ARTICLE IN PRESS

Journal of Environmental Management xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: http://www.elsevier.com/locate/jenvman

Review

Evaluating the environmental and economic impact of mining for post-mined land restoration and land-use: A review

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A R T I C L E I N F O

Keywords:
Environmental
Economic
Reclamation
Land-use
Post-mined

A B S T R A C T

Mining has been a long-standing key player in economic development, employment, infrastructure, and supply of essential raw materials for society. It has served as a viable route to economic transformation in resource-rich countries like Australia, Canada, the United States, and parts of Africa. In this review, the impact of mining has been conceptualized into economic, environmental, and social impacts. While it is clear that mining has transformed many economies, it has also impacted negatively on the environment and, to some extent, society. Some of the negative impacts of mining are loss of vegetation cover, mass destruction of water bodies, loss of biodiversity, land-use changes and food insecurity, increased social vices and conflicts, high cost of living, and air pollution. However, reclamation has been a viable way of reducing the negative impacts of abandoned mine lands and ensure productive and efficient utilization of mine wastelands. Compaction, low or high pH, low water holding capacity, gullies, bulk density, deficiency of micro, and macronutrients are the major factors limiting the productivity of mine wastelands. A combination of physical, chemical, and biological restoration practices is ideal for restoring the mine soil productivity. While the physical method deals with earth-battering, thus putting the land back to shape, the chemical and biological methods include various amendments such as biochar, compost, synthetic fertilizers, synthetic chelates, shrubs, and grasses, and nanoparticles. A combination of these three restoration methods restores soil fertility, stimulates microbial growth, and facilitates early ecological succession. However, before embarking on reclamation, the particular post-mined land use should be clearly stated, such as conservations, forestry, agriculture, construction, intensive recreation, non-intensive recreation, and lake or pool through land suitability and selection analyses. This review has guiding significance and recommendations for mining and post-mined rehabilitation.

1. Introduction

Mining is the extraction of geological materials or other valuable minerals from either the surface or deep down the earth, mostly from an orebody. According to studies (Amponsah-Tawiah and Dartey-Baah, 2011; Jain et al., 2016a), "mining is defined as the process of excavating into the earth to extract naturally occurring minerals usually of high value." It strengthens and underpins the industrial development of many countries. Mining also provides economic and social development, employment, the supply of essential raw materials for society, and has the potential to bring economic, social, and infrastructure development to remote and poorly developed areas (Coelho et al., 2011; Haddaway et al., 2019; Hossain et al., 2013).

The mineral mined is usually of high economic value to the miner than its adverse impact on the surrounding environment. This accounts for why most mineral explorers pay little or no attention to the impacts on the environment. Since many countries' growth and economic progress heavily relies on minerals, it is expected that the quest for mineral exploration would continue to surge. Historically, mining has served as a viable route to national development in most reource-rich countries like Canada, Australia, and the United States, where mining has been the main driver of economic growth and industrialization (Gibria, 2014). In Africa, both artisanal and small-scale mining (ASM) has been identified as a significant economic opportunity for people in rural areas and has contributed to the gross domestic product (GDP) of many African economies. Its negative impacts on the environment and society as a whole are expected to leap-forward if proper regulations are not strictly followed and enforced (Nakazawa et al., 2016; Zhou et al., 2015).

There are mainly two types of mining, thus surface mining and

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https://doi.org/10.1016/j.jenvman.2020.111623
Received 1 September 2020; Received in revised form 3 November 2020; Accepted 4 November 2020

Please cite this article as: Adator Stephanie Worlanyo, Li Jiangfeng, *Journal of Environmental Management*, https://doi.org/10.1016/j.jenvman.2020.111623

underground mining. Surface mining purposely exhumes ores at the surface or close to the earth's surface, including open-pit mining and dredging. Underground mining, however, removes minerals such as in hard-rock mining by extracting under the surface and removing the ore (Aryee et al., 2003; Balasubramanian, 2017; Gibria, 2014; Northey et al., 2013). Surface mining particularly the open-pit method is practiced in many developing nations, especially Africa by illegal small-scale and artisanal miners (Balasubramanian, 2017). It requires relatively less initial capital investment and is mostly executed by small indigenous artisans with fewer workers (Mensah et al., 2015). However, underground mining uses high-level machinery with a considerable level of sophistication and high demand for labor. It is mostly used to exhume hard minerals, usually, those containing metals deep down from the ground Balasubramanian, 2017). Regardless of the type and scale of production, mining consists of four main steps thus (1) exploration, (2) mining, (3) Mineral processing and dressing, and (4) Metallurgical processing (Balasubramanian, 2017; Gandy et al., 2016). Exploration is the first stage, which is done to locate deposits of economic interests. Mining is the extraction of material from the ground. Mineral processing and dressing include any physical, chemical and mechanical, methods employed for the separation of minerals from the gangue for further partial treatment. The gangue is mostly the most valueless and undesirable material. This stage generates the majority of the waste product and poses the highest number of health risks. It is principally made up of three main stages, thus preparation, concentration, and conditioning. The metallurgical processing includes the smelting and refining operations that produce pure metals and prepare the alloy. It includes several stages, such as pyrometallurgical operations, hydrometallurgical operations, and electrometallurgical operations (Haddaway et al., 2018; Lottermoser, 2010; Northey et al., 2013).

As the world population continues to surge, coupled with industrialization, the quest for mineral exploration increases daily (Gathuru, 2011). The outcome of these mineral explorations on the environment and nearby communities poses both negative and positive impacts (Haddaway et al., 2019). While some view the advent of the mining as having created a positive outlook in the society, others believe that it leaves more devastating effects on these communities (Adu-Yeboah et al., 2008; Gibria, 2014; Lottermoser, 2010). For instance, minerals such as gold, diamond, bauxite, and crude oil deposits have contributed enormously to most countries' economic fortunes (Yankson, 2010; Balasubramanian, 2017). Some of the economic gains from mining include foreign direct investment (FDI), employment creation, infrastructure improvement, and essential services such as adult literacy education and primary healthcare (Amponsah-Tawiah and Dartey-Baah, 2011; Balasubramanian, 2017; Haddaway et al., 2019). Though there are significant economic benefits of mining, however, mining can also cause severe negative environmental impacts such as contamination of water bodies, air pollution, land degradation, and damage to biodiversity (Cordy et al., 2011) as well as social impacts such as mass migration, displacement of people and properties, the spread of diseases like HIV/AIDS, and earthquakes (Mitchell and O'Neill, 2017).

Moreover, the amount of waste generated from mining and its overall adverse impact on the land, environment, water, soil, and air are enormous. Mining reaps agricultural lands of their value, which creates many hardships in the lives of people living within the mines (Haddaway et al., 2019). Once the environment is destroyed, prices of most necessities such as food, accommodation, and water shoot up (Festin et al., 2018). Mining ultimately alters the entire ecosystem, which leads to substantial land-use changes that generally affect the global economy. According to studies (Zhou et al., 2015), mining has eroded about 40, 000 km^2 of land in China, and only the abandoned mine land records an annual increase of about 330 km^2.

Similarly, over 700 million ha of land in Africa is degraded, with mining being a major contributor to this canker. These abandoned mine land usually suffer from deficient plant nutrient (N, P, K), toxic chemicals, poor physical structure, and extreme soil pH. Furthermore, mining causes adverse effects on human life. For instance, a high incidence of hypertension, lung cancer, pulmonary disorders, and kidney disease was positively correlated with mining (Wang et al., 2015).

Therefore, it is imperative from the above that the mined land should be restored to its original landscape or higher use after mine closure. Environment-friendly and cost-effective land reclamation practices should be adhered to by mines to increase available land size. Mining concessions should incorporate post-mined reclamation to the entire mining spectrum to return productivity to post-mined lands. Land restoration has been widely used to restore post-mined lands in some parts of the world, especially in developed countries. The goal of reclamation is to return the site to a condition that most resembles the pre-mining condition; to prevent or minimize in perpetuity, the release of contaminants from various mine sites (i.e., heavy metals released from tailings, open-pits, and impoundments); and how funds would be made available to ensure that the costs of reclamation and closure will be paid. However, this is not the case in most countries, especially third world countries (Feng et al., 2013). Because of this, there is an urgent need for proper land restoration programs or green mining to curb adverse environmental impacts emanating from mining. Only when this is done can the land be put back to its original use or more efficient use. In a nutshell, the writing of this review was necessitated by the fact that after a careful survey of several literature platforms, we could not find a single study that attempts to consolidate mining impacts with post-mined reclamation and land-use from a global perspective.

2. Impact of mining operations

Over the years, the impact of mining on the economy, environment, and society has attracted several views (Balasubramanian, 2017; Festin et al., 2018; Mensah et al., 2015; Ocansey, 2013). A study, (Widana, 2019) conceptualized the impacts of mining into several forms such as functionality (socio-economic, political and environment), duration (short-term, medium-term, and long-term), usefulness to society (beneficial, adverse, and neutral), place of occurrence (extraction site, processing plant, service area or down-stream), its nature (positive or negative) and the length of the impact (temporal or permanent). Others have also classified the impacts of mining into positive and negative (Sheoran et al., 2010). This study has classified mining's impacts into three broad categories, thus economic, environmental, and social impacts. Each of these categories has been further discussed and critiqued to enable comprehensive understanding. Fig. 1 below is a generalized conceptual framework showing the impact of mining on the three categories and the net effect under each category.

