperation from all relevant governmental and non-governmental agencies. The process begins with studying the economic and social reality in all its dimensions, identifying strengths, weaknesses, and development challenges. This is based on a deep analysis of reality and input from stakeholders in the public and private sectors.

After studying the economic and social reality and identifying the leading and promising productive sectors in Sudan, a clear picture can be formed about the natural, financial, and human economic capabilities and components. This helps determine competitive advantages, market-related factors, and prevailing consumption and productivity patterns.

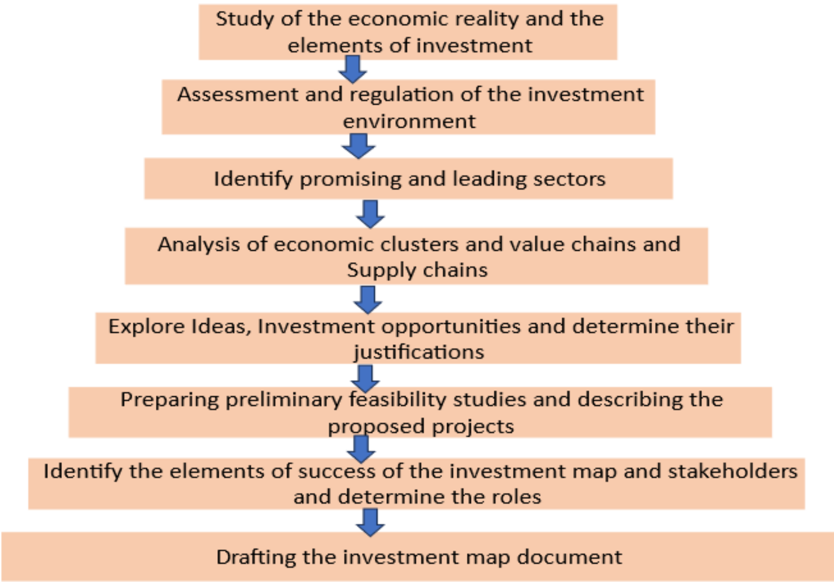

Figure 2: Stages of preparing investment opportunity maps

V. GEOSPATIAL INFORMATION AND DATABASE MINING

The Sudan Survey Authority provides crucial geospatial data and information that is essential for the sustainability of investment, mapping, and mining databases in Sudan. This data serves as the reference system for geospatial information. In recent years, a cooperation and partnership agreement were reached between the Ministry of Investment, the Ministry of Mining, and the Sudan Survey Authority to enhance the role of geospatial information systems in supporting investment sustainability in Sudan. The goal is to build a national framework for geospatial information, collect and process investment data, create integrated investment databases, and establish mechanisms to update investment data and information for relevant ministries and their partners in the public and private sectors.

The current challenge that faced by mining databases, is the integration of geospatial datasets from multiple sources, each with different formats, semantics, resolutions, and coordinate systems. Mining data aims to extract previously unknown, useful information, patterns, and trends from the data. This involves various disciplines such as geological and geophysical information, machine learning, statistics, high-performance computing, and information retrieval.

This research focuses on activating geospatial information in the mining industry by integrating Sudan's base map and investment map with the current and future geospatial mining data and by-product transactional updates. The geospatial data needed for creating a mining database and mining geospatial system are outlined in Table 1.

Geospatial data analysis is used in mining to process relevant mining information and data. The featured category contains information about geology and geophysics in Sudan, represented in the form of polygons indicating areas with mineral deposits.

TABLE 1: Shows a sample list of integrated mining geospatial data required

Source	Common geospatial data layers and attributes	Responsible party
Sudan basic map data	• base map system, • International and national administrative borders; • Geodetic reference systems, control networks, and local and global geodetic models. • Terrain, DTM, Contours, • Raster images and aerial photography. • Water sources, rivers, drainage patterns, hydraulic structures, • Natural and artificial monuments, settlements, transport highways, railways and tracks. • Land use, land cover, agricultural area, vegetation, forests, • Telecommunications coverage, etc.	Sudanese Survey Authority
Spatial data for countries	• Land surveying, property planning and maps, • Land use, cities, farms, settlements, • Population, education and health facilities • facilities services,	Governments of countries
Geospatial data mining	• Mining concession areas • Geological information, geological forms and structures, • Geological layers, faults, geological rocks, soil • Geophysical data: absolute and relative gravity, seismic, magnetic, • Earthquake information, gravity anomaly maps, • Space gravity data and global geopotential models. • Open mine data • Underground mine data • Hydrogeology and groundwater	Ministry of Mining and Sudanese Geological Research Authority

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These polygons represent permitted spaces for mining companies, either as the areal extent or surface projection of rocks where undiscovered mineral deposits may exist. The dataset is created by the Ministry of Mining, in cooperation with the Sudan Geological Survey (GRAS), the Ministry of Oil and Gas, and mining companies. Extraction technologies used for mining geospatial data include artificial intelligence and machine learning. These technologies allow geospatial analysts to gain insights into various fields, including mining works and services, environmental monitoring, urban planning, public health, and transportation. As a result, various applications have been developed, such as traffic forecasting, land use classification, and predictive modeling of natural disasters. Analyzing geospatial mining data enables decision-makers to make more effective and constructive decisions. Some spatial data mining techniques and methods include:

(a) Data collection techniques: This refers to the technology used to gather and organize data points based on their similarities, and is commonly used in spatial data mining to group similar geographical areas based on their characteristics.

