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Sustainability Science for Meeting Africa's Challenges

Sustainability assessment of mine-affected communities in Ghana: towards ecosystems and livelihood restoration

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Abstract Since the 1980s, many regions in Africa that are rich in mineral resources have undertaken significant reforms to attract foreign investments. While the reforms have broadly boosted mineral production and spurred economic growth, there is a general feeling among stakeholders in the mining sector that such investments have not lived up to their rhetorical promise of improving human well-being. In Ghana, such concerns are particularly pronounced in localities that host mining activities. In such areas, mining can have a series of sustainability impacts that affect manifold the local environment and the local communities. However, there is very little effort to systematically assess the local impacts of mining in Ghana and Africa in general. Our study develops a composite sustainability index that can provide a holistic assessment of the local sustainability impacts of mining. We apply this index to understand the sustainability of three communities surrounding the gold mine of the Newmont Ghana Gold Ltd., in the Ahafo South District of Brong Ahafo region. We combine indicators that represent the key local environmental, social, economic, and institutional impacts of mining to assess local sustainability during the active stages of mine development and operation. We use a series of different methodologies and participatory techniques to arrive at the different indicators, as well as to rate them. Results suggest that despite some between-community similarities for some environmental impacts, the local communities often had radically different scores for social, economic, and institutional aspects of sustainability. Based on the findings, we argue that restoration efforts need to be customized to reflect the between-community variation and go beyond simple landscape reclamation to include interventions that improve human well-being, secure infrastructure, and enhance the collaboration among stakeholders to enable the affected local communities' transition to sustainability.

Keywords Mining sustainability · Resettled communities · Composite indicator · Mining restoration · Ghana

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Introduction

Natural resource extraction, particularly mining, has often been seen as a catalyst for economic growth and development in Sub-Saharan Africa (UNECA 2011, 2013). Many countries such as Ghana, the Democratic Republic of Congo, Nigeria, Guinea, and Tanzania have for a long time remained over-reliant on exports from the mining of gold, diamond, oil, and other minerals to fuel their economies (UNECA 2011, 2013).

Since the 1980s, many African governments, backed by the World Bank, have implemented reforms in the mining sector to attract investments and to spire development (Campbell 2003; Pegg 2006). Initially, Ghana and subsequently other countries, such as Tanzania, Guinea, and Burkina Faso, have changed mining regulations through liberalization processes (Crisp and Kelly 1999; Haselip and Hilson 2005) to provide security of tenure, right to repatriate profits, and equity for foreign multinational investors (Salim 2003; Kumah 2006; Campbell 2009). In many countries, these reforms spurred a significant flow of investment into the mining sector, increasing in the process mineral production and economic output (Banchirigah 2006; APP 2013). This notwithstanding, some scholars have suggested that mining reforms in Africa have not lived up to its rhetorical promise, particularly when it comes to directly translating into poverty alleviation and job creation (Pegg 2006; Haselip and Hilson 2005; Ackah-Baidoo 2016). For instance, the Human Development Index (HDI) has consistently shown that some of the well-endowed economies on the continent continue to rank low on the HDI rankings (cf. Ackah-Baidoo 2016).

Most commentaries on why mining reforms in Africa have failed to catalyze wider socioeconomic benefits have pointed at:

(a) the creation of capital-intensive ‘enclaves’ that cannot facilitate effectively the growth of downstream industries and create jobs (Campbell 2003; Haselip and Hilson 2005; Ackah-Baidoo 2016);
(b) the failure of African governments to effectively utilize revenues from mining for development (Pegg 2006; Banchirigah 2006; Campbell 2012);
(c) the lack of implementation of good mining practices/standards that can have positive socioeconomic and environmental outcomes (Campbell 2012).

Due to the above, there are significant concerns about the impacts of mining at the local level. Mining impacts can be very diverse depending on the context and constitute an important sustainability concern for development/policy practitioners and researchers across all of the resource rich countries in the region (Twerefou 2009; Kemp 2010a, b; Mnwana 2015).

The mounting environmental and socioeconomic challenges in Ghana epitomize the prospects and challenges that the mining sector faces in the continent. Consistent with trends in other countries, mining reforms in Ghana have attracted huge foreign investments, increasing mining output, and spurring economic development in the process (Bloch and Owusu 2012). However, there is a consensus that mining in Ghana is not sustainable when considering its environmental, economic, and social impacts (Ackah-Baidoo 2016; Okoh 2014; Bloch and Owusu 2012; Teschner 2012). Often, the local communities that have hosted mining operations have been highly impacted (Basommi et al. 2016; Moomen and Dewan 2016; Okoh 2014; Akabzaa 2009). Yet, there is very little effort to systematically assess the local dynamics that arise when mining expands into rural landscapes in the country (Garvin et al. 2009; Kumah 2006).

Several mining firms across Africa have attempted to respond to the criticisms of their operations on local communities through the adoption of corporate social responsibility (CSR) agendas and the promotion of the Extractive Industries Transparency Initiative (EITI). However, local communities are often unenthusiastic about such initiatives (Hilson 2002). As a result, relations can become tense between companies and local communities (Mnwana 2015; Garvin et al. 2009). Often what is missing is the comprehensive monitoring and evaluation of community development initiatives that are implemented either by mining companies or national governments (Mnwana 2015; Kemp 2010a, b). Even when attempts have been made to evaluate community development initiatives in mining settings, the lack of concrete sustainability principles to assess mining impacts at the community level limits our understanding of the true effects of mining, including what types of community development initiatives work best (Kemp 2010a, b; Kumah 2006).

There is often a lack of post-mining restoration activities to mitigate the negative impacts of mining in Africa (Twerefou 2009). Even when restoration activities are planned, they tend to be limited to landscape restoration, which might be too narrow to safeguard the well-being of local communities considering the very diverse sustainability impacts of mining (Limpitlaw and Briel 2014). Thus, there is a need for the holistic understanding of the local sustainability impacts of mining as a first step towards designing solutions to improve the sustainability of the sector. As argued by Kumah (2006, p. 317), in the context of developing countries, a sustainable (gold) mine is one that “meets the needs of present and future generations, and which internalizes the cost of adverse biophysical, economic, and social effects on a community”. Sustainability in this context may require action on the part of mining firms that go beyond what is legally prescribed and mandated (Kumah 2006). The development and adoption of comprehensive assessment tools/toolkits is needed to assess the local sustainability impact of mining, providing the knowledge necessary to develop restoration measures and guide restoration activities in mine-damaged communities.