2.1. Economic impacts of mining

The economic impacts of mining are sparse and lack documented impact data for several operational mines and minerals. The extent of economic gain from mining is context-specific and vary from place to place dependent upon several factors such as quality of governance, type of technology used for extraction, location, economic environment, specialized skills of the workforce, and the nature of mining (Bennett et al., 2015; Widana, 2019). Notwithstanding all other factors, minerals such as gold, diamond, manganese, bauxite, and crude oil have offered significant contributions to the economic growth and development of most countries through foreign direct investment (FDI) (Balasubramanian, 2017; Yankson, 2010). According to Sheoran et al. (2010), every society and its growth largely depends on the mining industry to operate and maintain some comfort level. Minerals are blessings and a gift of nature, for they are meant to be developed, sold, and used to make life better for citizens. Mining companies also provide certain essential facilities and services such as good drinking water, community clinics and schools, and other infrastructure (David et al., 2016) for the mining communities. Furthermore, some mines especially legalized large-scale mines provide capacity-building workshops for some workers in the

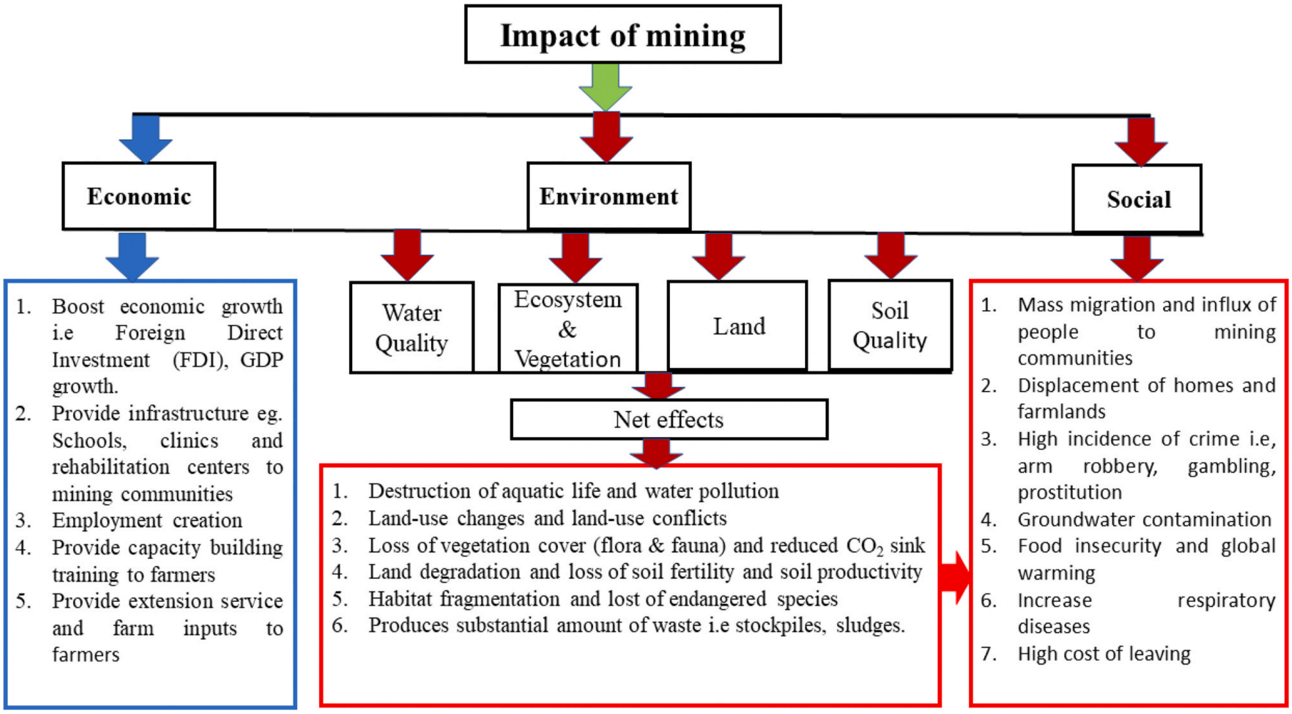

Fig. 1. a conceptualized framework depicting the general impact of mining. Authors' Construct (2020).

operational area and provide extension services to the farmers (Mahar et al., 2016; Ocansey, 2013). Employment creation, especially for abled bodied men and women. According to Gibria (2014), small scale mining employs over 13 million workers globally, whereas large scale mining provides direct employment for about 203 million workers. Graham et al. (2012) indicated that artisanal mining complements rural traditional subsistence farming, which largely serves as a poverty alleviation venture in most rural communities.

Many African countries export substantial quantities of minerals for foreign revenues, while most industrialized countries manufacture several mining products. In either case, it has an enormous net effect on the economy through Gross domestic products (GDP) (See Table 1 in the supplementary document). Some individuals' income from mining contributes to over 90% of their total household income, especially families directly engaged in mining (Widana, 2019). Barreto (2018) observed that gold miners from Kenya get about USD140 per month, which contributed to their livelihood support in several ways. According to Balasubramanian (2017), small-scale mining provides livelihood to about 13 million people on a global basis, while large-scale mining provides direct employment and economic sufficiency to about 2–3 million workers and their families worldwide. David et al. (2016) conducted a quantitative study on mining on the Nigerian economy's economic development using the Error Correction Model (ECM). The model was based on the assumption that crude petroleum, gas, solid mineral, manufacturing, and agriculture determine economic development. The model showed that per capita income was positively associated with solid minerals, whereas crude petroleum was negatively associated with per capita income both in the long run and short run. The study concluded that mining provides both direct benefits (income and employment) and indirect benefits (local and foreign purchase of domestic goods) to the economy. In countries like Botswana, Democratic Republic of Congo, Mozambique, and Guinea, revenues generated from mining alone accounts for more than half of their total export revenues (International Finance Corporation (IFC), 2014). In contrast, countries like Canada, the USA, Australia, and China have also depended heavily on mining for their industrialization and economic transformation (Domfe, 2003; Gibria, 2014) (see Table 1 in supplementary material).

2.2. *Environmental impact of mining*

2.2.1. *Impact on land and food security*

Regardless of the type or scale of mining, it has the potential to cause severe damages to the land if appropriate regulations are not put in place and strictly enforced (White, 2013). Several studies (Sheoran et al., 2010; Mensah et al., 2015; Sonja et al., 2018) conducted on the impact of mining have pointed out that both surface mining and underground mining have caused substantial adverse impact on the environment as well as land. Stockpiles, sludges, gullies, and tailings dams are some of the most common mining effects on the land. Campbell (2006) indicated that livelihood diversification is essential to rural people for poverty alleviation. However, when mining companies' activities destroy these lands and, to a more considerable extent, take possessions of it (Davies, 2014), farmers have no choice for any diversification strategies for their livelihood. For instance, Akabzaa and Darimani (2001) have reported that more than 70% of the total land area of a mining community in Ghana (Tarkwa) has been taken over by concessions of small-scale mining. The study further revealed that most small-scale mines after mine's closure mostly used 40–60% of their space for activities such as heap leached facilities, tailings dam, mine camp, open-pits, roads, and resettlement for displaced persons. The tailings dams, mine camp, and open-pits pose threats to humans as most of them serve as a reservoir for the breeding of mosquitoes, snakes, and other life-threatening creatures (Sikaundi, 2013; Sheoran et al., 2010).

In a worse scenario case, land which serves as the major livelihood support to these resource-poor farmers is either taken away or left barren after mining without any conscious efforts to reclaim the land. These barren lands stay for years after mine closure with its attendant consequences, while farmers wonder about what to eat (Rai et al., 2015). On average, a tailing dam can occupy up to 6.3 ha of land (Festin et al., 2018). Given that the annual projected yield of cassava per acre is 108,000 bags, then the tailings dam has denied a farmer a minimum of 275,351 bags per year. This has significant consequences for the farmers' incomes and their food security and livelihood. Kangwa (2008) estimated that an equivalent of 350 tons of waste are generated out of which tailings constitute 147 tons during the production of 1 ton of

Table 1
Major minerals mine in various countries and their contribution to GDP.

Country	Mining Contribution (% of GDP)	Major minerals mined	Comment
Australia	10	**Majors:** Bauxite and Diamond, **Others:** coal, iron ore, gold, uranium, zinc, lead, and silver	World third-largest producer of commodities
USA	N/A	**Main:** gold, copper, silver, lead, zinc, molybdenum and coal	World's leading mining nation currently. The largest producer of natural gas and the largest petroleum reserves
China	N/A	**Major:** Coal, Gold and aluminum, Tin, Titanium, and Zinc. **Others:** Bauxite, Mercury, Mica, and Iron	World's leading producer of coal, gold (403t in 2012), and aluminum. Mining rank's third in the world
Chile	N/A	**Major:** Copper. **Others:** gold, silver, molybdenum, zinc, manganese, Lithium and iron ore.	Most important mining country in Latin America. World's largest copper producer
Brazil	2	**Major:** Niobium, bauxite, Kaolin, iron ore, and nickel **Others**: gold, coal, and phosphates	World Largest producer of Niobium. Iron ore is the most important of mineral exports, (annual revenue exceeding $ 2.3 billion).
Indonesia	N/A	**Major:** tin, coal, copper, gold, and nickel. **Others:** bauxite, phosphates, iron sand, alluvial diamond	World Largest producer and exporter of Nickel. Also produces large volumes of tin and coal
India	N/A	**Major:** chromite, coal, iron ore, and bauxite.	Second biggest producer of aluminum and a major mineral producer in Asia and globally.
Mexico	N/A	**Major**: silver, base metals such as lead & Zinc, gold, celestite, and bismuth. **Others:** barite, manganese, salt, lead, and zinc	World's leading producer of silver, mercury, and bismuth. Ranked among the top ten producers of lead, manganese, salt, barite, and zinc
South Africa	>6.5	**Major:** chrome, gold, vanadium, manganese, and PGM's.	World's largest producer of Manganese and platinum and second-leading producer of palladium with 80% of the world's known manganese reserves. 72% of the world's known chromite ore reserves
Kazakhstan	27	**Major:** uranium, manganese and chromium ores, iron, coal.	World's largest producer of uranium
Peru	6.5	**Major:** Gold, silver, tin, copper, lead, and zinc	World's second-leading producer of silver. Leading producer of Gold in Latin America and a major producer of Gold in the world.
New Guinea	17.3	**Major:** gold, copper, and silver	Second largest copper producer after Chile
Russia	N/A	**Major:** diamond, nickel, copper, coal, gold, tin, and bauxite.	Leading producer of diamond and palladium, second-leading producer of natural gas, platinum, and mica
Zimbabwe	8	**Major:** gold, asbestos, chromite, coal, and base metals	Produces and supplies a significant amount of lithium, chrysotile asbestos and vermiculite in the world
Ghana	N/A	**Major:** Gold, Diamond. Bauxite, and Manganese	The largest producer of Gold in Africa and major producers in the world.
Zambia	N/A	**Major:** copper, cobalt. **Others:** lead, zinc, silver, gold, minor-platinum.	World's seventh-largest producer of copper. World's second-largest producer of cobalt

