Journal of Energy and Natural Resources
2026, Vol. 15, No. 1, pp. 17–25
https://doi.org/10.11648/j.jenr.20261501.13

Review Article

Industrial Potential and Geochemical Characterization of Diatomite Resources in the Ethiopian Rift Area: Value Addition and Strategic Economic Applications

Wakjira Tesfaye[1, 2, *], Megersa Bedo[1], Ljalem Yirga[1], Mitiku Tamene[1]

[1]Fertilizer and Chemical Input Research Department, Mineral Industry Development Institute, Addis Ababa, Ethiopia
[2]Center of Ethio-mines, Addis Ababa Institute of Technology, Addis Ababa, Ethiopia

Abstract

The Ethiopian Rift System, a segment of the broader East African Rift, serves as a significant repository for industrial minerals, among which diatomite stands out as a resource of high economic potential. This comprehensive review examines the geological occurrence, geochemical and mineralogical profiles, and industrial utility of Ethiopian diatomite, primarily concentrated in the Main Ethiopian Rift and the Afar Depression. With estimated reserves exceeding 46.53×10^6 metric tons, the deposits are characterized by high amorphous silica content, ranging from 76.4% to over 86% in their raw state, and reaching upwards of 96% through thermochemical purification. Mineralogical investigations identify Opal-A as the primary silica phase, with a diverse assemblage of benthic freshwater diatom species, including Staurosirella pinnata and Staurosira construens. The material exhibits exceptional physical properties, such as low bulk density (0.32–0.42 g/cm³) and high porosity (up to 85.6%), rendering it suitable for traditional applications in filtration, insulation, and as a lightweight filler. Furthermore, this review highlights transformative value-addition opportunities in advanced manufacturing, including 3D concrete printing for carbon sequestration and geopolymer foams for thermal energy storage. Strategic alignment with Ethiopia's 10-year development plan (2021–2030) suggests that local processing and import substitution could save significant foreign currency and catalyze regional industrial growth. However, the location of these deposits within sensitive lacustrine ecosystems, such as the Abiyata-Shala Lakes National Park, necessitates a balanced approach to development that integrates rigorous environmental impact assessments and sustainable mining practices.

Keywords

Diatomite, Main Ethiopian Rift, Geochemical Characterization, Value Addition, Industrial Minerals, Import Substitution, Sustainable Mining

1. Introduction

The development of industrial minerals is a critical driver for the structural transformation of developing economies. In Ethiopia, the mining sector has historically focused on precious metals, yet the vast potential of industrial minerals like

*Correspondence: Wakjira Tesfaye (watasfaye@gmail.com)

Received: 5 January 2026; **Accepted:** 22 January 2026; **Published:** 6 February 2026

diatomite remains largely underutilized. [1] Diatomite, a naturally occurring siliceous sedimentary rock, is composed of the fossilized skeletal remains of diatoms microscopic, single-celled aquatic algae. These frustules are primarily composed of amorphous silica ($SiO_2 \cdot nH_2O$), giving the material a unique suite of physical and chemical properties, including high surface area, exceptional porosity, chemical inertness, and low thermal conductivity [2].

The Ethiopian Rift System provides an optimal geological environment for the formation of massive diatomite deposits. The combination of intense Cenozoic volcanism and the presence of extensive lacustrine basins have facilitated the accumulation of high-purity diatomaceous earth. Volcanic activity in the rift has provided an abundant supply of dissolved silica through the deposition of ash and the influence of hydrothermal systems, while the closed basins created the stable water bodies necessary for diatom proliferation. Significant deposits have been identified in the Lakes Region of the Main Ethiopian Rift (MER), including Abiyata, Adami-Tulu, Gade Mota, and Chefe Jilla, as well as in the Afar Depression and the northern highlands at Lake Ashenge. Despite possessing an estimated 46.53 million tons of diatomite, of which 310,000 tons are considered high-grade, Ethiopia continues to import processed diatomite to meet the needs of its domestic industries (Ethiopian Ministry of Mines, 2007). The brewery sector, construction industry, and chemical manufacturers are the primary consumers, yet the local milling and refining capacity remains insufficient to meet modern industrial standards. This creates a significant opportunity for import substitution, a key pillar of Ethiopia's current economic reform agenda. [3] The 10-Year Development Plan (2021–2030) targets a rise in the mining sector's contribution to GDP from 2% to 14%, emphasizing the role of industrial minerals in providing raw materials for local manufacturing and enhancing export earnings [4].

Beyond traditional uses, recent scientific advancements have opened new frontiers for diatomite utilization. These include its use in advanced 3D concrete printing to enhance carbon capture, the synthesis of hierarchical geopolymer foams for thermal insulation, and the development of modified adsorbents for the removal of fluoride and heavy metals from water. These value-addition opportunities represent a pathway toward a knowledge-based mineral economy that integrates industrial growth with environmental sustainability [5-7].

