

The mining sector of Liberia: current practices and environmental challenges

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Received: 14 February 2017 / Accepted: 26 June 2017 / Published online: 18 July 2017
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Abstract Liberia is endowed with an impressive stock of mineral reserves and has traditionally relied on mining, namely iron ore, gold, and diamonds, as a major source of income. The recent growth in the mining sector has the potential to contribute significantly to employment, income generation, and infrastructure development. However, the development of these mineral resources has significant environmental impacts that often go unnoticed. This paper presents an overview of the Liberian mining sector from historical, current development, and economic perspectives. The efforts made by government to address issues of environmental management and sustainable development expressed in national and international frameworks, as well as some of the environmental challenges in the mining sector are analyzed. A case study was conducted on one of the iron ore mines (China Union Bong Mines Investment) to analyze the effects of the water quality on the local water environment. The results show that the analyzed water sample concentrations were all above the WHO and Liberia water standard Class I guidelines for drinking water. Finally the paper examines the application of water footprint from a life cycle perspective in the Liberian mining

sector and suggests some policy options for water resources management.

Keywords Mining · Environmental management · Water footprint assessment · Sustainability · Life cycle assessment · Water resources

Introduction

After the discovery of high-grade iron ore in Bomi Hills, Bong, and Nimba, natural resources have been the basis of Liberian economy and its people livelihood. Iron ore mining was the mainstay of the Liberian economy between 1960 and 1980, contributing more than 60% of export earnings and about 25% of GDP (Boakye et al. 2012), which then ranked Liberia as the largest exporter of iron in Africa and third largest in the world. Gold and diamond mining in Liberia was carried out largely by alluvial mining of small-scale operations, with estimates of over 100,000 artisanal miners in Liberia. But nearly 14 years of war (1989–2003) destroyed much of the country's productive infrastructure and brought mining to a virtual halt. Liberia is estimated to hold reserves ranging from between two to five billion metric tons of iron ore and three million ounces of gold (Boakye et al. 2012). The major mineral commodities produced in Liberia are iron ore, gold, and diamond. Mining concessions cover an operational area of 113,256 ha (Ministry of Finance 2013). Besides the production of iron ore, gold, and diamond, Liberia remains largely unexplored and has shown other minerals such as beryl, tin, columbite-tantalite, phosphates, zinc, copper, lead, rare earth minerals, nickel, molybdenum, beach sand (zircon, rutile, ilmenite, and monazite), bauxite, kyanite, chromite, uranium, and silica sands. All are characteristically associated

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with Precambrian/Proterozoic rocks which underlie most of the country.

Since the cessation of hostilities, revival of the mining industry has been an explicit government objective in its efforts to reconstruct the country and to underpin growth by leveraging Liberia's rich natural resources to the extent of attracting massive foreign investment of USD 7.6 billion and creating about 10,000 jobs (LEITI 2016; Ministry of Finance 2013). Investments comprise, among others, rehabilitation of old and installation of new mining plants, construction of railways, roads, and bridges. As a result, the Government of Liberia has enacted (2003–2006) a legal framework providing for the sustainable use and conservation of natural resources. However, the adoption of the environmental management tools such as Environmental Impact Assessment (EIA), Environmental Impact Statement (EIS), and the harnessing of best practices valorizing local knowledge are still lacking. Thus, the pressure on the environment is still heavy.

Industrial mining in Liberia includes gold and iron ore. The mining of these minerals is associated with huge environmental impacts ranging from land form degradation, pollution of air quality, loss of biodiversity, and watercourse contamination. The latter is of serious challenge in the mining sector because of the climatic condition of Liberia. For instance, the rehabilitated Nimba mine is estimated to generate 150 million tonnes of waste rocks (60 Mm³ of waste rocks) over its first 20 years mine's life (AcerlorMittal Liberia Limited 2013). In addition, the New Liberty Gold mining operations require 1.2 Mm³ of water annually and its tailings storage facility (TSF) is expected to discharge 9.4 Mm³ (received from rainfall and runoff during the wet season) of water annually into surface water streams (Aureus Mining 2014). Therefore, there are greatest potential impacts on water quality, human health, and ecosystem from these activities coupled with increased sediment load due to the high erosion potential of soil when disturbed and effluents discharged of toxic substances, such as cyanides and heavy metals including acid mine drainage (AMD) that can cause long-term impairment to watercourses and biodiversity (Akcil and Koldas 2006). Additionally, the data collection for environmental information has been decentralized among various line ministries and agencies, as well as international organizations and institutions which have a stake in the Liberian environment.