In this paper, we propose a comprehensive sustainability assessment method based on community perspectives and expert opinion to examine the local sustainability impacts of mining. Our study develops a composite sustainability index that can assess the sustainability impacts experienced by three local communities in Ghana. Our analysis views mining as a driver of systemic change that affects the local environmental, economic, social, and institutional conditions. This comparative analysis enables us to determine how each study community (with a largely similar location and socioeconomic characteristics); (a) It is impacted by mining activities (b) the magnitude of impact, (c) the response mechanisms, and (d) the implications for designing local restoration programs.

Initially, we describe the methodology, indicator selection and data collection methods, and the study sites. The results of the comparative analysis are presented across four impact categories (i.e., environmental, economic, social, and institutional). Finally, we put the impact results into perspective and propose restoration actions to mitigate the local sustainability impacts of mining, and to guide place-based holistic restoration interventions.

Methodology

Study site

Our study area is the South concession of Newmont Ghana Gold Ltd (NGGL) Ahafo mining, located in the Asutifi North District of the Brong Ahafo region of Ghana. The mine has a total area of 3111 ha extending from Amoma shelterbelt/Breserve on the northeast to Kenyase 1 and 2 on the south, and to the west Subri and Awonsu drainages (NGGL 2005b). Gold mining commenced in the 1990s as Ahafo Gold Project before NGGL finally took over from Normandy Ghana Limited in 2002 (Fig. 1). The operation began in 2003 with the consent of the Government of Ghana followed by commercial mining of the ore since 2006. Our study took place in 2015 during the active mine operation period of the mine lifecycle.

The Asutifi North District lies within the wet semi-equatorial zone and, therefore, experiences double maxima rainfall (GSS 2010). Forest reserves cover about 30% of the total land area in the study area, which is underlain with Birimian rocks from which the gold is mined (NGGL 2005c). In other words, to access to the Birimian rocks, forests must be cleared. As a result, the mining company destroys large forest areas to allow for gold mining. However, forests within this area are rich in tropical hardwood species such as Odum (*Milicia excelsa*), Ofram (*Terminalia superba*), Ofrumtum (*Funtumia elastica*), Esa (*Celtis mildbraedii*), and Kyenkyen (*Antiaris toxicaria*). Due to the indiscriminate tree felling, bad farming practices, and sand weaning, the natural vegetation is fast depleting (GSS 2010). The main soil types in the district

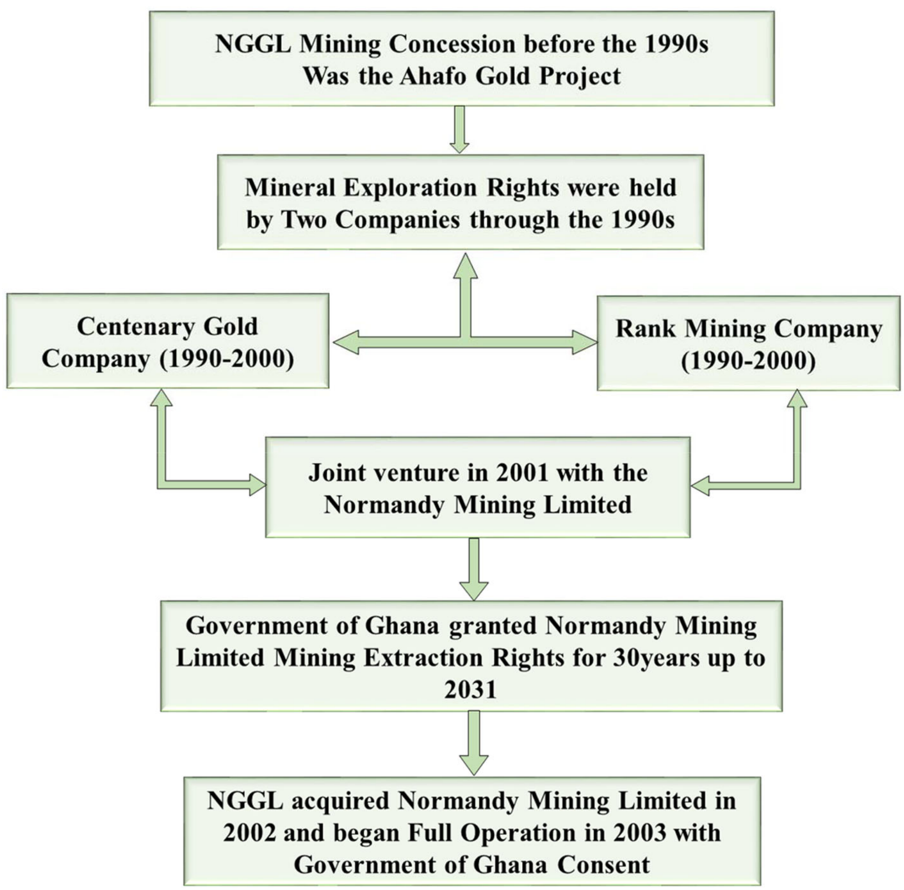

Fig. 1 Timeline of the Newmont Ghana Gold Ltd. mining activities

are forest ochrosols that are well drained with high humus content and are fertile (GSS 2010). The area also contains large mineral deposits such as gold, diamonds, and bauxite (NGGL 2005c).

Since the inception of NGGL mining operations, extensive areas of forest and agricultural land have been cleared. According to NGGL's sustainability report, these activities have up to date disturbed about 544 ha of land, with only 25 ha reclaimed (NGGL 2005a). As of 2008, out of the 53,500 ha of the concession, the area cleared and excavated stood at 3237 ha.

The primary livelihood source for the local communities surrounding the mining concession is agriculture, though the presence of NGGL mines has spurred other economic activities such as trading, food stalls, and street vending (GSS 2010; Kotey and Adusei 2009). Agriculture occupies about 66.7% of the active labour force, the majority being women. However, over 90% of those who engage in non-agricultural activities are still involved in agriculture as a secondary livelihood activity (GSS 2010). Agricultural land has been lost due to the excessive removal of vegetation and topsoil, leading to high level of soil erosion and the inability of soil to support plant growth. Furthermore, agricultural output has decreased in most communities due to the decision of many farmers (mainly subsistence) to move to occupations in the service sector or work for the mine (Kotey and Adusei 2009). Similar to forest and agricultural lands, water bodies (including the Tano River and its many tributaries) have been severely affected by mining. For instance, the volume and flow of water have been adversely affected, making some rivers seasonal, which leads to acute water shortages in some communities (GSS 2010).