copper alone. Additionally, Sikaundi (2013) revealed that almost 9125 ha of land in Zambia contains 791 million tons of tailings out of which, 388 ha are covered with 77 million tons of waste rock. Moreover, about 20,646 ha of land, is covered with 1899 million tons of overburden materials, and 279 ha filled with slags all within the Copperbelt province. Edraki et al. (2014) projected that from 5 to 7 million tailings dams are created globally every year. Also, vast hectares of mines sites are always cleared to pave the way for building infrastructure to support mining activities, such as roads (Jain et al., 2016b; Lawrence et al., 2017), ports, railway tracks (Mitchell and O'Neill, 2017), and power lines. This occupies significant portions of cultivable land and causes disproportionate destruction of biodiversity. All these menaces have significantly contributed to land-use changes and pose serious pollution hazards to human health (Yang et al., 2018), the environment, and agriculture (Festin et al., 2018). After excavating the minerals they are interested in, most of these mines leave the open-pit uncovered (Yang et al., 2018). After the mine is closed, the site is usually filled up with overburden materials (Rankin, 2011) or open-pits. When no effort is made for revegetating the land, it causes enormous land-use change. The disposal of such large volumes of waste generated from mines causes land-use changes and poses tremendous health challenges to the mining communities. Fig. 2 below shows the activities of small-scale illegal mining on the land.

2.2.2. *Impacts of mining on soil quality*

One of the areas that cannot be left out regarding the impact of mining on the environment is its effects on soil quality. Most mining sites are incapable of supporting crop production due to severe soil erosion (Fig. 3) (Asensio et al., 2013) and heavy soil compaction caused by the use of heavy machinery (Obiri-Nyarko et al., 2014; Sheoran et al., 2010). According to Mahar et al. (2016), mineral extraction significantly changes the soil's pH in dump-sites. Sometimes, the pH becomes highly acidic or basic, which is unhealthy for human use. The pH of a mining dump-site situated in Central Coalfield Limited (CCL) within the North Karanpura in the Ranchi district of Jharkhand State of India varies from 4.9 to 5.3 in addition to toxic heavy metals such as nickel, cadmium, and lead, which further worsens the situation (Maiti and Ghose, 2005). The pH of an existing mine or dump-site varies according to factors such as the underlying parent rock (Mahar et al., 2016), chemicals used during the mineral processing (Mitchell and O'Neill, 2017), and the physico-chemical composition of the heavy metals present (Sheoran et al., 2010). When the pH becomes too acidic or basic, it cannot fully support healthy

Fig. 2. Effects of Surface mining on the land. (a) Illegal mining ("Galamsey") (b) deposited slurry from surface mining in Ghana [**Reproduced with permission from** Mensah et al., 2015**).]** .

Fig. 3. (a, b, c & d) effects of mining on soil quality; (a & b) spontaneous sprouting of grasses from tailings due to low fertility (lack of N, P & K), Wind erosion on degraded soil (c) and compacted slurry after abandoned mine in Zambia (d) [**Reproduced from** Festin et al., 2018].

plant growth (Ghose, 2005; Yang et al., 2018). Even some soil microbes which carryout essential soil functions cannot survive in such soils hence rendering the soil unproductive.

Moreover, Sheoran et al. (2008) found out that the three most important plant nutrients (nitrogen, phosphorus, and potassium, (N, P, K)) were deficient in overburden dumps. This makes it unable to support plant growth unless supplied with fertilizers (Ghose, 2005; Sheoran et al., 2008). However, some micronutrients such as Fe, Mn, Cu, and Zn were present (Das and Maiti, 2005). Soil microbes, another vital component of the soil, have been studied. Soil microbes ensure aggregate stabilization, a necessary condition for maintaining structural stabilization of the soil (Nakazawa et al., 2016), improves pore size (Porosity) (Mahar et al., 2016), and enhances decomposition. However, studies (Feng et al., 2013; Sheoran et al., 2010) indicated that soil microbes' activities drastically declined once the soil profile was disrupted through compaction and blasting. Once their activity declines, they are slow to resume independently. Soil microbes consist of fungal and bacterial species that carry out decomposition and initiate a symbiotic relationship with several plants. They facilitate the uptake of essential nutrients like nitrogen and phosphorus in exchange for carbon (Festin et al., 2018). Contrary to this, most mining sites lack these important functions hence cannot support plant growth. They also produce polysaccharides that advance soil aggregation and enhances overall plant growth and performance (Das and Maiti, 2005; Festin et al., 2018).

Additionally, stockpiled soil, which comes as a result of heaping topsoil together, a common phenomenon in the mining industry, significantly affects the soil's biological, chemical, and physical properties (Carlson et al., 2015; Asensio et al., 2013). In an earlier study, Amegbey (2001) explained that stockpiled soil after a long time became anaerobic, causing plant propagules and other useful macro and microorganisms to die or significantly reduced. This affects the general quality of soil biodiversity and ecosystem functions . The stockpiling process also generates heat that kills some useful soil organisms that cannot endure such high temperatures. Amegbey (2001) indicated that, once the vegetation cover is removed, it invariably degenerates into the loss of some vital plant nutrients from the site. It takes a long time for such soil to naturally revegetate (Fig. 3 below).

The University of Connecticut, College of Agriculture and Natural Resources, Cooperative Extension System (2003), specified that when the organic matter content in soil is less than 4%, it is considered low, between 4% and 8% is considered medium and above 8% is seen as high organic matter content which is a necessary condition for optimum plant growth. However, Assel (2006) studied the site soil of Golden Star Resources, a gold mining company in Ghana, and found out that the site's soil organic content was approximately 0.14%. This is far below the recommended level of soil organic content ideal for plant growth. Therefore, it is imperative that after mine closure, the land should be restored to value for more productive use.

2.2.3. *Impact of mining on water quality*

The impacts of mining activities on water pollution have been recorded in many studies worldwide (Hilson, 2002; Aryee et al., 2003; Bloch and Owusu, 2012). Groundwater pollution due to acid mine drainage (AMD) and seepage flowing from disposed mine waste are the most common water pollution arising from mining (Likus-Cies′lik et al., 2017; Sracek et al., 2010). AMD is often produced when there is an exposure of sulfide-bearing rocks to oxygen and water. For instance, coal mining produces a significant amount of AMD. The AMD produced may contain toxic chemicals such as arsenopyrite, sulfur, and pyrite, which can easily seep into waterways and cause underground water pollution. In 2010, a coal steam gas operation in Queensland, Australia, resulted in groundwater contamination with a combination of dangerous chemicals such as benzene, toluene, ethylbenzene, and xylene (BTEX) (Gibria, 2014). A study conducted by Mensah et al. (2015) on the environmental impact of mining in Ghana Prestea, found out that most of the major rivers in the mining communities, which served as the primary source of water for both domestic purposes and farming were heavily polluted by the activities of mining (Fig. 4 below). The activities of small-scale illegal mining caused the majority of this water pollution, the study added. Fig. 4 below shows the mining effect on two different rivers (river Ankobra, left and River Aseesre, right) in Ghana by illegal small-scale mining activities. The illegal small-scale mining creates tailings dams containing toxic chemicals such as cyanide, mercury, arsenic, and other solid suspensions. After some time, these reservoirs cause spillage and leaks into the rivers (Titshall et al., 2013) and streams hence causing severe water pollution. To a larger extent, it causes disfiguration of water channels which results in drying up the water (Witze and Kanipe, 2015). The tailings dam is a slurry-like combination of residuals and throw-outs from the mine, which ultimately discharges into the lagoons (Festin et al., 2018). Tailings dams are characterized by low organic matter, low pH, high acidity, and a myriad of heavy metals (arsenic, cadmium, copper, manganese, lead, and zinc) with low stability and cohesion (Table 2 below) (Mensah, 2015; Titshall et al., 2013; Wong, 2003). Table 2 below shows the characteristics of a typical tailings dam from Zambia.