1.1. Geological Setting

The formation and distribution of diatomite in Ethiopia are inextricably linked to the tectonic and volcanic evolution of the East African Rift System (EARS). The Main Ethiopian Rift (MER) is the northern segment of the EARS, characterized by a complex history of lithospheric thinning, extensional faulting, and voluminous magmatism that spans from the Oligocene to the Present [8].

1.2. Tectonic Evolution and Basin Formation

The MER developed through a two-stage process that shaped the topography and sedimentary basins of the region. The early phase, occurring from the late Oligocene to the early Miocene, was characterized by the development of alternating and opposed half-grabens. By the late Miocene, these structures evolved into a more symmetrical rift system. The contemporary rift architecture is defined by a series of NE-SW trending marginal faults, which are intersected by the more recent NNE-SSW trending Wonji Fault Belt (WFB). The WFB represents the main spreading axis and is characterized by active faulting and Quaternary volcanism, which has been instrumental in the subsidence of the rift floor by as much as 2 km [9].

This extensional regime created numerous closed basins, many of which were occupied by expansive lakes during the Pleistocene and Holocene. The Ziway-Langano-Abiyata-Shala basin system in the central MER is a prime example of such a lacustrine environment [10]. These lakes were sensitive to both tectonic shifts and climatic forcing, expanding during humid periods to provide vast, stable habitats for diatom communities [11].

1.3. Volcanism and Silica Genesis

Silicic volcanism provided the essential chemical precursor for diatomite formation: dissolved silica. In the MER, volcanic activities ranging from fissure basaltic eruptions to rhyolitic caldera-forming events released significant quantities of volcanic ash and tephra. The weathering of these volcanic materials, alongside input from silica-rich hydrothermal springs, maintained high levels of dissolved orthosilicic acid in the lake waters. Geothermal studies in areas like the Shala and Aluto volcanic complexes indicate the presence of magmatic intrusions at depths below 7 km, which continue to drive hydrothermal activity in the rift floor. This continuous supply of silica, combined with nutrients derived from volcanic runoff, allowed for the rapid growth and accumulation of diatomaceous oozes that eventually lithified into diatomite [12].

1.4. Stratigraphic Context

Diatomite deposits in Ethiopia are typically found within Tertiary and Quaternary sedimentary sequences. They are often interbedded with or overlain by volcanic products, including pumice, unwelded tuffs, and ignimbrites. [3] For instance, in the Lake Abiyata area, the stratigraphy includes lacustrine sediments, pyroclastic ash, and the Bulbula and Shalo lacustrine deposits, which consist of gravel, sand, and mud. [8] In the northern Ethiopian plateau, Lake Ashenge lies in a faulted graben of mid-Tertiary flood basalts, where diatomaceous earth is found in association with lacustrine clays and peat [13].

Table 1. General stratigraphy of the Main Ethiopian Rift and its relation to diatomite formation. [8, 9].

Stratigraphic Unit	Age	Lithology	Relevance to Diatomite
Pre-Rift Sequence	Oligocene-Miocene	Plateau basalts, rhyolites	Source of detrital silica
Syn-Rift Sequence	Late Miocene-Pliocene	Ignimbrites, trachytes	Basin basement, tectonic control
Main-Rift Sequence	Pleistocene-Holocene	Lacustrine sediments, ash	Primary diatomite host
Wonji Fault Belt Units	Quaternary	Fissure basalts, pumice	Hydrothermal silica supply

2. Materials and Methods

The characterization of Ethiopian diatomite resources involves a multi-disciplinary analytical approach designed to evaluate its industrial viability. Research conducted by the Ministry of Mines, the Mineral Industry Development Institute (MIDI), and various academic institutions has established a standard framework for sampling and testing these resources [4].

2.1. Sampling and Preparation

Diatomite samples are typically collected from outcrops, stream sections, and trial pits across major deposit areas like Abiyata and Adami-Tulu. Sampling strategies often follow standard guides such as ASTM D4700-91 to ensure representative data. Once collected, the raw material undergoes physical preparation: Samples are washed to remove soluble impurities and dried at temperatures around 393 K (120°C) to remove moisture. The dried material is ground using alumina ball mills for approximately one hour and sieved through apertures ranging from 45 µm to 63 µm to achieve the desired particle size for analysis [14, 15].

2.2. Analytical Techniques

To determine the geochemical, mineralogical, and structural properties of the diatomite, several advanced techniques are employed: X-Ray Fluorescence (XRF): Used for the quantitative analysis of major element oxides (e.g., SiO_2, Al_2O_3, Fe_2O_3) and trace elements. X-Ray Diffraction (XRD): Critical for identifying the mineral phases, particularly the amorphous nature of the silica (Opal-A) and the presence of crystalline impurities like quartz or feldspar. Scanning Electron Microscopy (SEM): Provides high-resolution photomicrographs to assess the morphology, size, and preservation of diatom frustules, as well as the nature of the pore structure. Granulometry: Laser particle size analyzers are utilized to determine the particle size distribution, which is essential for assessing the material's suitability as a filter aid or filler [14].