Two communities (among those affected) by mining operations within the Ahafo South Mine concession were resettled in villages constructed by NGGL. The Ola resettlement village is located on the outskirts of Kenyase 2 (referred to as resettled site II) and contains 2028 individuals in 312 households (NGGL 2005d). Ntotoroso village (resettled site I) contains 566 individuals in 87 households (NGGL 2005d). Kenyase 1 (non-resettled site) was not resettled but a total of 242 households self-reported that are affected by mining through a pre-screening survey conducted by the research team (see below).

Development of the composite index

Sustainability science calls for a transdisciplinary approach to problem definition, assessment, and solution (Kajikawa et al. 2014; Kates 2011; Komiyama and Takeuchi 2006) Sustainability has received wide recognition for mining issues, but the vast majority of studies are either conceptual (UNDP 2016), focus on specific sustainability pillars (Kumah 2006), or focus on the assessment of the corporate organizational context relative to the perspective of host communities (GRI 2002; Azapagic 2004; Hilson and Potter 2003).

Our study echoes the call for transdisciplinary knowledge co-creation in sustainability science (e.g., Mauser et al. 2013; Schodl et al. 2015), and develops a holistic approach for assessing the local sustainability impacts of mining. Through expert opinion and stakeholder perspectives, we develop a composite index that includes indicators across the environmental, social, economic, and institutional pillars of sustainability (Singh et al. 2012). Our methodology culminates with the total community sustainability assessment framework (TCSAF), which is adapted and modified from the vulnerability assessment framework of Antwi et al. (2014) (see Fig. 2). This approach views mining as a driver of systemic change that affects the local environmental, economic, social, and institutional conditions. It assumes that mining impacts at the community level are determined by the sum total of the complex interaction between human and natural factors that emerge from mining activities.

For each sustainability pillar, several impacts and indicators were identified through a multi-stage process that involved literature review, household surveys, focus group discussions, and stakeholder consultation (Antwi et al. 2014, 2015) (see Fig. 3). Initially, potential mining impacts and indicators were identified through a literature review. These indicators were then refined and validated through a series of stakeholder and expert consultation processes (Fig. 3).

Scores were assigned for each individual impact (1 = low negative impact of mining, 2 = moderate negative impact of mining, and 3 = high negative impact of mining). To arrive at the sustainability score for each individual impact in each community, we used a combination of expert opinion and stakeholder input. As the different impacts can have either a direct or indirect effect on the livelihoods of local communities, "impact factors" were assigned (Antwi et al. 2014). An impact that has a direct livelihood effect is assigned a factor of 1, while an impact that has an indirect livelihood effect is assigned a factor of 0.5. The type of impact mechanism (i.e., direct/indirect) was derived through stakeholder consultation and participatory processes in each study community (see below).

Table 1 provides information about the different sustainability pillars, impacts, scores, impact factors, and data acquisition methods. The overall sustainability score for each pillar (i.e., environmental, social, economic, or institutional) was computed using the following equation:

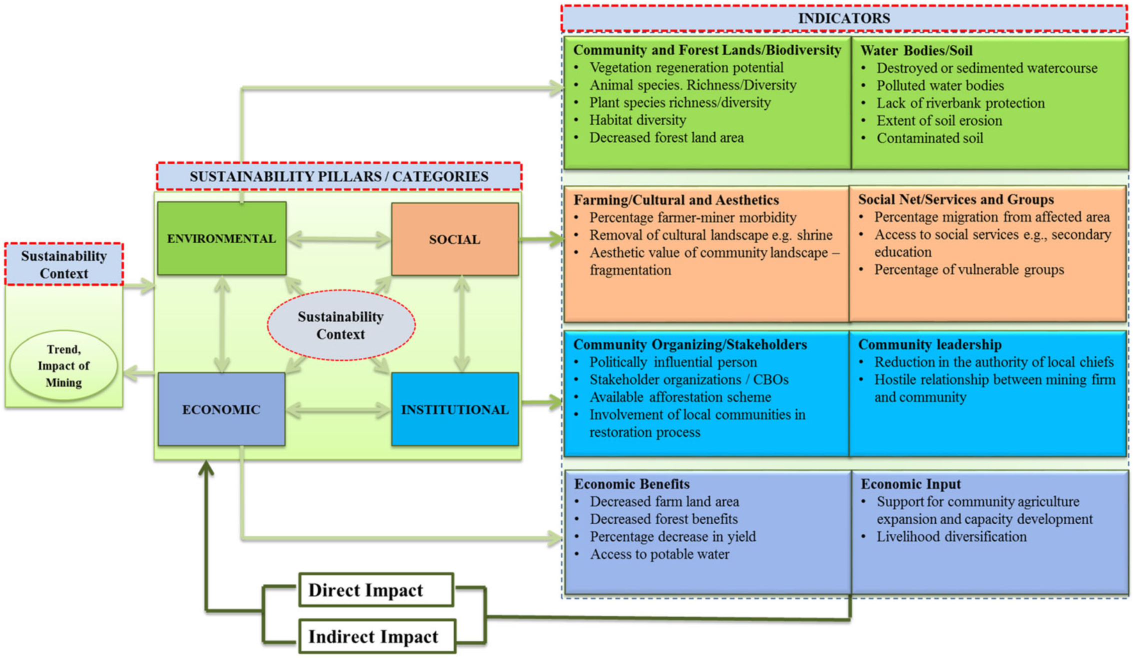

Fig. 2 Total community sustainability assessment framework (TCSAF). Source: Adapted and modified from Antwi et al. (2014)

$$\text{Computed Sustainability Score } = \sum_{t=1}^{t} \frac{(idx)wa}{t}; \quad t > 1, \tag{1}$$

where (idx) is the sustainability indicator score; a is the impact factor (direct impact = 1; indirect impact = 0.5); w is the weight for each sustainability indicator calculated as $w = (\text{Sustainability Score})/(\text{highest score})$, i.e., $w = 1/3$, $2/3$ and 1 for low, medium, and high indicator scores, respectively; and t is the total number of indicators for the pillar under consideration.

Finally, in deriving the Total Community Sustainability Score, each sustainability pillar is assigned a standardized weight of 25% to reflect the equal importance of each pillar for local sustainability. Thus, the total community sustainability (TCS) was estimated from the weighted sum of the environmental, social, economic, and institutional sustainability pillars.

Data collection and analysis

Data collection and analysis required the use of a mixed-method approach considering the diverse qualitative and quantitative data sets used for the development of the composite index (Table 1). Data were collected in 2015 with reference to the development of the mine in 2005. The sustainability scores explained in the previous section essentially represent the state of the different indicators for 2015. Where a pre-mining baseline is used this is the year 2005 when NGGL started officially operating in the study site.