Furthermore, Kumah (2006) revealed that from 1994 to 2001, major rivers in Ghana such as Anikoko, Angonabe, Bodwire, and Assaman rivers all in the western part of Ghana were heavily contaminated by cyanide spills. This resulted in a significant loss of aquatic lives, pollution of drinking water for some communities, and eventually, displacement of people as those rivers served as their primary drinking water. Studies (Festin et al., 2018; Mensah et al., 2015) have estimated that about 5 tons of mercury are released every year into water bodies, which has caused siltation and coloration of rivers streams. When this happens, the water bodies either dry up due to the severe siltation or become toxic for domestic use (Titshall et al., 2013). Aquatic organisms, both fauna, and flora in the water bodies, are destroyed leading to their extinction due to the de-oxygenation caused by mercury discharges. On the other hand, large-scale mining mostly underground mining uses explosives for blasting to pave the way for the mineral ore of interest. The effect of blasting is that it causes a breakdown of the soil profile (soil structure and texture), affecting the soil water holding capacity due to the substantial level of ground vibration (Mensah et al., 2015). Usually, during blasting, drilled holes are loaded with a certain number of explosives through detonating techniques to break rocks into fragments to reach the mineral ore (Agbeno, 2001). When this happens, it causes severe vibration, which interferes with sleeping or causes stress-related diseases like hypertension and causes irreparable damage to the underground water table (Bolong, 2016). This is evidenced by the fact that most mining communities do not get clean drinking water even from their boreholes. Some of the boreholes discharge dirty water (water mixed with mud) instead of clean water making residents' life uncomfortable. In a study, Adel (2013) reported that 40 hard rock mines in the United State of America caused in perpetuity the pollution of 17–27 billion gallons of water every year. The report added that it would cost the United States an estimated amount of 67 billion US dollars to treat these polluted waters per year caused primarily by acid mine drainage. This further deepens the severity of the extent of water pollution caused by mining activities, which needs the world's urgent attention.

Fig. 4. Pollution of two different rivers (river Ankobra, left and River Aseesre, right) in Ghana by illegal small-scale mining activities. [**Reproduced with permission from** Mensah et al. (2015)] .

Table 2
Composition of heavy metals and their concentration in mine wastes in Zambia (Chileshe, 2014).

Mine waste	Composition of various waste content									
	Clay (%)	Total Organic C(%)	Total N (mg/kg)	Bulk density (g/cm)	P (mg/kg/g)	K (mg/kg)	Mg(mg/kg)	Ca (mg/kg)	Na (mg/kg)	PH
Tailings dam	5.85	1.32	500.48	1.49	5.05	35.9	853	3309.5	50	7.89
Overburden	5	1.37	500	1.44	5.27	35	111	243	50	5.72
Mine waste	Composition of Heavy metals (mg/kg)									
	Cu	Co	Ba	Zn	V	Pb	Ni	Cr	As	Cd
Tailings dams	12,233.33	333.5	147.08	66.08	20.42	20.17	19.83	14.23	6.21	0.60
Overburden	5708.33	136.67	272.42	49.75	26.75	5.76	21.33	20.92	1.04	0.25

2.2.4. *Impact of mining on vegetation/ecosystem*

The impact of mining on vegetation is complex and diverse, depending on the type of mining and mining intensity. According to Festin et al. (2018), overburden stockpiled waste, alteration of the natural landscape, and creation of tailings dams are the most noticeable impacts of mining on the ecosystem. Also, mass clearing of the vegetation by mining activities can lead to slow biomass growth and fading of the vegetation. When this happens, carbon (CO_2) stored in the vegetation is lost, and the vegetation's ability to act as a carbon sink fades gradually (Huang et al., 2015). During mineral extraction, large quantities of topsoil are being exhumed to pave the way to reach the ore deposit. Top-soil covers the poor substrate and also provides improved growth conditions for plants. Mostly, the topsoil is rich in organic matter that contains the majority of the plant nutrients. Hence, removing it affects the biological, chemical, and physical properties of soil, which also affects plant growth (Sheoran et al., 2010). Moreover, Mensah et al. (2015) have indicated that the most pronounced effect of mining on the ecosystem is the loss of vegetation cover (Table 3). The authors expounded further that large tracts of land in six communities (Anfegya, Nankaba, Bondaye, Ashtown, Asoampa, Ankobra) where they conducted the study had lost its vegetation cover entirely. The repercussions of such a phenomenon are rapid development of massive gullies (Soulard et al., 2016), reduced soil water infiltration (Huang et al., 2015), excessive run-off, rapid erosion (Yang et al., 2016), reduction in groundwater recharge and eventually, permanent loss of land productivity (Jing et al., 2017; Yang et al., 2016).

While underground mining might have caused significant upshots on the vegetation cover (Yang et al., 2018). However, small-scale gold mining has been the major cause of loss of vegetation cover and mass deforestation in Africa (Cullen-Unsworth et al., 2014; Owen and Kemp, 2013). In small-scale illegal mining, open-pits and trenches are left uncovered, and this takes several years for the land to regain its productivity and become useful. In most cases where the open-pit is deep beyond a certain level, it becomes a trap for wildlife as some wild and even domestic animals can fall inside and cannot get out of it. Hilson (2001) further explained that surface clearing destroys biodiversity, such as flora and fauna, and produces air-borne particulate matter responsible for causing air pollution. Most flora and fauna in previously mined sites have suffered a loss of habitat and habitat fragmentation (Duri, 2016). Some of these living organisms, mostly insects, are vital for human life as they carry-out pollination and other ecosystem functions, which helps man's survival. Some of the major environmental/ecosystem effects of mining are erosion (Yang et al., 2018), sinkholes (Yang et al., 2018; Yang et al., 2016), soil contamination, loss of biodiversity (Soulard et al., 2016), ground and surface water contamination by the chemicals emitted from machines (Cravotta et al., 2014).

Moreover, the method of surface mining used by mostly registered large-scale, small-scale, and unregistered artisans often leads to disproportionate destruction of productive land, deforestation of forest cover, and mass trenching. Also, putting up infrastructure such as roads (Jain et al., 2016b; Lawrence et al., 2017), ports, railway tracks (Mitchell and O'Neill, 2017), and power lines to support mining activities can significantly affect migratory routes of animals and increase habitat fragmentation. Aryee et al. (2003) added that destroying the microbial community often results in low soil fertility and, ultimately, low soil productivity. According to Babut et al. (2003), land degradation and loss of cultivable land area are some of the most extreme gold mining effects. The authors stated that small-scale mining has led to about 26% loss of forest cover and 15–20% loss of arable land in five communities (Tarkwa, Dunkwa, Esaase, Ayanfuri, and Bogoso) in Ghana. Sheoran et al. (2010) indicated that mining, especially surface mining, often discharge large volumes of waste, which has enormous consequences on vegetation (see Table 3). Most mine-waste, especially underground mining, contains toxic heavy metals and other poisonous chemicals shown in Table 2 above. These substances make the vegetation unhabitable for most flora and fauna (Chileshe, 2014; Das and Maiti, 2005). When this happens, the rich ecosystem gets hampered, and ecosystem activities seize to continue in a short while.

Similarly, Sampat (2003) revealed that the quantity of waste produced depends on two important factors: the type of mineral extracted and the size of the mine. The study further explained that gold and silver are the two most wasteful minerals where 99% of its ore extracted end up as waste products, which pose severe threats to human health. The impacts of this waste on the environment and the individuals' health are often more for open-pit mines than it is for underground mines (Hilson, 2001), which tend to produce less waste. Del (2013) added that the extent that open-pits containing contaminated water from mines in the USA Nevada, is rising is disturbing and constitute an environmental and ecosystem threat. The problem is at its worst in Nevada, where it has been determined that mine pits from gold mines will contain more water than all of the freshwater reservoirs in the state, excluding Lake Mead.

2.3. *Social impact of mining*

According to the Center for Social Impact SCI, social impact is simply the "net effect of an activity on a community and the well-being of individuals and families." Mining contributes substantial adverse effects to society vis-à-vis its positive impacts. Some of the negative social impacts of mining may include a high crime rate and conflicts (Venkateswarlu et al., 2016), displacement of farmlands, and families (Tello, 2015). The migration of people from different communities to mine sites also results in high prices of goods and services within these communities (Ocansey, 2013). The reason behind the migration or influx of people to mining communities could be to engage in petty trading, to find jobs, or to enjoy certain existing essential facilities like clinics, schools, street light, and rehabilitation centers. This results in many social vices such as prostitution, drug abuse, gambling, physical assault, and arm robbery (Fussein, 1996) cited in Ocansey (2013). To stress this further, Adu-Yeboah et al. (2008) expounded that most young ladies who migrate to mining areas for trading or jobs end up resorting to prostitution after they could not find any better job. Sometimes, a whole community or a whole family could be displaced due to loss of farmlands, contaminated water, or fire outbreaks (Goswami, 2014) or high toxicity of the environment due to poisonous chemicals siltation and spillage (Warner et al., 2010). The atmospheric impact of mining on society is enormous. The emission

Table 3
Impacts of mining on the major subsectors of the environment.