Based on the current development trend, the objective of this paper is to carry out a systematic review of the current water use-related challenges in the Liberian mining sector particularly the water management issues and mining regulatory frameworks. Results from the review will be used to recommend policy strategies that promote sustainable water resources management in the mining sector. Accordingly, “[Historic and economic perspectives of the Liberian mining sector](#)” of this paper discusses the historical and economic contribution to the economy. “[Mineral legislation, regulatory](#)

[framework, and environmental challenges in the Liberian mining sector](#)” describes the current mining methods, legislative frameworks, and environmental challenges while “[Policy suggestions](#)” presents a case study and water resource management challenges. “[Conclusion](#)” presents policy suggestions and concludes with some recommendations.

Historic and economic perspectives of the Liberian mining sector

Liberia is a leading country in mineral resources with substantial iron ore, gold, and diamond deposits. Iron ore mining was previously undertaken by American and European companies in the areas of Bomi Hills, Bong Mines, Mano River, and Nimba. Those concessions resulted in widespread clearance of tropical rainforest for mines (open-cast pits), processing plants, housing and roads, railways, and unmanaged deposit sites. The Nimba mine for instance produced some 300 million tons of mining wastes (unwanted materials) that were deposited in the surrounding forest. Environmental impact assessments had not been conducted at the sites and potential risks were unknown.

Mining economic statistics and production

Statistics of government revenues by sector contribution indicates that the mining sector contributed to 53% (USD 53.38 million) of the total revenues during the FY14/15 (Fig. 1) and generating about 10,000 jobs. In the same year, the sector faced a drop in demand, production level, investment, and loss of employment as a result of the twin shock—Ebola virus disease and the price of iron ore. The value of the sector production in 2014 was USD 78.85 million (58.3%).

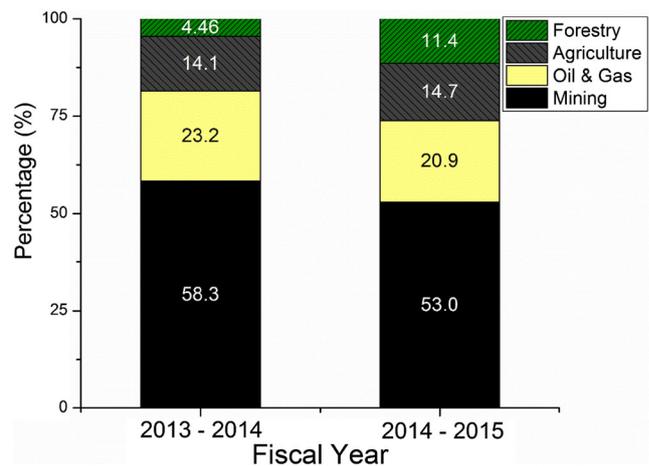


Fig. 1 Sector comparison for two fiscal years in Liberia. Source: LEITI Final Report, 2016; Ministry of Finance (2013) Annual Economic Review

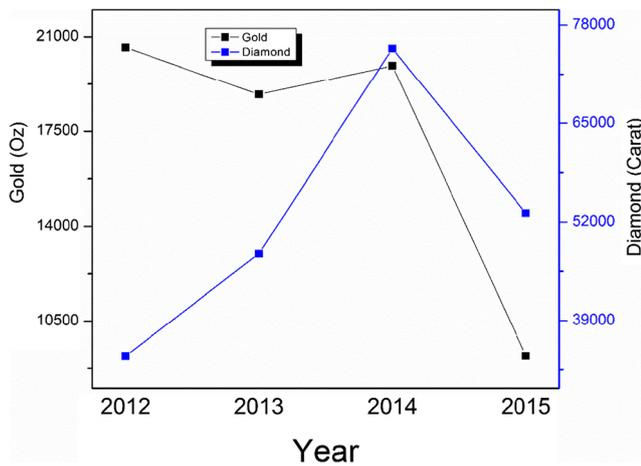


Fig. 2 Production of gold and diamond from 2012 to 2015 in Liberia. Source: LEITI Final Report, 2016; Ministry of Finance (2013) Annual Economic Review

Figures 2 to 3 shows the production of gold and diamond and iron ore from 2012 to 2015 (LEITI 2016).

Mining activities

There are different categories of mining activities in the Liberian mining sector, including artisanal/small-scale miners (ASM), medium size domestic enterprises, large-scale mining, and exploration companies. Currently, there are 1293 mining operations in the country (MLME 2010), of which 1142 (88.3%) are ASM, 65 (5%) are medium size, 78 (6%) are exploration companies, and 8 (0.6%) are large-scale enterprises. Among the large scale companies, the main producers are Arcelor Mittal (iron ore), China Union Investment (iron ore), MNG Gold Inc. (gold), and Aureus Mining Inc. (gold). The ASM are also involved in the extraction of gold and diamond. However, the development of these ASM