2.3. Purification and Modification Methods

Research into value addition has explored specific refining processes: Thermochemical Purification: Raw diatomite is subjected to hot-acid leaching, typically using 6M sulfuric acid (H_2SO_4) at 360–368 K for durations of 24 to 48 hours. This process aims to remove metallic oxides that block the pores. Surface Functionalization: Techniques such as silanization using agents like 3-aminopropyltriethoxysilane (APTS) or n-octyltriethoxysilane (OTS) are applied to introduce hydrophobic or reactive groups to the diatomite surface for wastewater treatment or composite manufacturing [16, 17].

2.4. Geochemical Characterization

The geochemical profile of Ethiopian diatomite is the primary determinant of its industrial quality. Analysis across several deposits reveals a high-purity siliceous material with varying degrees of volcanic and detrital contamination.

2.4.1. Major Oxide Composition

The predominant constituent of Ethiopian diatomite is silica (SiO_2), which typically ranges from 76.4% to over 86% in its raw form (Ethiopian Ministry of Mines, 2007). The silica content is inversely related to the presence of impurities such as alumina (Al_2O_3), iron oxide (Fe_2O_3), and alkaline oxides (Na_2O, K_2O) [3].

Table 2. Geochemical analysis (wt%) of major diatomite deposits in Ethiopia.

Deposit Location	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	CaO	MgO	LOI
Adami Tulu	86.70	3.36	2.20	1.63	0.84	0.14	0.22	3.66
Gada Mota	85.50	3.68	2.40	1.18	0.73	1.11	0.36	3.78

Deposit Location	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	K_2O	CaO	MgO	LOI
Chefe Jilla	84.50	3.14	1.50	1.64	0.78	1.89	0.72	4.68
Abiyata (Avg)	76.40	3.47	1.10	1.52	1.11	0.67	0.10	13.7

Adami Tulu has the highest silica (SiO_2) content at 86.70%, indicating a relatively pure diatomite deposit. Its low levels of other oxides and moderate loss on ignition (LOI) suggest limited clay mineral impurities and organic content. Gada Mota also shows high silica (85.50%) with slightly elevated alumina (Al_2O_3) and iron oxide (Fe_2O_3), hinting at minor clay and iron impurities. Its calcium oxide (CaO) and LOI are moderate, pointing to some carbonate and volatile content. Chefe Jilla features lower silica (84.50%) and the highest calcium oxide (1.89%) and magnesia (MgO) among the first three, suggesting greater carbonate mineral impurities. Its higher LOI also indicates more bound water or organic matter. Abiyata (Avg) stands out with significantly lower silica (76.40%) and a very high LOI (13.7%), strongly implying a substantial content of clay minerals, organic material, or water. This makes it the least pure of the deposits listed.

2.4.2. Comparative Geochemical Properties of Ethiopian vs. Global Diatomite

Table 3. Comparative Geochemical Properties of Ethiopian vs. Global Diatomite.

Region/Deposit	SiO_2 Content (%)	Porosity (%)	Typical Application
Ethiopian Rift (Adami-Tulu)	76.4 – 86.7	70 – 85	High-end filtration, Paint, Pharmaceuticals
USA (California/Nevada)	85.0 – 90.0	75 – 90	Industrial Filter Aids (Global Standard)
China (Jilin Province)	65.0 – 82.0	60 – 80	Construction, Absorbents, Fillers
Denmark (Moler)	70.0 – 75.0	50 – 65	Insulation Bricks, Chemical Carriers

The strategic imperative for domestic processing is underscored by the exceptional geochemical profile of the Ethiopian Rift deposits, which meet or exceed the benchmarks of established global commercial grades. While traditional market leaders like the USA (Celite) and China dominate the high-end filtration sector, geochemical assays of the Adami-Tulu and Abiyata deposits reveal amorphous silica (SiO_2) content reaching up to 86%, coupled with a specific gravity and total porosity that align with premium filter-aid standards. This high SiO_2 purity, characterized by a dominant Opal-A phase, ensures low levels of detrimental impurities like Al_2O_3 and Fe_2O_3, which are often higher in lower-tier global deposits. By leveraging these "world-class" material properties, Ethiopia can transition from a net importer of processed filter media to a competitive regional exporter, directly addressing the trade imbalance identified by the Ethiopian Revenues and Customs Authority [12, 15, 18].

2.4.3. Trace Elements and Impurities

While major oxides define the bulk chemistry, trace constituents like TiO_2 (0.17% - 0.28%), MnO (0.02% - 0.05%), and P_2O_5 (0.34% - 0.62%) are consistently low. The Loss on Ignition (LOI) values, particularly in the Abiyata deposit (13.7% average), are attributed to the presence of structural water, organic matter, and carbonates. High LOI can be problematic for certain high-temperature applications but is typically reduced during calcination processes [14].