Environmental sustainability assessment

The data for the indicators for the environmental sustainability pillar primarily were derived from field observations and spatial analysis. However, data for some environmental impact indicators were derived through household surveys, focus group discussions, and expert interviews (Table 1, see also next section).

Ecological surveys were used to collect data on animal species richness/diversity, plant species richness/diversity, and vegetation regeneration potential. The assessment entailed the sampling of indicator plant species (i.e., shrubs and trees) and animal species (i.e., invertebrate). The list of the targeted invertebrate and vascular plant taxa was derived using the taxonomic group list of Ghana and was based on their biological and geographical attributes (Caro and O'Doherty 1999). Expert elicitation techniques were used to synthesize expert opinion (e.g., from zoologists and biologists) and local community perspectives with regard to biological species taxonomic grouping (Monks et al. 2013). This technique is increasingly being used in the biodiversity conservation sector to guide decision-making (Donlan et al. 2010).

To monitor and compare the distribution of invertebrate species (as a means of assessing animal species richness/diversity), we used pitfall traps to sample ground-dwelling arthropods and dung beetles (Coleopteran Scarabaeidae) (Pekár 2002; Phillips and Cobb 2005). This method estimates relative arthropod activity rather than their absolute density, reflecting the individual abundance

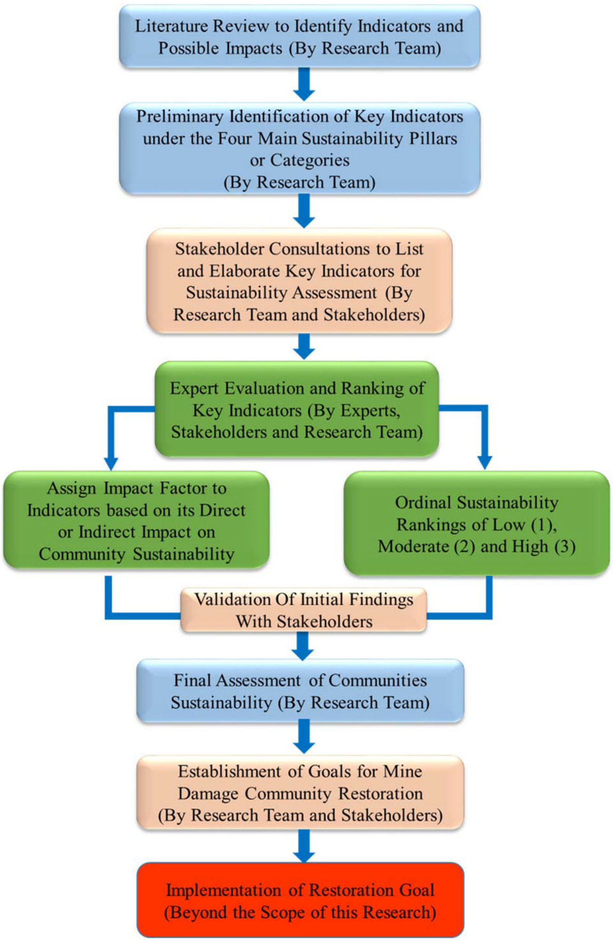

Fig. 3 Methodologies involved in the development of the total community sustainability assessment framework (TCSAF)

of each species (and movement rates) within a given habitat. This method has the advantage of being quick and cheap, and can reduce researcher bias (Pekár 2002). Twenty pitfall traps were activated with 600 ml of ethylene glycerol and placed at a distance of 20 m between each other in a regular grid plot of 20 × 20 m at both mined and non-mined areas. Traps were removed and changed every 10 days, resulting in 12 samples per sampling season. Sampling was undertaken during two seasons in the same year (2015): November–December that marks the end of the rainy season, and April–May that marks the succession of the rainy season. These seasons were chosen to avoid interference of the rain with sampling.

To determine plant species richness/diversity, we undertook plot-based ecological sampling (Tiner 1999). A total of 20 10 × 10 m quadrat plots was set up in mined and non-mined areas with the first quadrat laid at random, and subsequent quadrats spaced at regular intervals (Kent and Coker 1992; Mensah et al. 2016). Sampling was done in June–September 2015, which marks the peak of the rainy season and vegetation growth in the area. Shrub species were sampled by laying smaller square plots of 1 × 1 m within the bigger 10 × 10 m plots (Hershberger 1970). All individual species within these plots and subplots were counted based on their physiognomic characteristics with the help of a taxonomist (Arbonnier 2004). In each of the plots, we directly measured the girth at breast height (GBH) of individual trees species (i.e., 1.3 m from the ground). For trees that forked below 1.3 m, each stem that had a GBH equal to or greater than 10 cm was considered as an individual tree. Recordings of GBH were organized into size classes (with a class interval range of 50 cm) and by land use. Younger stages (seedlings and sapling) of trees were examined and identified in situ by their morphological features such as leaves and exude (Hopkins 1974).

Spatial analysis was used to assess impacts related to habitat diversity, habitat richness, and decreased forestland cover. This was done through the analysis of land use and landscape structural change in a GIS environment (Table 1). The spatial analysis was also used to assess some social (e.g., loss of cultural landscape, aesthetic value of community landscape) and economic (e.g., decreased farmland area) sustainability indicators, as shown in Table 1 and next section.

We used Landsat 7 ETM + and Landsat 8 Operational Land Imager and Thermal Infrared Sensor (OLI_TIRS) imagery to survey the changing mining landscape between 2005 and 2015. The land cover classification was conducted through both supervised and unsupervised classification (Antwi and Wiegleb 2008). As a first step, the iterative self-organizing data analysis technique (ISODATA) algorithm was used to cluster image pixels. The resulting clusters were re-organized into classes of respective years to guide the supervised classification process. Information gathered from the unsupervised classification, ground control points from Google Earth maps and secondary data from other studies in the area were used to train the spectral signatures into the various land-use/cover classes. The final supervised image classification was carried out using the Gaussian Maximum-Likelihood Classifier, which minimizes classification errors using the covariance matrix to account for variability in the classes (Hagner and Reese 2007; Shafri et al. 2007).