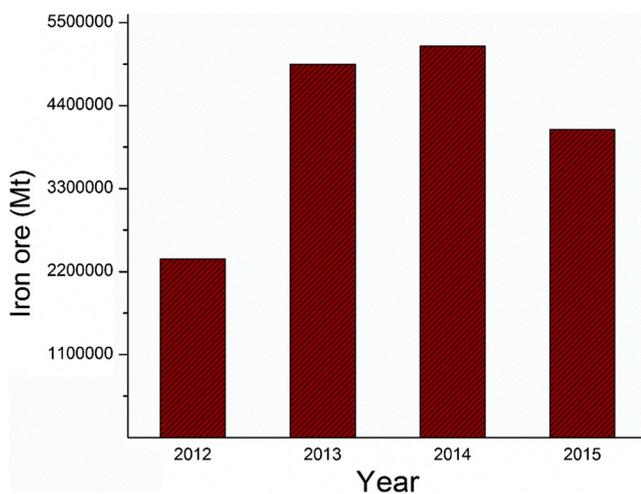


Fig. 3 Production of iron ore from 2012 to 2015 in Liberia. Source: LEITI Final Report, 2016; Ministry of Finance (2013) Annual Economic Review

operations is limited because of lack of resources and infrastructure. Consequently, there are inadequate information available on the ASMs and medium size enterprises in detailing their processes and economic activities. Nevertheless, the compilation and research of this information is a necessary activity. Table 1 shows the total productions of the large-scale mining companies operating in the Liberia.

Mineral legislation, regulatory framework, and environmental challenges in the Liberian mining sector

The Ministry of Lands, Mines, and Energy (MLME) is the Government Agency responsible for the administration of the mineral and mining sector, including granting mining licenses, and it has statutory oversight of the energy, land, minerals, and water sectors. The minerals and mining sector is regulated by the Mining and Minerals Law of 2000 and Exploration Regulations (MLME 2010). The Minerals Policy of Liberia was created in March 2010 to complement the Mining and Minerals Law. These documents outline the Government’s expectations with regard to the contributions of all stakeholders in the sustainable development of Liberia’s mineral resources. These laws are under review, but outline five types of mining licenses (Table 2). In addition to the mining licenses, there is a Mineral Development Agreement (MDA), which sets out the basis to acquire a class A mining license. The MDA sets out in detail the operational and fiscal terms for both exploration and mining and to ensure a straightforward transition from exploration to the mining phase of the operation provided that the operator has complied with the general provisions of the law. In negotiating an MDA, the Minerals Technical Committee has discretionary authority regarding those matters which are subject to the regulations, which together with the law specify principal terms and conditions.

License acquisition and procedures

Table 2 and Fig. 4 outline the various types of mining licenses and the procedures required to obtain the licenses, respectively. The duration, land size, and applicants’ eligibility are also indicated.

Mining technologies and processes

Currently there are four large-scale industrial mines (two in gold production and two producing iron ore) operating in Liberia with several others into exploration and mine development for both gold, but mainly iron ore (Table 1). Open cut mining method is generally employed by the operators. The ore is extracted from the mine and processed through the plant

Table 1 Large-scale mining companies' production and mineral reserves in Liberia

Mine/company	MDA/agreement	Production	Type of mineral	Ore grade	Mining method	Estimated reserves
Nimba Range/ AML	2005; 25 years	5.1Mt ore	Iron ore; hematite, magnetite	65–69% Fe	Open pit	417 Mt
Bong Mines/China Union	2009; 25 years	0.70Mt ore	Iron ore; magnetite	35–45% Fe	Open pit	290 Mt
Putu Range/PIOM	2010; 25 years	Mine development	Iron ore; itabirite, goethite	45% Fe	Proposed open pit	4.5 Bt
Bomi, Bea, Mano/WCL	2011, 25 years	Mine development	Iron ore; hematite, magnetite	51% Fe	Proposed Open pit	563 Mt
Kokoya/MNG	2004; 25 years	619.48 Koz Au	Gold	3.54 g/t Au	Open pit	1.84 Mt
Bea Mt./Aureus	2002; 25 years	2376.45 Koz Au	Greenstone gold	4.17 g/t Au	Open pit	8.7 Mt

Source: MLME, 2010; Mineral and Mining Law, 2000; LEITI Report, 2016; US Geology Survey Mineral Year Book, Liberia-2013; African Aura Mining Inc., 2010a, p. 8

AML ArcelorMittal Liberia, WCL Western Cluster Limited, PIOM Putu Iron Ore Mining

Mt million tonne, Bt billion tonne

to produce a concentrate. Tailings, or waste material, are then deposited in a tailing storage facility (TSF). The gold operation employs the conventional carbon-in-leach (CIL) method, which comprises of the following:

- A crushing and milling circuit
- Gravity circuit to recover coarse-free gold
- A CIL leaching and absorption circuit, in which cyanide leaches the gold from the crushed ore and carbon recovers the gold from the leachate slurry by absorption
- A tailing thickener to recover water (and therefore reclaim cyanide) from the tailings prior to its discharge to the tailings storage

Table 2 Types of mining licenses, land size, and duration in Liberia

License	Description	Validity period
Prospecting license	It is granted when an area has not already been subject to a valid mineral right granted to another person; the area granted shall not exceed one hundred (100) acres. The holder shall file and submit to the Minister of Land, Mines, and Energy a proposed work plan for the prospection. The prospecting license does not give the right to conduct commercial mining.	Six (6) months, renewable once for a further period of six (6) months provided that the holder meets his obligations under the law
Exploration license	It is granted when the area has not already been subject to a valid mineral right granted to another person; the exploration area shall be contiguous and shall not exceed one thousand (1000) square kilometers. The holder is to submit a proposed exploration program to the Minister of Land, Mines, and Energy within ninety (90) days after the issuance of the exploration license and shall commence exploration within one hundred and eighty (180) days after the issuance of an exploration license unless the Minister agrees to a longer period.	Not more than three (3) years and it may be extended for a single two (2) year term upon written application of a holder
Class C mining license	The production area covered by this license shall be not more than twenty-five (25) acres. One person may hold up to four (4) class C mining licenses at the same time. Holders of a class C mining licenses shall conduct mining predominantly as a small-scale operations.	One (1) year, renewable for further terms of 1 year each, if the holder has met all of his legal obligations
Class B mining license	Holders of a class B mining licenses can conduct mining as industrial operations. Production area is twenty-five (25) acres.	Five (5) years, renewable for not more than five (5) years.
Class A mining license	It is granted during or at the end of the exploration period of a discovery of exploitable deposits and is materially in compliance with, a Mineral Development Agreement, which has become effective, permitting mining in the proposed production area.	Not be more than twenty-five (25) years and may be extended for consecutive additional terms not exceeding twenty-five (25) years each.

Sources: MLME-Mineral and Mining Law 2000; LEITI Report 2016

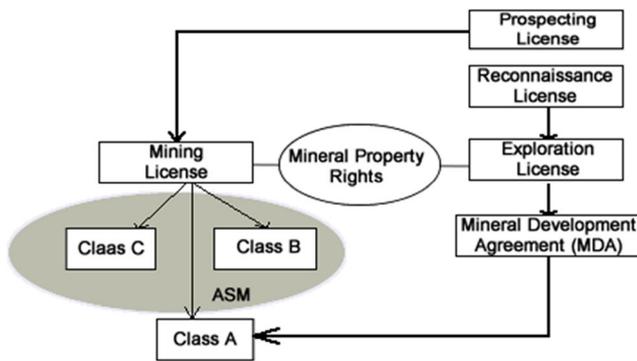


Fig. 4 Basic mineral titles and procedures in acquiring mining licenses with individual license description given in Table 2 in Liberia. Source: Ministry of Lands, Mines and Energy

- An acid wash followed by an elution circuit to strip gold from carbon
- Electro-winning of the gold from the elutriate solution and smelting of the loaded electrodes to produce gold dore.

These mining and mineral processing technologies require sufficient energy, water, and chemical reagents as sources for operations; thus polluting groundwater, watercourses, and habitats from spills and leakages of toxic or hazardous substances significantly.

Regulatory framework

The principal agency for the management of the environment in Liberia is the Environmental Protection Agency (EPA). The Environmental Protection Agency Act of Liberia (EPA 2003) mandates the EPA to coordinate, monitor, and supervise all activities in the field of the environment. The EPA makes mandatory to file an Environmental Impacts Assessment (EIA) and Environmental Impacts Statement (EIS) to obtain government approval prior to initiating activities. In the case of the mining sector, an EIA declaration format has been specifically designed for mining activities. The EIA has five component phases: namely, project screening; scoping; description of the project/action, alternatives, and environmental baseline; identification of environmental impacts; environmental management plan/design of corrective measures; and monitoring and control. This EIA process is similar to other EIA processes worldwide in that the EIA is a process that analyzes and evaluates the impacts that human activities can have on the environment. Also, its purpose is to guarantee a sustainable development that is in harmony with human welfare and the conservation of ecosystems; thus, proven itself to be an effective tool in environmental planning and management (Jay et al. 2007; Ortolano and Shepherd 1995; Toro et al. 2010; Wathern 1994; Wood 1993).