2.5. Mineralogical Analysis

XRD data confirms that the amorphous phase, Opal-A, is the primary mineral constituent of Ethiopian. This amorphous state is critical for its reactivity in chemical applications and its high porosity. However, the presence of crystalline phases is common, including: Quartz and Feldspar: The most prevalent crystalline impurities, likely derived from air-fall ash or terrestrial runoff. Clay Minerals: Minor amounts of illite, halloysite, and montmorillonite have been detected in various sections. Zeolites and Others: Traces of mordenite, wairakite, and clinoptilolite suggest localized post-depositional alteration or hydrothermal influence [14, 15].

2.6. Physical and Structural Properties

The industrial value of diatomite is largely dictated by its unique physical structure, which is a direct consequence of its biogenic origin and geochemical purity [3].

Table 4. Technical and physical properties of Ethiopian diatomites.

Physical Parameter	Abiyata	Adami Tulu	Chefe Jilla
Porosity (%)	85.6	73.4	76.7
Bulk Density (g/cm^3)	0.42	0.42	0.32
Shaking Density (g/l)	169	162	163
Jolting Density (g/l)	260	258	268

The material possesses exceptional porosity and low bulk density, making it an ideal candidate for filtration and lightweight insulation. SEM investigations reveal that the diatom frustules in these deposits are well-preserved, exhibiting hierarchical pore structures that include both interconnected mesopores and macropores. Micropaleontological studies identify a dominance of pennate diatom forms elongated and bilaterally symmetrical valves which contribute to the material's high specific surface area.

2.7. Industrial and Economic Applications

The unique properties of Ethiopian diatomite make it a versatile raw material for a wide range of established and emerging industries. Its high silica content and structural integrity are utilized across sectors as diverse as food processing, construction, and environmental engineering. Brewery Applications: Major Ethiopian breweries, including Dashen, BGI Ethiopia, St. George, and Habesha, utilize diatomite for beer filtration. During the clarification process, diatomite removes yeast cells and high-molecular-weight proteins, ensuring the clarity and biological stability of the final product. Waste Management: The byproduct of this process, known as diatomaceous earth sludge (DES) or brewery spent diatomaceous earth (BSDE), presents its own opportunities. Research has shown that DES can be reused as a modifier for asphalt binders, improving the rutting resistance and stiffness of pavements. Diatomite's low thermal conductivity and lightweight nature are highly valued in the construction materials sector.[18] Insulating Bricks and Tiles: It is used in the production of lightweight, heat-resistant bricks and thermal insulation for industrial furnaces and energy-efficient buildings. Cement and Pozzolans: Diatomite acts as a pozzolanic additive in cement and concrete formulations. Replacing a portion of Portland cement with diatomite can improve sulfate resistance and reduce the dry unit weight of the concrete, which is beneficial for high-rise or seismic-resistant structures [19].

Agriculture and Chemical Carriers: The high absorptive capacity of diatomite (up to several times its own weight) makes it an effective carrier for liquid and solid chemicals. Agrochemical Carriers: Diatomite is used as a carrier for pesticides and fertilizers, allowing for a more controlled release of active ingredients and preventing their leaching into groundwater Soil Amendment: In agriculture, diatomite is applied to improve soil structure, increase aeration, and enhance the water-holding capacity of sandy or degraded soils. Trials using brewery-spent diatomite have shown it to be a safe organic fertilizer that can enhance cereal yields such as teff and wheat. Chemical and Industrial Fillers: Due to its inertness, brightness, and high surface area, diatomite is common filler in various manufacturing processes: Paints and Plastics: It serves as a functional filler to control gloss, improve durability, and enhance the mechanical properties of polymers. Abrasives and Polishing: The skeletal remains are hard yet fragile, making diatomite a gentle abrasive used in toothpaste and specialized metal polishes [14, 20].

2.8. Value Addition Opportunities

The transition from exporting raw diatomite to producing high-value engineered products is a strategic imperative for Ethiopia's industrial minerals sector. Recent research has identified several cutting-edge applications that leverage the unique hierarchical structure of diatomite. Advanced 3D Concrete Printing and Carbon Capture.

A transformative application of diatomite has emerged in the field of 3D concrete printing (3DCP). Researchers have developed sustainable concrete mixes that incorporate diatomaceous earth to achieve superior environmental and mechanical performance. Carbon Sequestration: The sponge-like hierarchical porosity of diatomite (ranging from 2 to 100 nm) provides numerous active sites to trap CO_2. When used in 3D-printed Triply Periodic Minimal Surface (TPMS) structures which maximize surface-area-to-volume ratios these mixes can capture 142% more CO_2 than traditional concrete. Structural Integrity: Unlike many porous additives that weaken concrete, the pozzolanic reaction between diatomite silica and calcium hydroxide creates additional calcium silicate hydrate (C-S-H) gel, increasing compressive strength over time (peaking at over 30 MPa). [19] Diatomite is also being utilized as a natural carrier for Phase Change Materials (PCMs) in geopolymer foams for energy-efficient construction. Thermal Efficiency: Encapsulating PCMs like paraffin within the porous structure of diatomite ensures stability and environmental compatibility. These composites can increase the specific heat capacity of building materials by nearly 50%, allowing for effective thermal energy storage and regulation. Sound Absorption: The interconnected pore network of diatomite-loaded foams significantly improves sound absorption properties, making them ideal for high-performance acoustic insulation. 3D Printing Filaments and Polymer Composites In the polymer industry, diatomite is being investigated as a renewable filler for 3D printing filaments, such as those based on polylactic acid (PLA). Cost and Performance: Replacing 10 wt% of PLA with diatomite can reduce filament costs by 5% to 10% with only minor mechanical setbacks. Furthermore, post-processing techniques like cold hydrostatic extrusion can nearly double the compressive strength of these composites by mitigating crack initiation through pore closure. Functional Agents: The high surface area of diatomite protruding from printed objects provides a platform for immobilizing chemical sensors, as well as antibacterial and antiviral agents [21].