The accuracy of classifications for 2005 and 2015 was 89.6 and 91.4%, respectively. Kappa coefficient (Congalton 1991; Foody 2002) of 0.861 and 0.896 were attained, respectively. This suggests a strong agreement between the accuracy of the classifications of the producer and the user (Chapman and Hall 1991). The change detection extension was used for each map year (from 2005 to 2015) to identify changes among different land cover types. Landscape metrics were computed using Patch Analyst V-3.1 to study

Table 1 Elements of the total community sustainability assessment framework (TCSAF)

	Sustainability impact	Mechanism	Data collection and analysis	Type of data	Impact factor (a)	Sustainability score		
						Resettled site I	Resettled site 2	Non-resettled site
Environmental sustainability	Soil contamination	Soil pollution due to chemical deposition (e.g., mercury) from mining activities	Secondary data analysis Community perspectives through FGDs	Qualitative	1	1	1	2
	Vegetation regeneration potential	Plant ability to regrow and restore vegetation cover to its original state following mine-related disturbance	Plot-based sampling of indicator plant species Community perspectives through FGDs Expert judgment	Quantitative/qualitative	1	2	3	1
	Destroyed/sedimented watercourse	Impediment of the profile of water bodies or siltation and reduction of water flow due to large amounts of sand, stones and pebbles deposited in the river bed	Expert interviews Expert judgment through field observation of river volume and flow	Qualitative/quantitative	1	2	2	3
	Water pollution	Presence of pollutants in water bodies that reduce safety for human consumption and other animals	Expert judgment through field observation of water quality Community perspectives through FGDs	Qualitative/quantitative	1	1	2	3
	River bank protection	Loss of vegetation along watercourses and riparian strips	Expert judgment based on site visits Vegetation survey	Qualitative/quantitative	0.5	2	2	3
	Richness/diversity of animals	Type and population of animal indicator species in the area before and after mining activities commenced	Pitfall trap sampling (for ground-dwelling arthropods) Secondary data analysis	Quantitative/qualitative	1	1	2	3
	Richness/diversity of plants	Type and population of plant indicator species in the area before and after mining activities commenced	Plot-based sampling of indicator plant species	Quantitative	1	2	3	2

Table 1 continued

	Sustainability impact	Mechanism	Data collection and analysis	Type of data	Impact factor (a)	Sustainability score		
						Resettled site I	Resettled site 2	Non-resettled site
	Habitat diversity	Forms of patches (habitats) in the landscape	Landscape analysis (e.g., NumP, MPS) using patch analyst	Quantitative	0.5	1	3	2
	Forest loss	Area of natural forest cleared for mining	Land-use and land cover change analysis	Quantitative	1	2	3	2
	Soil erosion	Extent to which denudation processes have destroyed soil	Expert judgments through survey of existing erosion spots and erosion control structures	Quantitative	0.51	2	3	1
Social sustainability	Farmer-miner economic mobility	Number of farmers that abandoned farming for jobs in the mining sector	Household surveys Community perspectives through FGDs	Quantitative/qualitative	1	3	3	2
	Loss of cultural landscape (e.g., shrines)	Loss of cultural landscape elements (e.g., sacred groves, shrines, ancestral burial sites) due to mining	Community perspectives through FGDs Expert judgment through site visits Land-use and cover change analysis	Qualitative	1	1	3	1
	Loss of aesthetic values (e.g., due to landscape fragmentation)	Changes in the aesthetic value of the landscape considering the local cultural and historical context	Community perspectives through FGDs Landscape analysis (e.g., NumP, MPS) using Patch Analyst	Quantitative/qualitative	1	1	3	2
	Migration from affected areas	Levels of migration from the community, gender of migrants, migrants' destination areas, links with household back home (e.g., through remittances)	Household surveys Community perspectives through FGDs	Quantitative/qualitative	1	2	3	1
	Access to social services (e.g., secondary education)	Existence within community or ease of access to health facilities (e.g., hospital, clinic, CHIPS compound)	Expert interviews Expert judgment through site visits Community perspectives through FGDs	Qualitative	1	3	3	3

Table 1 continued

	Sustainability impact	Mechanism	Data collection and analysis	Type of data	Impact factor (a)	Sustainability score		
						Resettled site I	Resettled site 2	Non-resettled site
	Vulnerable population	Prevalence of vulnerable groups who may need assistance or depend on others after the changes caused by mining in the local communities	Household surveys Community perspectives through FGDs	Quantitative	1	2	3	3
Institutional sustainability	Politically influential person in community	Existence of local or regional political or business figure(s) that mediates community concerns with mining firms	Expert interviews Expert judgment through site visits	Qualitative	0.5	3	1	1
	Implementation of afforestation schemes	Existence or introduction of schemes that serve to regulate, protect and restore forests to its natural state	Expert interviews Expert judgment through site visits Community perspectives through FGDs	Qualitative	0.5	2	1	1
	Stakeholder organizations/ CBOs	Existence advocacy organization group (locally based or external) supporting the community in matters related to mining	Expert interviews Community perspectives through FGDs	Qualitative	1	1	1	3
	Loss of authority of local chiefs	Weakened authority of local chiefs that affect their ability to address the impact of mining (incl. negotiating compensation with mining companies)	Expert interviews Expert judgment through site visits	Qualitative	0.5	2	2	1
	Relations between NGGL and community leaders	Strained relationship between the mining firm and community leaders	Expert interviews Community perspectives through FGDs	Qualitative	1	1	2	3
	Local community participation in restoration activities	Use of indigenous and local knowledge (ILK) for restoring mining damages	Household surveys Community perspectives through FGDs	Quantitative/ qualitative	0.5	2	3	3
Economic sustainability	Community capacity development	Schemes available and instituted to assist farmers (e.g., provision of seedling, improved variety of seeds)	Expert interviews Community perspectives through FGDs	Qualitative	1	2	3	2

Table 1 continued

Sustainability impact	Mechanism	Data collection and analysis	Type of data	Impact factor (a)	Sustainability score		
					Resettled site I	Resettled site 2	Non-resettled site
Livelihood diversification	Availability of other income generating activities to supplement farming (e.g., artisans, trading, off-farm employment)	Household surveys Community perspectives through FGDs	Quantitative/qualitative	1	1	3	2
Loss of farmland area	Changes in the extent of arable land accessible to communities	Land-use and land cover change analysis	Quantitative	0.5	3	2	2
Loss of forest benefits	Decrease in the benefits derived from forest resources	Expert interviews Household surveys Community perspectives through FGDs	Quantitative/qualitative	1	2	1	2
Decrease in agricultural yields	Decrease in farm output	Expert interviews Household surveys Community perspectives through FGDs	Quantitative/qualitative	1	1	2	3
Access to potable water	Access to rivers, wells, boreholes and springs	Household survey Expert judgment through site visits	Qualitative/quantitative	1	2	3	2

landscape structural transformation, e.g., habitat diversity, habitat richness, and habitat fragmentation (Antwi and Wiegleb 2008).