Environmental challenges

The laws in place for mining operations in Liberia, therefore, tend to be broad and ineffective. Additionally, there are overlaps and conflicts between different pieces of legislation (e.g., Public Procurement and Concession Act and the Minerals and Mining Law of 2000) that govern the sector. Furthermore, data collection is mainly carried out by various governmental bodies concerned with environment protection and policy (Forestry Development Authority, Ministry of Lands, Mines, and Energy). Besides, basic environment statistics such as water resources (surface and ground water abstraction, water used by sectors, freshwater availability, precipitation, evapotranspiration, water quality, river inflow/outflow) and land degradation information are mostly not available. Some available data are of limited time and geographical coverage. Those data often result from case studies or projects of limited duration. After the study or project ended, data collection usually stopped. Other available data are not up-to-date; consequently, hindering data collection and reporting processes. The lack of adequate logistics, personnel, and funding also constrain proper governance, particularly in relation to field monitoring and technical audit functions.

Water use in the mining sector and its associated environmental impacts have not been properly investigated. Although, the large-scale mines are in their early stages of operations and are located in and around major river courses and its tributaries. Presently, the gold mines in Liberia use cyanide in the recovery process, cyanide leaching is the standard method used for recovering approximately 83% of most gold throughout the world today (Karahan et al. 2006). Also, the uncontrolled management of cyanide when comes in contact with waterways has serious environmental and health consequences. In recent time there have been public outcry by local mining communities of contaminated drinking water sources (streams, creeks) from mining concessions in the country.

Water resource management is one of the greatest global challenges of the twenty-first century (Boccaletti et al. 2010). The mining industry and water resources are critically linked; mining needs substantive amounts of water to proceed but can also have major impacts on surface and ground water resources. Given water’s primary role in sustaining ecosystem, communities, and economies, the mining industry is recognizing the challenges posed by sustainable water resources management and is embracing the opportunities it presents (Mudd 2008). In contrast to the abundance of mineral wealth in Liberia, water resources are vulnerable to environmental impacts from mining activities. Unless appropriate corrective actions are taken, the mining sector is expected to place further degradation on the country’s undeveloped water resources.

For mining projects, there are a number of factors that can affect the embodied water of a metal or mineral output, including (Mudd 2008):

- Climate conditions (e.g., temperate, arid, tropical)
- Primary water source: surface water, ground water, or saline water (marine or otherwise)
- Ore mineralogy and geochemistry (especially as this affects processing)
- Tailings and waste rock/overburden management (especially as this affects water management)
- Type of commodity
- The extent of re-use and recycling
- Mine-site water management regime (e.g., allowable discharges or not; treatment)
- Surrounding communities, land uses, and/or industries (e.g., towns, national parks, farms)
- Project design and configuration (e.g., open cut and/or underground mining, concentrator and/or smelter)
- The initial moisture content of the ore and waste rock
- Surrounding hydrogeological conditions (high permeability aquifer; artesian ground water depressurization issues)

It is also expected that ore grade will steadily decline as high grade ores are preferentially mined (Mudd 2010; Mudd and Weng 2012); and the decline in ore grade has large ramifications regarding the potential environmental impacts of mining wastes (Northey et al. 2013). However, different mining methods and mineral processing techniques have unique water requirements. Therefore, reduction in ore grade will require more improved technologies and energy consumptions. These activities will in turn affect water quality through erosion and sedimentation, contamination with heavy metals, acid rock drainage, chemical contamination, and sewage and microbial contamination. The average grade of iron ore in Liberia currently is relatively high (up to 60% Fe see Table 1), but will gradually decline as mining progresses, therefore, requiring sinter/concentrator plant for beneficiation of saleable concentrates.

Case study

China Union (Liberia) Bong Mines Investment—Bong Mines—is a subsidiary of China-Union Hong Kong Mining Company, Ltd. (Wuhan Iron and Steel Corporation) located in Bong County, Central Liberia. The mine is situated 10° 13' 38" N and 6° 48' 0" E and located 78 km northeast of Monrovia, the capital city of Liberia (Fig. 5). The total area of the mining concession is 610 km² surrounded by over 20 towns including cultural sites, some of which were relocated due to impacts of the mining operations. The mean annual rainfall of the concession area is approximately 2700 mm. The company started production in early 2014 to June 2015, but later suspended operations in late 2015 as a result of the twin shock—Ebola virus disease in Liberia and the price of iron ore.

The mine site is located in an area that has many small surface water bodies that are used by communities for drinking and fishing and support aquatic life; thus, predicted to have the potential to alter the flow properties and degrade the water quality of the surface water bodies. The affected water bodies include Wadea Creek, Yia Creek, Wea Creek, and the St. Paul River Basin. Runoff (4.5 m³/s) from the waste rock dump (WRD) discharges into the Wadea Creek while overflows (10.6 m³/s) from the tailings dam discharges into the Wea Creek. The Yia Creek is located north of the tailings dam. These creeks flowing downstream of the mine drain into the St. Paul River, which is the primary water source for the mine and is located approximately 10 km northwest of the mine.