Sector	Subsector	Major impacts
Ecosystem/ Vegetation/ Forestry	Flora Fauna Forest species	Many wildlife species depend on vegetation for food, nesting sites, and cover for an escape from predators hence, clearing the vegetation exposes them to danger. Displacement and loss of biota (flora and fauna) through the removal of vegetation and the topsoil. Habitat fragmentation and disruption of food chain hence limiting dispersal or cutting off migratory routes which lead to the decline of species. Clearing of site depletes the forest of several essential resources to man such as timber. This affects the wood industry which leads to higher prices. Reduction and weakening of the carbon sink
Land		Mining activity produces a large volumes of waste rocks, sludges, mill water, and tailings. This pile up on the surface of the land and occupy relatively large areas of land, reducing land use availability and increasing pressure on land supply. Open trenches and gullies mostly by surface mining not only pose a threat to human life but reduce available land size. It also serves as a gateway to easy erosion of the land. The use of heavy-duty equipment such as excavators, trucks, and blasters etc. causes severe compaction of the land
Water	Watercolor Water pH Water odor Turbidity Water biodiversity	Acid mine drainage (AMD) can discolor the receiving water bodies; Drop of water pH (streams, lakes, and rivers) that receive discharges from AMD; Discharges from mine effluents and seepages can affect drinking water quality such as color, odor, turbidity etc. Significant concentrations of sulfate, metalloids, and metals from waste mines and impoundments at sulfide mines contaminates underground drinking water sources. Decrease biodiversity, changes in species diversity, and death of fish and other water organisms due to the high concentration of bioavailable metals and metalloids. Heap leaching and blasting can cause elevated levels of cyanide and nitrogen compounds (ammonia, nitrate, nitrite) in water.
Soil	pH Texture Structure Percolation Microorganism etc.	Waste rocks, overburden piles, and spoils affect soil quality such as soil pH, soil texture, and soil structure etc. Spills, stumbles, leaks from hazardous materials and windblown particulate matter or dust can lead to contaminate the soil. Destruction of the soil through surface disturbance or excavation leads to soil erosion, soil infertility, and soil toxicity which eventually leads to the inability to support plant growth. Physical disturbance of the topsoil during stripping, stockpiling, and reinstatement causes unusually large N transformations and eventual loss of it. Loss of N-fixing and disruption of microbial community growth
Air	Air Quality	Particulate matter from overburden containing toxic heavy metals such as arsenic, cadmium, and lead affects the human respiratory tract, skin, eyes. During pyrometallurgical processes, some metals such as zinc, mercury, cadmium and arsenic emit poisonous gases when heated which renders the air dangerous for human health. Loss of CO_2 uptake capacity due to depletion of dense tropical and rain forests where large scale mining operations mostly take place. This results in an unhealthy balance between CO_2 emission and CO_2 uptake.

Authors' compilation, (2020).

of gaseous pollutants does occur during the burning of sites and other operations that involve ore reduction (Aryee et al., 2003). One common practice of mining is the burning of gold amalgam in the open air, which produces hazardous fumes into the atmosphere. This endangers their lives as well as nearby settlers.

Furthermore, poor compensation schemes given to farmers by miners is another significant problem. This can lead to land-use conflicts between farmers and mining companies. Ocansey (2013) stated clearly that most land-use conflicts in Africa between farmers and mining companies resulted from unsatisfactory compensation schemes. A situation where the mining communities feel that the mining proceeds are unevenly or unequally shared, it can lead to tension and uprising. Asides from this, air pollution resulting from burning and discharge of airborne particulate matter can make lives in mining areas quite uncomfortable (Dontala et al., 2015) as the environment is polluted with chemicals, smoke, and fumes. The largest air pollution sources from mines come from particulate matter transported by the wind from excavations, transportation of materials, blasting, fugitive dust from tailings facilities, waste dumps, stockpiles, and haul roads. Additionally, exhaust emissions from mobile sources such as cars, trucks, and other heavy-duty equipment raise these particulate levels. Combustion of fuels in stationary and mobile sources, explosions, and mineral processing also releases many gases into the atmosphere. This can lead to conditions like pneumoconiosis (black lung diseases), asthma among miners and settlers nearby (Dontala et al., 2015; Ocansey, 2013) hence forcefully causing many people to relocate to different communities with its attendant consequences. Again, some young men engaged in the mining end up losing their lives due to either physical assault or the collapse of the shift valleys (Motseo, 2013).

3. Restoration of abandoned mined lands

Land degradation, soil toxicity, nutrient deficiency, and pollution are major threats to world economic progress. As stated earlier, mining has eroded about 40,000 km^2 of land in China alone, and the abandoned mine land records an annual increase of about 330 km^2. These abandoned mine land usually suffer from deficient plant nutrient (N, P, K), toxic chemicals, poor physical structure, and extreme soil pH (Zhou et al., 2015). Also, an earlier report from the World Resource Institute (WRI, 2016) showed that more than 700 million ha of land in Africa is degraded. Given this, restoration of mined sites or lands is essential to every nation, whether developed or developing (Lima et al., 2016; Mborah et al., 2015). Regardless of the mining scale, the mining site must ensure that the land is restored to its original use or even to a higher value after its closure (Pietrzykowski, 2015; Wu et al., 2010). Cooke and Johnson (2002) indicated that mineral ore gets depleted with time, bringing a particular mine to closure. The process of ensuring that the ecological integrity of previously disturbed land is restored is called land restoration. According to Sheoran et al. (2010), land reclamation includes managing the soil to ensure that the chemical, physical, and biological disturbances of the soil, including the soil fertility, pH, microbial community, and other nutrient cycles that rejuvenates the soil to bring back its productivity are well adhered to. Whereas, the Society of Ecological Restoration said, “Ecological restoration is the process of supporting the recovery of an environment that has been degraded, damaged or destroyed‘‘. Meanwhile, the traditional way of restoring lands was by long rotation forest following. The difficulty with the traditional method is that currently, the population is fast increasing, and pressure is been mounted on available land space; hence, long rotation fallows are not ideal. In the mining setting, restoration is often the same as rehabilitation and could be put as the progression towards regaining the native ecosystem (Lima et al., 2016). According to Cooke and Johnson (2002), post-mined land restoration stages are the restoration goal, restoration objectives, and quantifiable success criteria. The restoration goal should be sustainable and able to meet the local people's needs at an affordable cost. The objectives for the restoration should be prioritized to know what comes first, and the success achieved should have a defined scale over time (Barrow, 2012). In this review, all three terms, thus, reclamation, restoration, and rehabilitation have been used interchangeably to mean the same thing.

Both the federal government and local governments must enforce laws to make land restoration an integral of the mining industry. According to studies (Kavamura and Esposito, 2010; Lone et al., 2008; Lebrun et al., 2017), long-term mine spoil reclamation should be able to establish stable and sustained nutrient cycles that would engineer both microbial activities and nutrients replenishment. Certain factors should be considered before planning for restoration. According to studies (Forjan et al., 2017; Holl and Aide, 2011), every restoration approach, either active or passive, hinges on four essential criteria thus (1) the goals for restoration; (2) the context of landscape; (3) resilience of the ecosystem and (4) the estimated cost of the restoration. These four criteria are carried out based on the three major practices/methods of land restoration: physical restoration, chemical, and biological (Asensio et al., 2013; Festin et al., 2018). None of these three methods works best alone. The three practices should be carried to complement each other to facilitate easy recovery and rehabilitation of the land. Carrying out these three major restoration practices helps the degraded land regain its fertility to support optimum plant growth (Carlson et al., 2015). Given this, increased land productivity of most degraded soils or mine wastelands can be achieved by adding some soil amendments such as saw-dust, wood residues, sewage sludge, poultry droppings, and animal manure to stimulate and improve microbial growth. It should be noted that during reclamation, the pre-mining soil conditions could be achieved easily when these amendments succeed earth-works and precede planting of grass and tree species (Barrow, 2012; Forja'n et al., 2017). In this case, all three methods, thus physical, chemical, and biological methods, have been applied. Some mine reclamations have resorted to the use of only one or two methods or even natural succession. The disadvantage of this practice is that the reclamation process may take a longer time and the landscape might not be suitable for multipurpose land-use. For instance, the degree of open-pits and the magnitude of the landscape's alteration could be so severe that earth-work must be done first before starting any soil amendment practices (Asensio et al., 2013; Beesley et al., 2011; Farrell et al., 2010). The three methods of land restoration or reclaiming degraded wastelands have been discussed in detail below.

3.1. Physical/mechanical method

The physical restoration method focuses on the earthworks, thus putting the land back to its virgin shape after mining. The overall objective of the physical method seeks to achieve three things (1) reduce erosion, (2) reduce soil compaction while improving soil quality, and (3) create conditions appropriate for revegetating the mine wastelands. According to Seenivasan et al. (2015), plowing, grading, smoothing, and topsoil replacements are often carried out. Contouring and soil amendments such as adding organic matter, topsoil, or biochar are also done to reduce the speed and effect of run-off and enhance microbial community development. During the process of restoration with topsoil, the soil could be moved from nearby sites or salvaged topsoil from old mines is used (Mensah, 2015). However, some studies (Bradshaw, 2000; Festin et al., 2018; Sheoran et al., 2010) have specified that this process is expensive because the salvaged topsoil can have low nutrient and biological quality due to a more extended period of stockpiling. Topsoil and manufactured technosols are mostly used in physical treatment. Technosols are mine wastes usually modified with organic materials like manure, paper mill wastes, sewage sludge, or green-waste compost (Pietrzykowski et al., 2017). Amending soils with organic scums is an effective and ideal method for increasing soil quality with less treatment (Asensio et al., 2013; Festin et al., 2018). While this method proves to be cost-effective, it is also relatively non-destructive to the environment compared to the use of topsoil removed and brought in from nearby sites. Using vegetative compost can increase microbial growth and reduce the impact of erosion from run-off (Carlson et al., 2015). The compost decreases the concentration of contamination within the soil, binds soil particles together through a strong, cohesive bond, and creates a more suitable growing environment for plants (Watkinson et al., 2017). The high incorporation of organic materials in the manufactured technosols can increase soil water and nutrient holding capacity and concentrations, respectively. This allows pioneer species to colonize the soil, enabling the soil to return to its virgin state. According to Tetteh et al. (2015), slope-battering or earthwork was initially carried out to reshape an abandoned gold mine landscape. Topsoil amendments using poultry droppings, cow dung, and chemical fertilizers, especially Nitrogen, Phosphorous, and Potassium (N, P, K), were immediately applied to the oxide-containing materials, and crest drains were created to minimize the effect of run-off and erosion.