Modified diatomite presents a low-cost, eco-friendly solution for Ethiopia's water quality challenges: Fluoride Removal: Diatomite modified with aluminum hydroxide has shown exceptional results in removing fluoride from drinking water in the Rift Valley, reaching removal efficiencies of 89.4%. [22] Heavy Metal Sequestration: Surface functionalization with silane coupling agents (e.g., APTS, KH-570) allows for the creation of composites capable of the time- and cost-efficient removal of heavy metals like lead and cadmium, as well as volatile organic compounds like formaldehyde [23].

2.9. Strategic Economic Applications

Ethiopia's diatomite resources are a central component of its strategy for industrialization and self-reliance. The economic rationale for developing these resources is built upon import substitution, job creation, and export diversification.

Import Substitution and Trade Balance

Despite possessing massive reserves, Ethiopia is a net importer of processed diatomite. Data from the Ethiopian Revenues and Customs Authority highlights a persistent reliance on foreign supply to support domestic industries like brewing and paint manufacturing [3].

Table 5. *Diatomite supply and import trends in Ethiopia (2014–2023).*

Year	Imported Quantity (Tons)	Imported Value (1000 USD)	Domestic Production (Tons)	Total Consumption (Tons)
2014	295	287	4,600	4,895
2016	387	298	5,000	5,387
2018	517	470	5,000	5,517
2020	210	191	5,000	5,210
2022	259	255	5200	5455
2023	58	83	5410	5493

The average annual expenditure on diatomite imports from 2014 to 2023 was approximately 300,700$. Establishing local milling and thermochemical purification facilities would not only save this foreign currency but also insulate domestic industries from global supply chain disruptions and exchange rate volatility.

In alignment with global market dynamics, Ethiopia's current production of approximately 5,400 tons while showing steady growth remains a marginal fraction of a worldwide market projected to reach USD 3.16 billion by 2034. Globally, the industry is dominated by the United States (32%), Denmark (17%), and China (10%), which leverage advanced calcination technologies to meet the 54% of global demand concentrated in the high-grade filtration sector. The discrepancy between Ethiopia's massive high-grade reserves (estimated at over 40 million tons) and its persistent net importer status highlights a strategic opportunity to capture the 5.3% annual global growth rate, particularly as demand surges in Asia-Pacific and North America for sustainable water treatment and eco-friendly construction additives. By transitioning from raw extraction to domestic value-added processing (calcination), Ethiopia can shift from a dependency on foreign supply to becoming a competitive regional supplier, transforming a trade deficit into a strategic industrial advantage [3].

Strategic Development Goals

The mining sector is a priority under Ethiopia's 10-Year Perspective Development Plan (2021–2030) and the Homegrown Economic Reform program. GDP Contribution: The government aims to increase the mining sector's contribution to GDP from the current 2% to 14% by 2030. [24] Export Earnings: Mining is projected to account for 37% of export earnings by 2030. High-grade diatomite from the central rift is seen as a commodity with significant regional export potential to markets like India and the East African Community. [25] Employment: The sector is expected to expand its workforce significantly, providing skilled and semi-skilled employment for millions of citizens. [24] To realize this potential, the Ethiopian government has implemented a series of reforms designed to attract private investment: Legal Protections: The Mining Proclamation No. 678/2010 provides security of tenure and allows for the deduction of exploration and development costs. [26] Financial Incentives: Investors benefit from a competitive income tax rate (35%), a duty-free import regime for capital goods, and lower royalty rates compared to precious metals. Geoscience Data: The Ministry of Mines is focused on generating and disseminating high-quality geological data to reduce exploration risk for potential developers [24].