Social, economic, and institutional sustainability assessment

The assessment of the social, economic, and institutional sustainability indicators was done using data collected through household surveys, semi-structured expert interviews, participant observation, and focus group discussions (FGDs).

We first conducted FGDs with 11 adult males and 11 females in each study community to validate and rank the pre-identified sustainability impacts and indicators. Two FGDs were conducted in each study community: one in May 2015 and one in July 2015. Participant selection factored in the length of participants' stay in the community, their personal experiences being affected by mining activities, and their participation in community work. Participants were asked to suggest specific indicators to reflect better the impacts of mining in their communities. In addition, participants identified whether each impact had a direct or indirect effect on their livelihoods. The FGDs enabled the research team to revise the initial list of impact and indicators identified through the literature review, and to update the protocol for the household survey (see below). During the FGDs, the research team also undertook field observations in all communities to understand the impact of mining on the water sources used by each community, and the general condition of the landscape and drainage systems (including rivers).

Following the FGD and field observation, we conducted the household survey. The sample size for each community was derived using the probability proportional to size (PPS) sampling technique (Yansaneh 2005). Following the PPS protocol, respondents in each community are selected proportionally based on the total number of households in the community. Since information on the number of households in the resettled communities was available, we selected approximately 40% of the total households for the household survey. Due to lack of information on household numbers in the non-resettled community, a pre-screening survey was undertaken by the research team to identify households who had been affected by mining. A total of 242 households self-reported as having been affected by mining. Out of these 242 affected households, we randomly selected 40%. Overall, we surveyed a total of 35 households in resettled community I, 125 in resettled community II, and 97 in the non-resettled community (Table 2) in May–July 2015. The household survey included both open- and close-ended questions related to whether household members have been affected by mining in the household, livelihood activities, access to social services, migration of household members, relationship with the mining company, and the perceptions of mining impacts.

Twenty-seven expert interviews were held with different stakeholders related to mining at the local, regional, and national levels to get their perspective about the selected sustainability impacts (Table 3). These expert interviews also facilitated the selection, scoring, and ranking of the sustainability indicators. At the local level, interviews were held with community leaders, including representatives of traditional authorities (e.g., chiefs) and opinion leaders that had an in-depth knowledge of social and institutional issues within their communities. We also interviewed non-governmental (NGOs) and community-based organizations (CBOs) that are involved in mitigating mining impacts at the local level. The interviews also touched on which mitigation programs could be more effective to address the sustainability impacts of mining at the community level. At the regional and national levels, expert interviews were held with representatives of government institutions, including the Environmental Protection Agency, and the Minerals Commission of Ghana that is responsible for monitoring, licensing, and designing mining policies in Ghana. These interviews enabled the study team to appreciate the role and responsibilities of governmental and non-governmental organizations in mining development and operation. Finally, we interviewed representatives from the mining company (i.e., NGGL), including the public relations officer and a community liaison officer. These interviews touched on the relationship between mining companies and local communities, and the measures being taken to mitigate mining impacts on the communities.

Results

Environmental sustainability

The environmental sustainability pillar largely focused on landscape-level indicators. The two main landscape issues are the land cover change that occurred over a 10-year period (2005–2015) and its impact on landscape structure. The main land cover types in the study site are forest, agriculture, settlement and open land, and surface mine area. Figure 4 outlines the land cover types and study communities, while Fig. 5 shows the fraction of each land cover type for 2005 and 2015.

Table 4 shows a transition metric analysis of land cover change between 2005 (initial state) and 2015 (final state). A previous surface mine concession existed before NGGL took over in 2003 and began commercial mining operations in 2006. Thus, effectively after the 2005 survey, a total of 3463.2 ha of surface mine area changed to the forest (1806.1 ha), agricultural land (1299.2 ha), settlements and open land (322.8 ha) and 35.0 ha of mine pits, waste dumps, and water bodies (Table 4).

While the decrease in forest cover was comparatively high in both resettled communities compared to the non-resettled community (Fig. 4), effectively, there was an increase of 2562.8 ha of forest cover in the study period (Table 4). This was due to the reforestation of the degraded forest areas with *Cedrela odorata* and *Tectona grandis* (NGGL 2005d) in an effort to conserve the western side of the Bosumkese Forest Reserve (SGS 2005). A total of 44.8 ha (0.41%) of forest cover changed into tailings storage, mine pits, waste dumps, and water bodies due to the commercial mining activities of NGGL from 2005 onwards. This, in effect, precipitated the physical and economic displacements of 1701 households (9575 people) living in the project area. About 138.4 ha (1.28%) of forest

Table 2 Characteristics of surveyed households

	Resettled site I	Resettled site II	Non-resettled site
Total households	87	312	242
Interviewed households	35	125	97
Number/proportion of male respondents	20 (57.1%)	60 (48.0%)	51 (52.6%)
Number/proportion of female respondents	15 (42.9%)	65 (52.0%)	46 (47.4%)

Table 3 Characteristics of expert interview respondents

	Organizational affiliation/division	Number of expert
Mining company	Newmont Ghana Gold Limited, Ahafo Concession	
	The Public Relations Division	3
	NGGL Community Office	2
	NGGL's External Affairs	2
Government organization	Environmental Protection Agency	3
	Minerals Commission	2
	Local Government (District Assembly)	2
NGO/Civil society Organizations	External NGO and Community-Based Organization/ NGO Collaborative for Development Action	4
	Conservation International Ghana	
	Ghana Wildlife Society	
Community stakeholders	Local Youth Associations	2
	Women Association	3
	Unit Committee	2
	Traditional Leaders	2
Total		27

cover was converted into settlements and open lands (Table 4) mainly because of the opening up of the area due to mining operations and population increase.

Approximately 572.4 ha (41.1%) of settlement and the open land area was maintained between 2005 and 2015 (Table 4). Resettling the communities and converting open land; however, was made possible by converting a total of 182.9 ha (13.1%) for tailings storage, mine pit, waste dump, and water bodies (NGGL 2005a). Overall, settlements and open lands experienced a total class change of 820.5 ha and an increase of 2537.9 ha between total coverage of 1392.93 ha in 2005 to 3930.21 ha in 2015 (Table 4). At the same time, a combined total of 1005.0 ha (3.53%) of agricultural land cover changed to tailings storage, mine pits, waste dumps, and water bodies (NGGL 2005a). A substantial area of 2896.6 ha of agricultural land changed to either settlements or open areas due to the infrastructural needs during the development of the Ahafo South Project, which displaced 710 households (4513 individuals) from the project area; see Table 4 (NGGL 2005d).