Furthermore, Shutcha et al. (2015) investigated the potential of applying limestone and compost on degraded technosols. Results showed that both limestone and compost could be an effective amendment for boosting crop yield as well as heavy metals immobilization and reducing their deleterious impacts on plant fecundity. Nevertheless, some organic materials are not suitable for the manufacture of technosols. For instance, Watkinson et al. (2017) indicated that technosols with high proportions of primary paper sludge have higher pH, which caused lower shoot biomass in plants than technosols manufactured from woody residuals. An earlier study by Cuske et al. (2016) also showed that alkaline sewage sludge dramatically increased Cu phytotoxicity. This can also significantly impact soil biota and ultimately threaten agriculture productivity on such reclaimed soils. Recently, using biochar as an amendment for reclaiming abandoned mine land has gained global attention. Biochar is a carbon-like material made by burning organic material from agriculture and forestry. It is produced by pyrolysis of plant biomass at mostly 300–1000 °C (Spears, 2018; Zhang et al., 2012). Biochar also contains some essential plant nutrients such as N, P, K, Ca, Mg, Fe, and Zn. These are bioavailable for plant growth (Forja'n et al., 2017; Sovu et al., 2011). Recent studies (Lebrun et al., 2017) have suggested that biochar can affect the behavior of heavy metals in the soil by varying their availability, transport, spatial distribution, and solubility. The application of biochar can also increase the soil's pH and enhance the physical properties of soil by raising its porosity and thereby its water holding capacity (Carlson et al., 2015), hence immobilizing heavy metals and reducing the uptake by plants (Lomaglio et al., 2017).

3.2. Chemical method

Contaminants such as heavy metals, metalloids, and asbestos are removed from the soil, and the soil's pH corrected using chemical methods (Mensah, 2015). In a real-world scenario, the chemical method is generally done alongside the physical or mechanical method. The chemical method focuses primarily on the addition of chemical fertilizers (Nitrogen, phosphorous, and potassium), and the addition of other important micronutrients such as zinc, copper, lime, and synthetic chelates. The overall objective of the chemical method of soil reclamation is to improve plant nutrient uptake, correct the soil pH, improve the soil texture and structure, enhance heavy metal bioavailability, and solubility. Ultimately, it improves overall soil physicochemical properties and reduces soil contamination (Forja'n et al., 2017). Seenivasan et al. (2015) attempted to amend sodic soils (salt-affected soils) in south India's semiarid regions. A combination of different treatments was carried out after earth-battering (physical treatment) involving the addition of gypsum (chemical treatment), spreading decomposed bagasse pith, and green manuring with Sesbania rostrata and Eucalyptus camaldulen-sis (phytoremediation) (See Table 4 below). Results indicated that a reduction of 10% in soil pH was achieved, electrical conductivity (33% reduction), and 20% in exchangeable sodium percentage was achieved compared to the initial values.

Moreover, Acid mine drainage (AMD) is the most important mine waste that causes a soil's chemical transformation. One of its major effects on the soil that needs to be corrected is that it lowers the soil pH. As such, to correct AMD, the soil pH has to be elevated beyond the threshold for iron-oxidizing bacteria. According to Mensah (2015), the soil's pH can be elevated by adding inorganic chemicals such as limestone and biologically treating the soil, such as adding organic materials (Seenivasan et al., 2015). If the pH value is below 3.5, Fe (III) acts as an oxidizing agent of pyrite . Earlier studies by Heyden and New (2004) reported that AMD is corrected through buffer by applying residual lime to impoundment dams. Others have indicated that adding synthetic chelators such as ethylenediamine, tetraacetic acid (EDTA), diethylenetriamine pentaeacetic acid (DTPA), and ethylene glycol tetraeacitic acid (AGTA) improved the bioavailability and solubility of heavy metals (Festin et al., 2018; Pereira et al., 2010). Chelates increase metal solubility in soils, overcome the diffusional limitation of metals in the rhizosphere and facilitate translocation of metals from the root region to the shoot (Zhou et al., 2015). Chelating reagents that are strong such as Sodium-EDTA, are used for increasing the flexibility and bioavailability of the bonded metal ions and soil phase. For example, when calcium salt ($Ca(H_2PO_4)_2\ H_2O$) with low solubility was applied on Mg-contaminated soils, it aided the plant growth rate (Wang et al., 2015). Also, when oxide-containing material was spread on the topsoil, it improved the soil stability (Tetteh et al., 2015). However, the problems limiting the application of the chemical method are high skill/technicians demand, high cost for chemicals, high cost for machines, and potential for secondary pollution of groundwater, which can adversely affect soil quality in the event of an excessive application (Wu et al., 2010).

Additionally, nanoparticles' application has also come to the limelight as a novel method for the restoration of mine wastelands due to their large specific surface area, deliverability, and responsiveness (Liu and Lal, 2012; Tafazoli et al., 2017). The authors noted that zero-valent iron nanoparticles, zeolites, iron sulfide nanoparticles, phosphate-based nanoparticles, and carbon nanotubes (CNT) have significant potential for soil reclamation. When zero-valent iron nanoparticles were applied to heavy metals contaminated mine site, there was a corresponding increased removal of heavy metals and improved growth of the planted tree seedlings (Tafazoli et al., 2017).

Table 4
Chemical composition of the various soil amendments (Seenivasan et al., 2015).

Parameters	Gypsum	Green manure	Composted bagasse pith	Eucalyptusleaf litter
Total N (%)	Trace	2.07	1.72	1.27
Total P (%)	0.23	0.48	1.62	0.17
Total K (%)	Trace	1.96	0.63	0.94
Calcium (%)	19.50	0.90	1.96	1.08
Magnesium (%)	3.05	0.71	1.35	0.75
Carbon (%)	Trace	31.20	31.50	27.80
Zinc (mg/kg)	Trace	425.00	375.00	368.00
Iron (mg/kg)	Trace	68.00	39.00	17.00
Manganese (mg/kg)	Trace	152.00	218.00	75.00
Copper (mg/kg)	Trace	12.00	16.00	8.00
C: N ratio	–	15.07	18.31	21.88

3.3. Biological method

The biological method, sometimes called phytoremediation, involves introducing microbes and green plants to carry out phytoextraction and phytostabilization to minimize the noxious effects of existing and potential contaminants (Mendez and Maier, 2007). The biological method improves overall soil quality for pioneer spices to boost revegetation, modifies the bioavailability of heavy metals in the soil, and increases plant growth. Since natural revegetation may be slow due to poor soil quality and may even bring evasive species which are undesirable and harmful, phytoremediation methods of soil reclamation and revegetation such as phytostabilization and phytoextraction have proven as a better alternative (Fig. 5 below). Phytoremediation includes two stages: phytoextraction, which includes uptake and translocation of heavy metals by plants; phytostabilization, where plant species, as well as soil amendments, are used for the immobilization of heavy metals through absorption and accumulation by their roots, shoots, or precipitation within the rhizosphere (Bolan et al., 2011). Mostly plants used for biological amendments have two major strategies for heavy metal resistance, thus exclusion and accumulation. Plants that limit metals' translocation to their upper parts (aboveground part) and therefore maintain fairly low concentrations of heavy metals in their shoots are excluders. On the other hand, the accumulators translocate and build up high levels of metals in their upper regions (shoots) (Peng et al., 2012; Festin et al., 2018). Some plant species can accumulate more than 1000 lg g^{-1} of chromium, nickel, copper, cobalt, and lead or more than 10,000 lg g^{-1} of zinc and manganese in their harvestable portions or aboveground dry matter; such plants are called hyperaccumulators. More than 420 hyperaccumulators have been known worldwide and 5 reportedly identified in China (Faucon et al., 2007; Li, 2006; Li and Tang, 2004), 30 identified in South Central Africa (Faucon et al., 2007). While studies on phytoremediation over three (3) decays now has focused primarily on grasses and shrubs, Chaturvedi et al. (2012) revealed that trees could be better alternatives since they have a more in-depth and more prominent root system. Trees produce comparatively larger biomass, which can decontaminate soils for more extended periods and accumulate more significant amounts of heavy metals.

Despite the potential of phytoremediation techniques in treating mine wastelands polluted with heavy metals and other contaminants, it has some limitations, especially phytoextraction. For instance, (1) Most naturally occurring hyperaccumulator grass and shrubs species have slow growth and low biomass production; (2) long period needed to remediate contaminated soils; (3) risk of recycling of heavy metals back into the environment if appropriate disposal mechanisms are not in place; (4) limited bioavailability of metals; (5) their applicability is limited. For instance, not all hyperaccumulators are suitable for all sites containing moderately or highly toxic concentrations of metals (Ali et al., 2013; Sarwar et al., 2017). Consequently, a better alternative and sustainable technology called phytostabilization emerged over the years (Bolan et al., 2011; Titshall et al., 2013). As indicated earlier, grasses and shrubs used for phytostabilization limit heavy metals' translocation to their upperparts. This helps them to preserve a relatively low concentration of heavy metals in their shoots. Comparatively, native plants are highly preferred to non-native plants for phytostabilization purposes to decontaminate metalliferous sites. The reason being that such species can survive, grow and reproduce under such tense conditions (Titshall et al., 2013).