Environmental and Sustainability Considerations

The exploitation of diatomite resources within the Main Ethiopian Rift (MER) necessitates a robust geodynamic and environmental framework to safeguard the region's unique lacustrine ecosystems. Primary deposits, notably those in the Abiyata and Adami-Tulu sectors, are situated in high-sensitivity zones within or adjacent to the Abiyata-Shala Lakes National Park (ASLNP). Hydrological modeling indicates extreme sensitivity to anthropogenic stressors; industrial water abstraction primarily for soda ash extraction and potential diatomite beneficiation has exacerbated lacustrine regression, with Lake Abiyata's surface area contracting by approximately 50% over the last five decades [8]. This hydrological instability triggers a trophic cascade: fluctuations in salinity and depth threaten the specialized habitats of migratory avifauna, specifically the lesser flamingo (Phoeniconaias minor) and great white pelican (Pelecanus onocrotalus), and have precipitated a collapse in indigenous fisheries. To mitigate these impacts, industrial operations must implement closed-loop water recycling systems to eliminate raw water withdrawal and adopt progressive backfilling during the extraction phase to prevent groundwater contamination and surface runoff. Furthermore, the application of geosynthetic clay liners (GCLs) in processing waste-ponds is essential to prevent the leaching of alkaline effluents into the rift's fragile groundwater system, thereby ensuring that mineral extraction aligns with sustainable hydrogeological management [27].

Regulatory and Policy Landscape: The Ethiopian government has established a comprehensive regulatory framework to manage the environmental impacts of mining: Environmental Impact Assessments (EIA): Under Proclamation No. 299/2002 and the Mining Operations Proclamation, any small- or large-scale project that alters the environment must obtain an approved EIA before receiving a license. [28] Artisanal and Small-Scale Mining (ASM): While ASM is a critical livelihood source; its informal nature often bypasses formal environmental oversight. This has resulted in localized land degradation, deforestation, and the siltation of watercourses. Current policy aims to formalize the ASM sector, providing miners with technical support and "Simple Environmental Information Sheets" to encourage responsible practices [29].

To ensure that diatomite development aligns with the "African Beacon of Prosperity" vision, several sustainable practices are recommended: Selective Surface Mining: Mining operations should minimize the total surface area exposed at any one time to reduce habitat disruption. Progressive Reclamation: Disturbed areas should be reclaimed and revegetated with native species. Diatomaceous earth makes an excellent growing medium, facilitating the restoration of forested or grassland ecosystems within 10 years of site closure. Advanced Pollution Control: Modern processing facilities must implement dust control (e.g., baghouses) and water treatment systems (e.g., siltation ponds) to ensure that emissions and runoff comply with national standards [28].

3. Conclusion

The characterization of diatomite resources in the Ethiopian Rift System reveals a clear paradox: Ethiopia possesses world-class deposits of a versatile industrial mineral, yet it remains a minor player in the global market and a net importer for its own domestic needs. This situation is driven by a lack of integrated industrial infrastructure and the historical prioritization of metallic minerals. From a geochemical perspective, the Ethiopian deposits are of moderate to high quality. The raw SiO_2 content of 84% - 86% in the Lakes Region is highly competitive, and the successful application of hot-acid leaching to reach 96% purity demonstrates that these resources can be upgraded for high-end pharmaceutical and catalyst applications. The dominance of pennate diatom species and the high porosity of the material further confirm its suitability as a premium filter aid.

The potential for value addition is perhaps the most compelling argument for a revitalized diatomite industry. The integration of diatomite into 3D concrete printing not only addresses Ethiopia's infrastructure needs but also positions the country as an innovator in carbon sequestration technology. Furthermore, the reuse of brewery waste as a soil conditioner or asphalt modifier illustrates the potential for circular economy practices that reduce the environmental footprint of existing industries.

However, the strategic expansion of this sector faces significant hurdles. The most immediate challenge is the location of major deposits in ecologically sensitive zones. The ongoing desiccation of Lake Abiyata serves as a stark reminder of the consequences of unsustainable resource extraction. Any future diatomite mining must be governed by a rigorous "Triple Bottom Line" approach balancing economic gain with social welfare and environmental protection This requires not only stricter enforcement of EIA regulations but also the adoption of cleaner, water-efficient processing technologies. Economically, the path forward requires bridging the gap between mining and manufacturing. The 10-Year Development Plan provides the vision, but implementation will depend on attracting foreign direct investment (FDI) and fostering partnerships between academia and the private sector. By simplifying export procedures and incentivizing local value addition, Ethiopia can transform its diatomite from a dormant resource into a strategic economic pillar. This comprehensive review has established that the diatomite resources of the Ethiopian Rift System possess significant industrial potential and geochemical merit. With over 46 million tons of reserves characterized by high silica purity and exceptional physical properties, these deposits are well-suited for a broad range of applications, from traditional beer filtration and thermal insulation to cutting-edge carbon sequestration and geopolymer synthesis.

The strategic importance of these resources lies in their ability to drive Ethiopia's import substitution agenda and contribute to the ambitious 14% GDP target for the mining sector by 2030. However, the successful development of the diatomite industry will require a shift from the extraction of raw materials to the production of high-value, refined industrial products.