On the 18th of November 2016, a total of six 1.5 L grab water samples, four (4) from surface water (SP1-SP4) and two (2) from ground water (SP5-SP6). Samples SP1 and SP2 were collected from the pump station and tailings dam respectively, which overflows discharge into the Yia and Wea creeks. Samples SP3 and SP4 were taken respectively from upstream and downstream of Wadea Creek while SP5 and SP6 were taken from the Botota and Gorzue communities located near the mine. These samples were taken to the laboratory of the College of Environmental Science and Engineering in Tongji University as shown in Table 3. Figure 6 shows the water sample points of collection.

Laboratory analysis Laboratory analyses were carried out to assess the concentrations of physical and chemical water quality parameters of each sample gathered. Some parameters that were analyzed for determining pollution loads from point and non-point sources were limited to total dissolved solid (TDS), turbidity, electrical conductivity (EC), total organic carbon (TOC), Fe, Al, As, Zn, P, V, B, Ba, Ca, and Cr, mainly because of their relevance as water quality indicators.

Results

Despite the prolonged suspension until now, heavy metals (e.g., iron, aluminum, calcium, and zinc) are present in high concentrations, but with some variations due to the sample points location relative to the mine. Also, the inception of ground-water aquifer with abandoned mine pits may have minimum contribution. The measurement results of these samples were compared to drinking standards instead of surface water quality standard for two main reasons as follows: firstly, the water bodies are used directly as drinking and domestic water by communities located in and around the mine, which is evident by some of the sample points; secondly, there is no surface water quality standard for Liberia. Also, with respect to some of the sample point locations, technically, it is not appropriate to compare the measurement results of sample points (SP1, SP2, and SP3) with a drinking water standard because at this

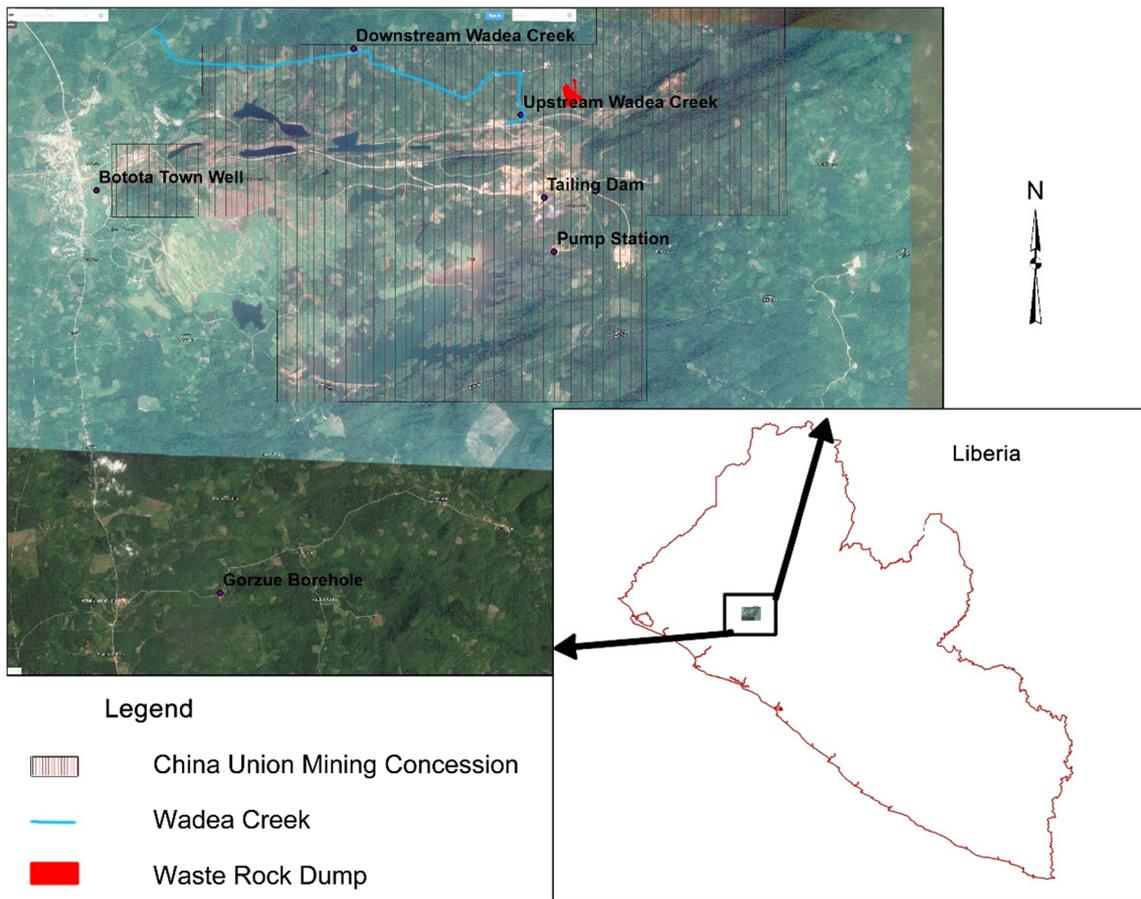


Fig. 5 Google earth image of the water sample point location of China Union

location, the water is not directly consumed by the communities in and around the mine, but it is the source of their drinking water at sample points (SP4, SP5, and SP6). Therefore, the results should be view from the perspective of those sample points collected from drinking water sources.