(b) Classification techniques: This involves categorizing data points based on their attributes, and is used in mining spatial data to classify geographic areas based on factors such as land use and soil type.

(c) Association rule mining: This technique is used to discover relationships between variables in a dataset. It can be applied in spatial data mining to identify correlations between different geographical variables, such as land use and environmental factors.

(d) Outlier detection: This is the process of identifying data points that significantly differ from the rest of the data. In geospatial data mining, it can be used to detect abnormalities in geographical areas based on their environmental, social, or economic characteristics.

(e) Spatial regression: This technique models the relationship between a dependent variable and one or more independent variables, considering the spatial autocorrelation of the data. It is used in geospatial data mining to model the relationships between different geographical variables.

(f) Decision tree: A type of machine learning algorithm that is used to classify geographic areas based on their attributes. It can be applied in mining to determine the most important factors affecting land use, environmental factors, and other geographical variables.

(g) Machine learning is a subset of artificial intelligence that involves using algorithms to learn from data and make predictions or decisions. In mining, there are various types of machine-learning techniques, such as: -

(i) Supervised Learning: The goal of supervised learning is to learn a function (Y) that can predict the target variable accurately for new, unlabeled data. It is a type of machine learning algorithm that involves training a model on a labeled dataset with a known outcome or target variable for each data point. Examples of supervised learning algorithms include linear regression, logistic regression, decision trees, random forests, and support vector machines (SVMs).

(ii) Unsupervised Learning: Unsupervised learning seeks to discover patterns and structures in data. It is a type of machine-learning algorithm that involves training a model on an unlabeled dataset without a specific target. Examples of unsupervised learning algorithms are principal component analysis (PCA) and outlier detection.

(iii) Reinforcement Learning: In robotics, gaming AI, and control systems, reinforcement learning is frequently used. It is a type of machine learning algorithm where an agent learns to make decisions in an environment through trial and error. The agent is rewarded or punished for each action it takes, to increase the total reward over time.

(g) Interpretation and evaluation: The results of machine learning analysis must be interpreted and visualized before they can be communicated to stakeholders. Interpretation entails identifying the most important data features and patterns, while visualization entails the use of techniques such as heat maps, scatter plots, and interactive maps.

VI. GEOSPATIAL INFORMATION SYSTEM FOR MINING

Mining geospatial information systems (GIS) help describe objects, events, or features at or near the surface of a mine site. Geospatial data combines location information (coordinates) and attribute information (characteristics of an object, event, or phenomenon) and temporal information (the time or lifetime during which the location and attributes exist).

Geospatial data can be collected, shared, and analyzed. Given the volume of geospatial data, its organizations routinely require, many mining stakeholders have to look to geospatial services for data exchange, sharing, and integration. Data quality must always be maintained, regardless of the source of the geospatial data, as poor data leads to models of little or limited use. Aggregated or shared geospatial data should be analyzed and used to create data visualizations, including maps, graphs, and statistics, to display historical changes and current transformations.

The geospatial Investment map relates specifically to the physical mapping of mining data within a visual representation overlaid with other layers showing potential areas of mining activities, and helping with the analysis, administration, and modeling of mining data. Using geospatial data for mining provides many benefits to mining enterprises, including:

- Better understanding of customers' preferences, behaviors, and associated characteristics, enabling the development of business exploration, production, targeted marketing, and improved customer engagement.
- Improved operations through the identification of patterns and trends in the mining industry, leading to more efficient routing, reduced costs, and improved resource allocation.
- Making data-driven decisions based on geographic context, allowing for risk mitigation, identifying opportunities, and planning for future growth. This requires institutions to promote collaboration between mining data and other geospatial databases to leverage the required information

and ensure an acceptable approach to implementing mining activities.

VII. Conclusion

Sudan has introduced the implementation of geospatial information technologies and made significant progress in developing and transforming government institutions to enhance their geospatial information productivity and to be linked with investment efficiency in all government sectors. Development plans and investment opportunities have been focused on achieving national goals in various investment sectors through, the application of performance indicators, follow-up, and adjustments based on changing priorities.

This paper aims to highlight the path ahead and provide geospatial data and information to create the Sudan investment map to be integrated with the mining sector databases, including mining companies of various sizes, and to bridge the development gap between the states of Sudan. The paper also, emphasizes that implementing and integrating geospatial data can revolutionize the mining industry by providing valuable insights that benefit the decision-making process throughout the mining business, from exploration and prospecting to extraction and production.

Fundamentally, geospatial information can improve efficiency, safety, and quality. Mining data integration, especially with modern technologies like artificial intelligence and machine learning. These, are increasingly being used in the mining industry, leading to a promotable future in which mining operations are further improved. This integration leads to safer, more efficient, and sustainable mining, in which, geospatial data and information play a crucial role in the field of mining exploration, help in identifying potential mineral deposits, aid in site selection and planning, enable predictive modeling and resource estimation, facilitate extraction and production of metals, and assist in risk management, and environmental monitoring.

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