To achieve this, it is recommended that the Ethiopian government and industrial stakeholders: Prioritize the establishment of domestic milling and thermochemical purification facilities to meet the quality standards of the brewery and pharmaceutical sectors. Promote the adoption of 3D concrete printing and sustainable building technologies that utilize diatomite to address national infrastructure and climate goals. Implement a rigorous environmental management framework for the Lakes Region that includes progressive reclamation, water conservation, and the formalization of artisanal mining practices. Enhance international collaborations to access the technologies and markets necessary for high-value diatomite exports. By integrating geological abundance with technological innovation and sustainable management, Ethiopia can effectively leverage its diatomite resources to foster long-term industrial growth and environmental stewardship.

Abbreviations

3DCP	3-Dimensional Concrete Printing
DES	Diatomaceous Earth Sludge
BSDE	Brewery Spent Diatomaceous Earth
LOI	Loss on Ignition
SEM	Scanning Electron Microscopy
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
TPMS	Triply Periodic Minimal Surface
PCM	Phase Change Material
GCL	Geosynthetic Clay Liner

Acknowledgments

The authors sincerely thank the Mineral Industry Development Institute of Ethiopia for its institutional support and for providing access to facilities, technical expertise, and research resources that enabled the successful completion of this study, titled Industrial Potential and Geochemical Characterization of Diatomite Resources in the Ethiopian Rift System: Value Addition and Strategic Economic Applications. The professional cooperation and assistance of the institute's staff are gratefully acknowledged.

Author Contributions

Wakjira Tesfaye: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Software, Writing – original draft.

Megersa Bedo: Methodology, Software, Formal analysis, Data Curation.

Ljalem Yirga: Writing – original draft, Investigation, Validation, Visualization.

Mitiku Tamene: Investigation, Writing – original draft, Formal analysis.

Data Availability Statement

The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Martins, P. M. G. (2014). Structural change in Ethiopia: An employment perspective (Policy Research Working Paper No. 6749). World Bank. https://openknowledge.worldbank.org/handle/10986/16915

[2] Morgan, D. J. (2007). Industrial minerals and artisanal mining study (Ethiopia World Bank Energy Access Project): Summary of activities, findings and recommendations of industrial minerals sub-project (Report No. CR/06/181N). British Geological Survey. https://nora.nerc.ac.uk/id/eprint/19660/

[3] Ethiopian Ministry of Mines. (2007). Industrial minerals and rocks of Ethiopia (Draft Report). Addis Ababa, Ethiopia.

[4] Federal Democratic Republic of Ethiopia (FDRE). (2021). Ten-year development plan: A pathway to prosperity (2021–2030). Planning and Development Commission. Addis Ababa, Ethiopia.

[5] Senol, Z. M., & Simşek, S. (2020). Removal of Pb^{2+} ions from aqueous medium by using chitosan-diatomite composite: Equilibrium, kinetic and thermodynamic studies. Journal of the Turkish Chemical Society Section A: Chemistry, 7(1), 307–318. https://doi.org/10.18596/jotcsa.634590

[6] Teng, F., Xu, F., Yang, M., Yu, J., Zhang, D., & Weng, Y. (2025). Development of sustainable strain-hardening cementitious composites containing diatomite for 3D printing. Journal of Building Engineering, 103, 112170. https://doi.org/10.1016/j.jobe.2025.112170

[7] Yu, J., Wang, Y., Xu, F., Zhang, D., & Weng, Y. (2025). 3D concrete printing of triply periodic minimum surfaces for enhanced carbon capture and storage. Advanced Functional Materials, 35(8), 2416026. https://doi.org/10.1002/adfm.202416026

[8] Japan International Cooperation Agency (JICA). (2012). The study on Rift Valley Lakes Basin integrated resources management master plan in the Federal Democratic Republic of Ethiopia. Ministry of Water and Energy.

[9] Benvenuti, M., Bonini, M., Moratti, P., & Sani, F. (2002). The Ziway–Shala lake basin (Main Ethiopian Rift, Ethiopia): A revised stratigraphic, pedological and geomorphological framework. Journal of African Earth Sciences, 35(2), 247–269. https://doi.org/10.1016/S0899-5362(02)00115-6

[10] Le Turdu, C., Tiercelin, J.-J., Gibert, E., Travi, Y., Lezzar, K. E., Richert, J.-P., Massault, M., Gasse, F., Bonnefille, R., Decobert, M., Gensous, B., Jeudy, V., Tamrat, E., Mohammed, M. U., Martens, K., Atnafu, B., Chernet, T., Williamson, D., & Taieb, M. (1999). The Ziway–Shala lake basin system, Main Ethiopian Rift: Influence of volcanism, tectonics, and climatic forcing on basin formation and sedimentation. Palaeogeography, Palaeoclimatology, Palaeoecology, 150(3-4), 135–177. https://doi.org/10.1016/S0031-0182(98)00216-2

[11] Wondmagegn, T., Mengistou, S., & Barker, P. A. (2019). Testing of the applicability of European diatom indices in the tropical rift valley lake, Lake Hawassa, in Ethiopia. African Journal of Aquatic Science, 44(3), 209–217. https://doi.org/10.2989/16085914.2019.1612590

[12] Samrock, F., Grayver, A., Eysteinsson, H., & Saar, M. O. (2018). Magnetotelluric image of trans-crustal magmatic system and hydrothermal reservoir beneath the Tulu Moye geothermal prospect, Main Ethiopian Rift. Journal of Geophysical Research: Solid Earth, 123(3), 2035–2052. https://doi.org/10.1002/2017JB014860

[13] Giday, W., Hart, W. K., Renne, P. R., Sharp, W. D., Shackley, M. S., & Ambrose, S. H. (2019). Geological and geochronological context of the Lake Ashenge area, Northern Ethiopian Plateau.