Moreover, to ensure the successful implementation of phytostabilization, soil amendments should be a fundamental prerequisite to improve the growing conditions of the species and carry out immobilization. This decreases the heavy metals' bioavailability and then prevents food chain poisoning through leaching from heavy metals (Erakhrumen, 2007). As indicated earlier, heavy metal immobilization can be improved using synthetic chelators, rhizosphere, microbes, and biochar in combination with organic residues (Sarwar et al., 2017). For instance, Mahmoud and Abd El-Kader (2015) revealed that the use of

Fig. 5. Restoration stages of rare earth mine at Heping county in China; (a) Original mined land, (b) the land with ecological restoration for 2 years, and (c) the land with ecological restoration for 5 years **[Reproduced from** Zhou et al. (2015)**]**.

phosphogypsum led to an increased immobilization of four heavy metals (zinc, nickel, lead, and cadmium) than when phosphogypsum was combined with rice straw composites. However, a later investigation revealed that the phosphogypsum combined with rice straw composites treated soils significantly improved canola's biomass production. Also, Seth (2012) observed that fungi altered root exudates' composition and the soil's pH. This modified and enhanced the heavy metal bioavailability and their uptake by the plants. Some microorganisms, such as bacteria that promote plant growth and mycorrhizal fungi influence heavy metal availability and uptake at the rhizosphere. These bacteria have proven to lessen the toxicity of heavy metals (Chen et al., 2015; Rajkumar et al., 2012).

The use of biochar as a soil amendment for immobilizing heavy metals from mine wastelands has proven to be the most affordable and effective method so far (Beesley et al., 2011; Festin et al., 2018). Biochar immobilizes heavy metals and improves soil quality parameters (Carlson et al., 2015) such as soil aeration, microbial community growth, better soil texture and structure, and soil pH. Due to properties such as high pH, alkalinity, and large specific surface area, biochar can effectively immobilize toxic heavy metals (Namgay et al., 2010; Paz-Ferreiro et al., 2014). A study investigated the response of woody plants to soil amended with biochar. It concluded that the addition of biochar caused about a 41% average increase in biomass and hence holds promise for forest restoration (Thomas and Gale, 2015). Also, Ilunga et al. (2015) concluded that planting of trees species as a site amendment strategy created a long-term vegetation cover with improved soil conditions such as less compacted soils and reductions in soil bulk density due to the deep roots system. Trees such as Acacia mangium Willd, Gliricidia sepium (Jacq.) Kunth ex Walp, Leucaena leu-cocephala (Lam.) de Wit and Senna siamea (Lam.) were planted on an abandoned mine wasteland in Ghana (Tetteh et al., 2015). It improved soil stability and effectively enhanced the land's return to its original state between 1 and 11 years. Nevertheless, in an earlier study, Bozzano et al. (2014) remarked that native tree species adapted to mine sites significantly reduced their mortality rate. Studies of contaminated mine sites have shown that trees that are either legumes or pioneer species showed a higher survival rate. Examples are species of Acacia and Leucaena (Mensah, 2015), and species of Albizia (Gathuru, 2011; Singh et al., 2004). According to Siachoono (2010), after refilling the open-pits with the topsoil of an abandoned mine in Kenya, 26 tree species were planted on the site. After six months of planting, three species (*Casuarina equisetifolia* Forst, Conocarpus lancifolius Engl. and Diels and Cocos nucifera L. (coconut palm)) survived. Out of the three that survived, one of them was dominant and behaved as a pioneer species with evergreen foliage. The next stage was the introduction of microbes such as millipede to initiate organic matter formation. After 30 years of restoration, more than 510 species of different organisms were found there. More recently, the use of transgenic plants has also emerged. In this novel technology, plants are genetically engineered through the insertion of transgenes for increased bioaccumulation and degradation of metals (Venkateswarlu et al., 2016). For instance, the heavy metal resistance gene, ScYCF1, (extracted from yeast) was introduced into popular trees, and it reduced toxicity symptoms, enhanced growth, and yielded higher phytoextraction capacity (Shim et al., 2013).

3.4. Post mining land-use selection

Mining is temporary land use. Mostly, the mine is closed when the resources are depleted. After its closure, there is a need for proper restoration and a sound land-use selection. Usually, in planning the selection process it is always important to consider two factors; the pre-mining land-use and the post-mined (current) land-use. According to Cao (2007), lands that have been destroyed by the activities of mining, regardless of the gravity of destruction, still has the potential for reuse following acceptable restoration practices.

3.4.1. Factors influencing the post-mined land selection

There are several alternatives to post-mined land use. However, the choice of particular land use must be carefully selected after a broad and sound analysis considering the economic, engineering, environmental, and social analysis of the problem. It is imperative to consider if the land use and morphology of the selected location would support either the current land-use or the pre-mining land use. Bangian et al. (2012) stated that each section of the post-mined land should be considered independently. An appropriate alternative post-mined land use that meets the defined objectives should be selected. In line with this, Doley et al. (2012) proposed four important steps to consider in planning post-mined land-use selection. According to the authors, the following steps should be considered: (i) Identify the landscape and the kind of soil characteristics that would be required to revegetate the post-mined land into its original native ecosystem; (ii) assessed the resource or inputs essential to attain a sustainable 'original' ecosystem or an appropriate alternative ecosystem; (iii) estimate the resource gap between original and alternative ecosystems and lastly (iv) modify the nature or degree of impact of disturbance in relation with the target ecosystem to attain a sustainable outcome. Jiali et al. (2017) classified land use under three main types: agricultural land-use, forest land-use, and developed land-use using the Grey relational equation approach. Before a land-use selection is made, land suitability analysis should be carried out on each plot/side of the area to ascertain if it would be suitable for the selected purpose. Grey relational analysis is an important tool for land suitability analysis (Yang et al., 2008; Elena-Arce et al., 2015). It compares the evaluation values to the reference values (Kuo et al., 2008). The reference values are those factors with optimum suitability. However, due to differences in units and range among different factors, a standardization process is always necessary. Jiali et al. (2017) carried out a standardization process when they used the grey relational technique for land restoration suitability analysis based on the following equations.

$$X'_{ij} = \frac{X_{ij} - X_{min}}{X_{max} - X_{min}} \tag{1.1}$$

$$X'_{ij} = \frac{X_{max} - X_{ij}}{X_{max} - X_{min}} \tag{1.2}$$

Equation (1.1) is used for the attributes in which a higher value suggests better suitability, whereas **equation (1.2)** is used for attributes in which a higher value indicates poor suitability. X'_{ij} denotes the normalized value of the jth factor of evaluation in cell i, $X_{i\,j}$ is the value of the jth evaluation factor in cell i, Xmax and Xmin are the maximum and minimum values of the jth evaluation factor, respectively. The grey relational equation is shown in **equation (1.3)** below.

$$\varepsilon_{ij} = \frac{\underset{i}{min}\ \underset{j}{min}\left|X^*_j - X'_{ij}\right| + \rho\ \underset{i}{max}\ \underset{j}{max}\left|X^*_j - X'_{ij}\right|}{\left|X^*_j - X'_{ij}\right| + \rho\ \underset{i}{max}\ \underset{j}{max}\left|X^*_j - X'_{ij}\right|} \tag{1.3}$$

ε_{ij} is the Grey relational degree between evaluation indicator j and its optimal value of the cell i; X^*_j and X'_{ij} are the normalized results for the optimal value and evaluation factor of indicator j, respectively, and ρ is the distinguishing coefficient, which usually has a value of 0.5. Usually, the area to be reclaimed is divided into cells of reasonable sizes. In the work of Jiali et al. (2017), they partitioned the area into cells of sizes 30 m × 30 m. This helps to analyze and understand the heterogeneity within the mined site. Each of the divided areas is referred to as "cell i".

Earlier studies by Sweigard & Ramani (1984) as cited in Festin et al. (2018), attributed a successful post-mined land use and selection to two major factors: natural land use factors and cultural factors. According to the authors, the natural land-use factors include climatic, geomorphic, hydrologic, and soil characteristics of the site, while the cultural factors consist of demographic, economic, and geographic characteristics that emanate from human activities. The natural factors are more appropriate for the location selection and the cultural factors are mostly applied for the land-usage (Miao and Marrs, 2000). Consequently, the cultural factors are the primary factors upon which final decisions regarding land-use rest. Masoumi (2014) listed four broad factors that should be considered for any land-use selection, thus economic, environmental, social, and technical factors. The economic factors are very crucial for post-mined land-uses as it forms the building block for reviewing all other factors and final decision making.

3.4.2. Major post-mined land uses

Studies (Bangian et al., 2012; Masoumi and Rashidinejad, 2011; Narrei and Osanloo, 2011) have outlined a classified framework of all feasible post-mined land uses under 8 categories. These 8 categories in order as they appear in their framework are; agriculture land-use, forestry land-use, lake or pool land-use, intensive recreational land-use; non-intensive recreational land-use; construction land-use; conservation and pit backfilling as shown in Table 5 below. Errington (2001) carried out a study on post-mined land uses in British Columbia and concluded that 53% of the land was to be used for the habitation of wildlife, 22% for forest conservation, 9% for pasture, and the remaining 16% for other purposes. Cao (2007) mentioned Pasture, recreational areas, wildlife habitat, wetlands, fish ponds, block making, and swimming pool as some major post alternative land uses. Miller (2008) indicated that Aquaculture was the major and most preferred alternative in west Virginia, whereas Miao and Marrs (2000) pointed out that Aquaculture and forestry remain the most dominant alternative post-mined land use. From the various literature reviewed, several important factors need to be considered and reviewed before final decisions are made when considering the choice for post-mined land selection and restoration. Moreover, each of these factors should be vetted

Table 5
Post-mined land use alternatives and their technical requirements (Biny-yuan et al., 2014; Errington, 2001; Miao and Marrs, 2000; Miller, 2008; Narrei and Osanloo, 2011).