At the landscape level, the number of patches (NumP) and mean patch size (MPS) was used to measure habitat richness and fragmentation. The higher the NumP, the smaller the MPS and the richer and fragmented the area. Table 5 shows landscape structural changes in the study sites between 2005 and 2015. NumP increased from 5660 in 2005 to 10,518 in 2015 (Table 5), suggesting that habitat fragmentation nearly doubled over the 10-year period of mining. The mean patch size (MPS) reduced between 2005 and 2015 further confirming the high levels of forest fragmentation. The Shannon Diversity Index (SDI) suggests a very negligible increase in habitat diversity at the landscape level.

These findings support the intermediate disturbance hypothesis, which states that severe disturbance as in the case of these communities or prolonged absence of disturbance generally has depressing effects on biodiversity, but intermediate disturbance seems to enhance diversity in a system[1] (Pickett and White 1985). Interestingly, the mean shape index (MSI) shows a marginal decline in habitat shape complexity or heterogeneity between 2005 (MSI = 1.43) to 2015 (MSI = 1.42) (Table 5). It is quite possible that land-use activities related to mining led to the deterioration of the landscape structure, though marginally (McGarigal et al. 2012; SGS 2005). According to Ney-Nifle and Mangel (2000) and Vitousek et al. (1997), habitat fragmentation could affect the survival of plant species leading to biodiversity loss. Table 6 summarizes species richness and diversity in the study sites.

When considering all 10 indicators of environmental sustainability (Table 7), resettled site I was the most environmentally sustainable as it had the lowest score (0.95), followed by the resettled site II (1.53) and the non-resettled site (1.57) (Table 8). The higher environmental sustainability of resettled site I can be attributed to its lower reported levels of soil contamination, water pollution, and forest degradation (Table 7). Resettled site II also benefited from the development of some physical infrastructure such as potable water systems provided by NGGL. Soil erosion rates were reported to be high in both resettled

[1] An SDI of zero suggests that the landscape contains only one patch and thus no diversity.

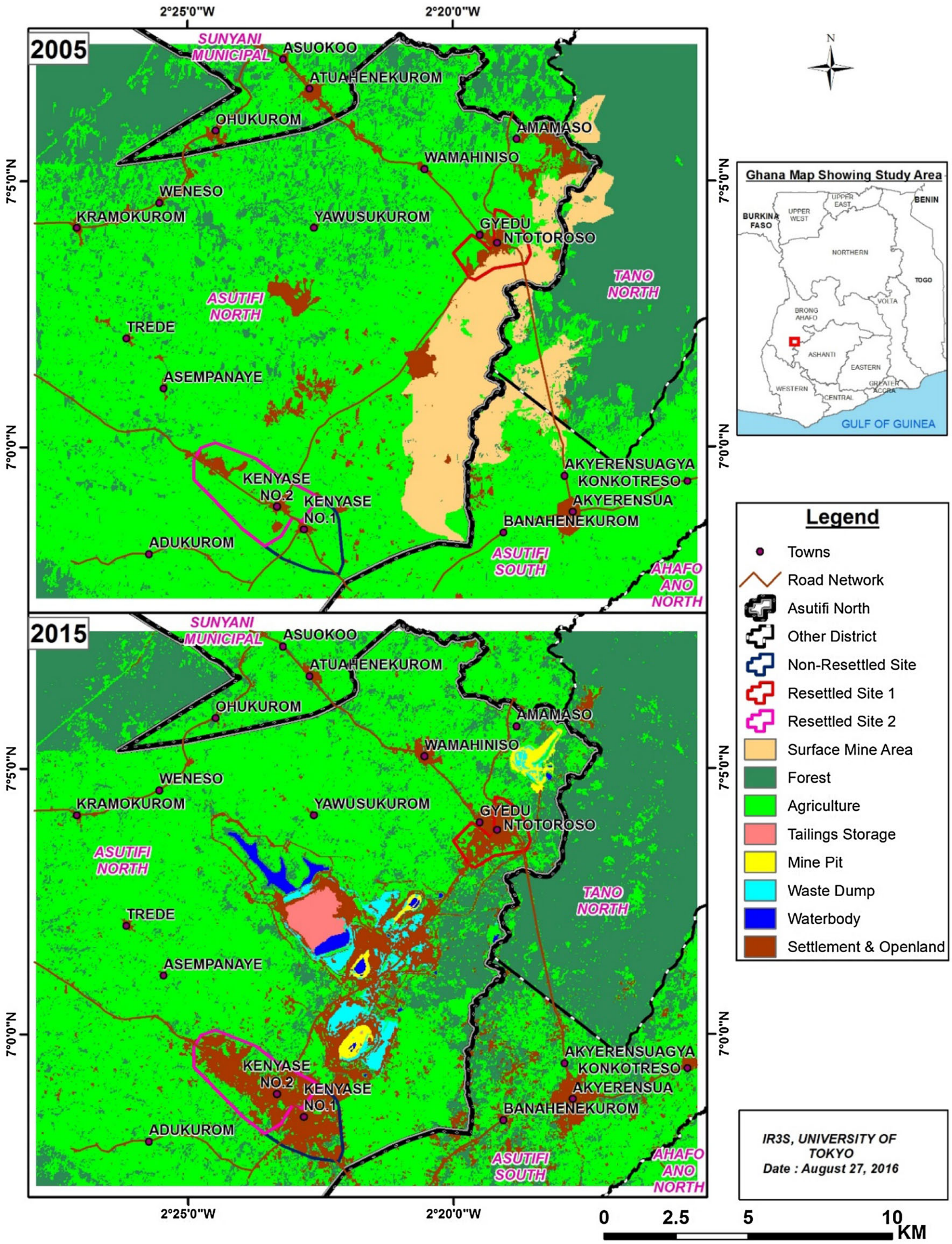

Fig. 4 Land-use types and study communities

communities, with interviews with community leaders, suggesting that poor draining systems (particularly in resettled site I) and lack of tree cover as the major causes of soil erosion. The low species richness and diversity in both resettled sites due to the removal of vegetation for mining activities also reflects the poor vegetation regeneration potential (Table 7). The non-resettled community had the lowest environmental sustainability due to its proximity to the mining site (Fig. 4). For instance, the community had most of its forest cover removed to pave way for mining