[14] Kebede, S., Kaneko, F., & Woldai, T. (2019). Geochemical and physical characterization of diatomite deposits in the Main Ethiopian Rift: Implications for industrial applications. Journal of African Earth Sciences, 158, 103551. https://doi.org/10.1016/j.jafrearsci.2019.103551

[15] Kebede, S., Beshah, B., & Liyew, G. G. (2024). Effect of purification and milling parameters on the quality of Ethiopian diatomite for filtration and filler applications. International Journal of Mineral Processing and Extractive Metallurgy, 9(1), 12–28. https://doi.org/10.11648/j.ijmpem.20240901.12

[16] Kebede, H., Gemta, A. B., Kassahun, G. B., Andoshe, D. M., & Tadele, K. (2024). Thermochemical purification and geochemical characterization of Ethiopian rift diatomite for industrial applications. ACS Omega, 9(1), 1047–1060. https://doi.org/10.1021/acsomega.3c07381

[17] Zhang, Y., Zhao, J., Chu, J., Zhou, Y., Wei, Y., & Tian, Z. (2016). Surface functionalization of diatomite with 3-aminopropyltriethoxysilane and n-octyltriethoxysilane for enhanced wastewater treatment and composite manufacturing. Journal of Alloys and Compounds, 688, 1141–1151. https://doi.org/10.1016/j.jallcom.2016.07.267

[18] A. Przybek, M. Łach, M. Hebdowska-Krupa, K. Miernik, and J. Mikuła, "Research of the physical and chemical properties of diatomite as a carrier of phase change materials for use in advanced building materials," Frontiers in Materials, vol. 11, Art. no. 1507779, 2024. https://doi.org/10.3389/fmats.2024.1507779

[19] Li, J., Zhang, W., Li, C., & Monteiro, P. J. M. (2019). Green concrete containing diatomaceous earth and limestone: Workability, mechanical properties, and life-cycle assessment. Journal of Cleaner Production, 223, 672–679. https://doi.org/10.1016/j.jclepro.2019.03.077

[20] Dessalew, G., Beyene, A., Nebiyu, A., & Ruelle, M. L. (2017). Use of industrial diatomite wastes from beer production to improve soil fertility and cereal yields. Journal of Cleaner Production, 157, 22–29. https://doi.org/10.1016/j.jclepro.2017.04.093

[21] Aggarwal, S., Singh, P., & Kumar, A. (2019). Development of diatomaceous earth-filled poly (lactic acid) composites for 3D printing filaments. Journal of Applied Polymer Science, 136(12), 47221. https://doi.org/10.1002/app.47221

[22] Wang, S., He, J., Chen, Z., Jiang, Q., Li, S., & Wang, J. (2020). Aluminum-modified diatomite for fluoride removal from groundwater in the Ethiopian Rift Valley. Journal of Hazardous Materials, 384, 121350. https://doi.org/10.1016/j.jhazmat.2019.121350

[23] Zhang, Y., Zhao, J., & Liu, Z. (2016). Surface functionalization of diatomite with silane coupling agents for heavy metal ion sequestration. Microporous and Mesoporous Materials, 225, 100–108. https://doi.org/10.1016/j.micromeso.2015.12.003

[24] Federal Democratic Republic of Ethiopia (FDRE), "Ethiopia 2030: An African beacon of prosperity: Ten-year perspective development plan (2021–2030)," Planning and Development Commission, Addis Ababa, 2021.

[25] HornReview, "Ethiopia's mining boom: Projections for 2030 and regional export dynamics," The Horn Review, Jan. 2025.

[26] Federal Democratic Republic of Ethiopia (FDRE), "Mining Proclamation No. 678/2010," Negarit Gazeta, Addis Ababa, 2010.

[27] Federal Democratic Republic of Ethiopia (FDRE). (2002). Environmental Impact Assessment Proclamation: Proclamation No. 299/2002. Federal Negarit Gazeta.

[28] De Haan, J., Dales, K., & McQuilken, J. (2020). Mapping artisanal and small-scale mining to the Sustainable Development Goals. University of Delaware; Pact. https://doi.org/10.2139/ssrn.3532756

[29] Engdaw, B. D. (2020). Assessment of the trends of greenhouse gas emission in Ethiopia. Geography, Environment, Sustainability, 13(2), 135–146. https://doi.org/10.24057/2071-9388-2018-61