S/ no.	Type of Land-use	Examples of Land-use types	Technical Requirements
1	Forestry	Orchard, lumber production, woodland, shrubs, herbs, and native forestation	The land may have a suitable grade, and the topsoil is needed. Topsoils should not be less than 0.3 m for tree planting, and the plant-pit should not be more than 1 m. The isolated layer is needed if the filling material contains harmful elements. The thickness of the filling material should not be less than 0.4 m, and the filling material should be punning
2	Agriculture	Arable farmland, garden, pasture, nursery	Land leveling, topsoil spreading. Where food crops would be planted, the topsoil thickness should not be less than 0.5 m. Also, the humus layer should not be less than 0.2–0.3 m. The material used for filling should not contain any harmful chemicals or elements. Its isolation layer should be thicker than 0.4 m. The hydraulic condition should be good. The demand for topsoil: the soil mass density should not be more than 1.5 g/cm3. The proportion of clay and sand is 1: 3 or1:2. The porosity should not be less than 40%–50%. The content of the soluble sodium sulfate and magnesium sulfate is no more than 5%. Sodium oxide is no more than 0.01%, and the pH value should be 6–8
3	Conservation	Habitation for wildlife, water supply (surface and underground)	The land needs to be punned well, and native plant species introduced.
4	Construction	Residential, commercial (shopping center), industrial (factory), educational (construction of schools of any kind) and, block and brick molding, sustainable community	The land needs to be punned well, and the houses need anti-deformation measures
5	Intensive Recreation	Sports field, sailing, swimming, fish pond and game	The land needs to be punned well. The isolated layer is needed, and its thickness should not be less than 0.5 m. Besides, cement to harden the surface is needed if necessary.
6	Non-intensive Recreation	Park and open green space, Museum or exhibition of mining innovations	The land needs to be punned well and harden the surface if necessary
7	Lake or pool	Aquaculture, sailing, swimming, water supply	The gradient of the shoreside should not be too steep. The area of the water should not be too large. The quality of the water should meet the water quality standard for fisheries

or evaluated independently based on sound analysis and judgment while considering the end-users.

4. Conclusion and considerations

This current work reports the impact of mining, post-mined reclamation, and post-mined land-use from a global point of view. In this review, the impact of mining has been classified under three major categories; economic, environmental, and social impacts. Mining has been a long-standing key player in economic development, employment, infrastructure, and supply of essential raw materials for society. Historically, mining has served as a viable route to economic transformation in resource-rich countries like Australia, Canada, the United States, and some parts of Africa. Nevertheless, mining has also created a significant negative impact on the environment and society at large. Some of these adverse effects of mining are loss of vegetation cover, destruction of aquatic life and water pollution, food insecurity, land-use changes, and its attendant conflicts, high cost of living, loss of soil productivity, increase in social vices such as prostitution, robbery, and drug abuse and high incidence of respiratory-related diseases. There is a need for proper land reclamation strategies to be incorporated into the entire mining spectrum. Reclamation is an indispensable part of sustainable land management and land-use. Every reclamation aims to restore the abandoned land or the mined site to its native landscape or a better landscape. Physical, chemical, and biological restoration practices constitute the most widely used and accepted methods of restoring abandoned post-mined lands that have been discussed. The physical methods of reclaiming abandoned mine lands deal with earth-battering thus putting the land back to its virgin shape after mining. This reduces the impacts of runoff, minimize compaction, and create conditions suitable for revegetation of mine wastelands. Base on the magnitude of the open-pits and extent of alteration of the surrounding landscape, topsoil replacement is often carried out following plowing, grading, and smoothing. Usually, the topsoil moved from nearby sites, or topsoil salvaged from mining is used. However, salvaged topsoil that has been stockpiled for a long time has low nutrient and biological quality and is expensive. Topsoil and manufactured technosols (mine wastes amended with organic materials) are preferable candidates for physical soil amendments due to their high nutrient content, enhancing microbial community growth and soil functioning.

Mine wastelands or abandoned mine lands are often characterized by high proportions of toxic heavy metals, metalloids, low pH, and other contaminants. Correcting the soil pH, increasing soil fertility, and removing the toxic heavy metals is often achieved by chemical land reclamation practices. It focuses on adding macronutrients (N, P, K), micronutrients (Zinc, copper, iron, manganese), lime, and synthetic chelates to the soil. Chemically treating the soil after earth-works and topsoil replacement improves nutrient uptake by plants, enhances heavy metal bioavailability and solubility, and ultimately improves overall soil physicochemical properties and reduces soil contamination. In AMD, which is one of the most common and severe effects of mine wastelands, it can be corrected through buffer by applying residual lime to impoundment dams. Additionally, the use of chelates increases metal solubility in soils and breaks the diffusional limitation of metals in the rhizosphere. This facilitates easy translocation of metals from the root region to the shoot. Recently, the application of nanoparticles as a novel method for the restoration of mine wastelands has emerged due to their large specific surface area, deliverability, and responsiveness. For instance, zero-valent iron nanoparticles, zeolites, iron sulfide nanoparticles, phosphate-based nanoparticles, and carbon nanotubes (CNT) have significant potential for soil reclamation. However, the problems limiting the application of the chemical method are the high cost for chemical reagents and machines, the need for skilled technicians, and the potential for secondary pollution of groundwater, which can adversely affect soil quality in the event of excessive application.

To enhance the ecological succession and minimize the noxious effects of existing and potential contaminants, biological or phytoremediation is often carried out. It could be used as a single reclamation strategy on abandoned mine sites where the magnitude of the landscape's alteration is minimal. In this case, microbes and green plants are directly introduced to the site and follow natural succession. The concept of biological restoration was borne out of natural revegetation. However, natural revegetation is slow due to poor soil quality and may serve as a potential source for bringing undesirable evasive species. Aside from using phytoremediation as a single reclamation strategy, it could also be used to combine other reclamation methods where planting pioneer and nitrogen-fixing native species follows site amendments to immobilize the migration of heavy metals and improve the nutrient availability and soil structure. Soil amendments with biochar, synthetic chelators, rhizosphere, microbes, and other organic materials improve the growing conditions of the species and ensure effective immobilization. This decreases the heavy metals' bioavailability and then prevents them from leaching to groundwater or entering into food chains. Phytoremediation improves the overall soil quality for pioneer spices to boost revegetation, modifies the bioavailability of heavy metals in the soil, and increases plant growth. Aside from grasses and shrubs, trees also provide better alternatives due to their deeper and bigger root system and produce comparatively larger biomass. From the literature reviewed, evidence suggests that when trees are used in phytoremediation, it can decontaminate the soil for more extended periods, and accumulate greater amounts of heavy metals. It also ensures less compacted soils and reductions in soil bulk density due to the deep roots system. Despite phytoremediation's success, it has some limitations, such as the slow growth of pioneer species, risk of recycling heavy metals back into the environment, and limited bioavailability of the metals. Lastly, abandoned post mine lands can be put to several uses following successful reclamation. However, before reclamation, land selection and suitability analysis should be made comparing the pre-mining land use, and post-mined land uses. The selection criteria should consider the environmental, economic, social, and technical factors to make a sound judgment. Some major potential post-mined land uses are conservations, forestry, agriculture, construction, intensive recreation, non-intensive recreation, lake or pool, and pit-backfilling as a last resort.

4.1. Recommendations

Based on the findings from the study, the following recommendations are given. Mining should be preceded by stakeholder engagement with mining communities to outline better compensation schemes and post-mined land restoration models, which would be practical, and economically feasible. This is particularly important for mining communities where illegal small-scale mining takes place, especially in Africa. The government should enact a regulatory framework to stop the illegal small-scale artisanal mining, especially in Africa, and roll-out community mining programs where members from mining communities would be trained on sustainable small-scale mining. Legislations governing large scale mining activities should be enforced to ensure strict compliance. Natural revegetation is slow and does not supplement the soil with the right nutrients; hence reclamation should be inclusive, thus incorporating physical, biological, and chemical methods.

Regarding topsoil replacement, manufactured technosols should be used instead of salvaged topsoil from near sites due to the fewer amounts of nutrients it contains. Though some nanoparticles and synthetic chalets have also proven to be effective in improving the chemical and biological properties of reclaimed sites, it is expensive and should be used moderately. Future reclamation projects should also consider the use of more tree species other than grasses. Evidence from the literature reviewed suggests that preference has been given to grass species; meanwhile, trees have a more in-depth and bigger root system and the ability to produce comparatively larger biomass and decontaminate the soil for a longer period. In a nutshell, an increase of tree species diversity on wastelands leads to a corresponding increase in C stocks and N-fixing in the soil.

Declaration of competing interest

The authors therefore declare that there is no known competing interest either financially or otherwise between them which could potentially jeopardize the publication of this manuscript.

Acknowledgment

This research is financially supported by the National Science Foundation of China, grant number (41701629). We acknowledge all researchers from whose original works this paper is written. We also acknowledge those who granted us copyright access to reproduced their materials and all the reviewers who provided expert advice for a better result.

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