The Fe and TDS concentrations in all of the water sample exceed the WHO and Liberia Water Standard Class I (drinking water) guidelines (Fig. 7a, b) respectively. Aluminum, boron, and calcium were also present in high concentrations in some of the water samples (Fig. 7d) as well as phosphorus and zinc which were found in all of the water samples. The concentration of chromium in sample 6 exceeds the Liberia Water Standard Class I (drinking water) guidelines (Fig. 7e).

Accumulation of these heavy metals, which formed in association trace elements lead to carcinogen, diarrhea, etc. and acid rock drainage (ARD). The concentrations of turbidity, TOC, and EC are shown in (Fig. 7c). Despite the short term of operations, the arsenic concentration in some of the samples is at the level of WHO and LSW Class I standards for drinking water. Arsenic is known for its toxicity in both human and the environment when it accumulates. The TOC concentration is extremely high in sample points (SP4, SP5, and SP6) because of shifting cultivation farming done by the communities while as the high concentration turbidity in sample points (SP1, SP2, and SP3) is due to the fact that those points are located near the mines likewise the concentration of EC (Fig. 7f).

Table 3 Sample point description and location of the case study site

ID	Sample description	Location/UTM coordinates
SP-1	Mite pump station	E: 359,127/N: 751,575
SP-2	Tailings pond	E: 358,929/N: 752,677
SP-3	Upstream Waydea Creek near WRD	E: 358,460/N: 754,375
SP-4	Downstream Weydea Creek	E: 355,071/N: 755,746
SP-5	Well water from Botota-mining town	E: 349,843/N: 752,854
SP-6	Borehole water from Gorzue nearby town around the mine	E: 352,377/N: 744,592

SP sample point, WRD waste rock dump, E easting, N northing

Fig. 6 Photographs of the water sample point collection of China Union; *S* surface water sample; *G* ground water sample; S1: Pump Station; S2: Tailing Dam; S3: Upstream Waydea; S4: Downstream Waydea; G1: Well, Botota Town; G2: Borehole, Gorsue Town



It can be suggested that the mining operations, when stringent water management is not taken, will significantly impact the local water environment and have health consequences. Aquatic habitat and water users from villages located within and around the mine concession are the main receptors for the project. Aquatic habitat can be affected by changes in water

quality, changes in channel morphology induced by changes in stream hydrology (driven by sediment transport) as well as changes to the flow regime itself. Human receptors are potentially affected by changes in surface water quality and water availability. Secondary effects can result from any aquatic habitat impacts that affect fishing.

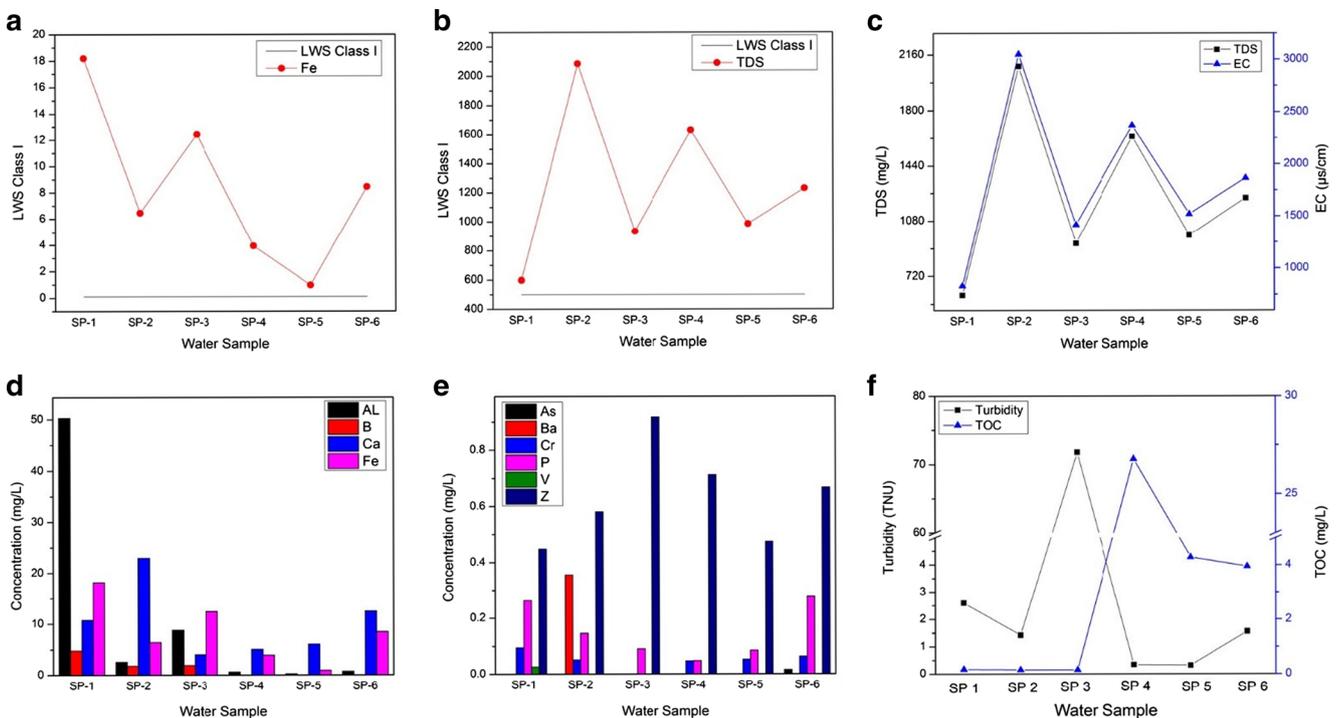


Fig. 7 Water quality monitoring. **a** Compare the concentration of iron with LWS Class I. **b** Compare the concentration of TDS with LWS Class I. **c** Concentration of EC and TDS in the water samples. **d, e** Concentrations of the various metals in the water samples. **f** Concentration of turbidity and TOC

Policy suggestions

A number of environmental assessment tools and methodologies have been developed by the scientific community in recent years to assess water use and related impacts of the mining industry. One of the methods for assessing water use on a life cycle basis that is probably most widely used is the water footprint approach developed by (Hoekstra et al. 2009). This alignment was reflected in the development of the international standard, *ISO 14046 water footprint—principles, requirements, and guidelines*, which defines a water footprint as a “metric that quantifies the potential environmental impacts related to water” (ISO 2014).

Despite the large environmental impacts associated with the mining industry, there have been relatively few attempts to quantify water-related impacts from the industry using these methods. For instance, CSIRO Mineral (Norgate and Jahanshahi 2004; Norgate et al. 2004a; Norgate et al. 2004b; Norgate and Rankin 2000; Norgate and Rankin 2001; Norgate and Rankin 2002) and others (Giurco et al. 2000; Giurco et al. 2006; Lunt et al. 2002; Van Berkel 2000) used LCA methodology to assess the environmental impacts of various metal production processes practiced either currently or potentially in Australia. (Northey et al. 2016) identified a range of opportunities and few limitations on the use of water footprint assessments in mining industry. Among the opportunities are water footprint and LCA can be used to provide a more holistic assessment of the benefits and drawbacks of technologies being developed and deployed in the mining industry through the consideration of indirect (supply chain) impacts; improve the usefulness and relevance of water related data disclosures that are presented by corporate sustainability reports. Particularly for companies that have facilities in multiple regions with differing water contexts.

The development of water footprints of mined products is heavily dependent upon rigorously quantified estimates of the flows of water into and out of production processes, and the quality of water associated with these flows (Northey et al. 2015). The Minerals Council of Australia and the University of Queensland recently developed the “Water Accounting Framework for the Minerals Industry” that provides a method for individual mining companies to consistently record and report water flow, quality, and storage data for their individual operations (Mineral Council of Australia (MCA) 2012). Overtime, the increased adoption of this framework should lead to improvements in the quality and availability of data that can be used in water footprint assessments. Measuring water use and assessing its environmental impacts in the Liberian mining sector, particularly on a life cycle basis, are therefore important first steps towards sustainable mining in the sector. These statistical information could be used in the preparation of the National State of the Environment reports.

Conclusion

The mining sector is vital to Liberia’s economic and social development, owed largely to the endowment of its natural resources. The sector contribution to the GDP will continue to grow as new discoveries are made and the development of new mines. The Mineral and Mining Law needs to be updated to address contemporary technical, legal, and regulatory issues; thus requires empowering the EPA, other line ministries and agencies to adequately monitor and regulate the mineral and mining sectors. It is recommended that the ASM should be organized into a cooperative for proper management and accountability.

Adopting the Water Accounting Framework for the Minerals Industry and water footprint from a life cycle assessment perspective will ensure all mining companies consistently record and report water outflow, intake, quality, and storage data; quantity and quality of water discharged in water courses; and recycle and reuse water in process plants in the Liberian mining sector with respect to water resources management.

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