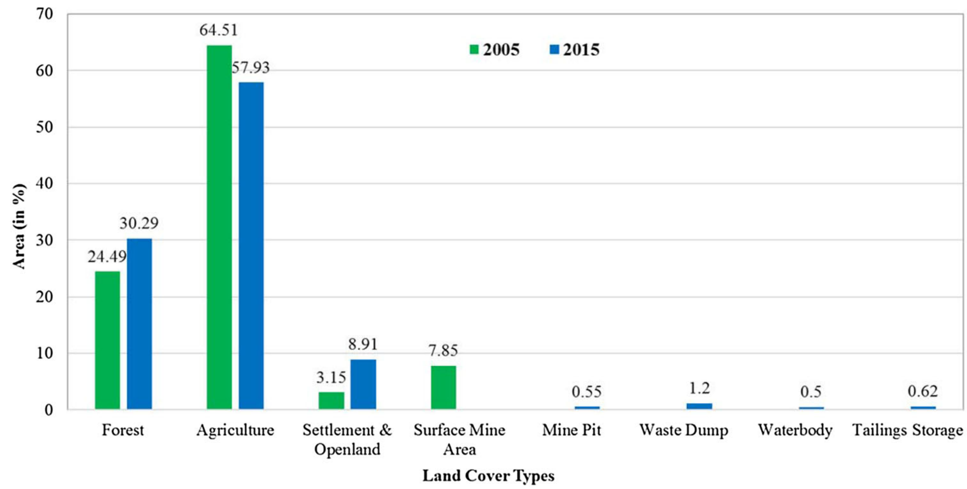

Fig. 5 Area of land-use types (in %) in 2005 and 2015 in the study area

Table 4 Land cover change transition matrix between 2005 and 2015

	2005 (acreages and percentages)				
	Forest	Agriculture	Settlement and open land	Surface mine area	Class total
2015 (acreages and percentage)					
Forest	7306.83 (67.61%)	4044.69 (14.21%)	212.22 (15.24%)	1806.12 (52.15%)	13369.86 (100%)
Agriculture	3317.67 (30.70%)	20523.06 (72.09%)	425.43 (30.54%)	1299.24 (37.52%)	25565.40 (100%)
Tailings storage	25.56 (0.24%)	241.74 (0.61%)	6.75 (0.48%)	0	274.05 (100%)
Mine pit	2.79 (0.03%)	172.53 (0.61%)	52.11 (3.74%)	16.74 (0.48%)	244.17 (100%)
Waste dump	5.4 (0.05%)	441.18 (1.55%)	74.34 (5.34%)	9.18 (0.27%)	530.10 (100%)
Waterbody	10.62 (0.10%)	149.58 (0.53%)	49.68 (3.57%)	9.09 (0.26%)	218.97 (100%)
Settlement and open land	138.42 (1.28%)	2896.56 (10.17%)	572.4 (41.09%)	322.83 (9.32%)	3930.21 (100%)
Class total	10807.29 (100%)	28469.34 (100%)	1392.93 (100%)	3463.20 (100%)	
Class change	3500.46 (32.39%)	7946.28 (27.91%)	820.53 (58.91%)	3446.46 (100%)	
Image diff	2562.57 (23.71%)	−2903.85 (−10.20%)	2537.28 (182.15%)	−3219.03 (−92.95%)	

Table 5 Landscape changes in the study sites

Year	SDI	MSI	MPS	NumP
2005	0.94	1.43	7.80	5660.00
2015	1.03	1.42	4.20	10518.00

activities, while its water sources were also highly polluted and sedimented due to the lack of riverbank protection.

Social sustainability

The two resettled communities seem to have experienced more severe social impacts compared to the non-resettled community (Tables 7, 8). For instance, the removal of cultural landscape elements such as shrines and gravesites deprived communities a sense of place and belonging connected to their cultural and historical heritage. Both resettled communities were the most impacted by the removal of cultural landscape elements as they were physically moved from their original location (Table 5). In both communities, key informants complained that some aspects of their sense of living such as their connection to the land and dead ancestors were taken away from them due to this relocation.

Another important social impact has been the increasing numbers of individuals in vulnerable groups, i.e., children, senior citizens, physically disabled, and women (Table 7). This is linked to increased immigration of the active working population from the study communities, and particularly the resettled communities due to decreased

Table 6 Species richness and diversity in study sites

Plant and animal species	Local name	Family	Resettled site I		Resettled site II		Non-resettled site	
			RD	RF	RD	RF	RD	RF
Trees								
Antiaris toxicaria	Kyenkyen	Moraceae	0.65	0.61	0.45	0.85	0.75	1.69
Baphia nitida	Odwen	Fabaceae	0.4	0.1	0.3	0.61	0.43	0.7
Griffonia simplicifolia	Kagya	Fabaceae	2.1	2.79	1.8	0.81	2.3	1.69
Shrubs								
Ficus exasperata	Nyankyerene	Moraceae	2.81	2.24	0.3	0.7	3.11	2.67
Ocimum gratissimum	Onunum	Lamiaceae	0.23	0.42	0.68	1.33	2.93	2.12
Dracaena arborea	Nsomme	Dracaenaceae	2.05	3.33	0.68	0.85	0.68	1.33
Insects								
Coleoptera scarabaeidae	Dung Beetle	Scarabaeidae	2.05	1.93	2.13	2.27	2.01	1.98
Onthophagus fuscatus	Beetle	Scarabaeidae	1.53	2.4	1.84	1.72	1.64	1.72

RD relative diversity, *RF* relative frequency

livelihood opportunities and the abandonment of farmland (see next section).

Economic sustainability

In terms of economic sustainability, the selected indicators largely focused on agricultural livelihoods as all study communities are rural and mostly dependent on farming. Resettled site I has the highest economic sustainability (1.03), followed by the non-resettled community (1.50), and the resettled site I (1.89) (Table 8). Since both resettled communities were directly impacted by mining (due to their physical relocation), there was a higher emphasis on providing support for farm development and implementation of diversified livelihood options (Table 7). As a result, both resettled communities scored better in terms of farm yield compared with the non-resettled community (Table 7).

Although expert interviews with community stakeholders suggest that the mining company provided potable water to residents of the resettled communities due to the high levels of water pollution, both resettled communities reported poor access to potable water compared with the non-resettled community (Table 7). FGD participants complained that the lack of access to potable water is a major problem for local households as they have to spend extra time and resources to seek for alternative water sources, which takes a toll on other livelihood activities.

Institutional sustainability

Resettled site I and II have the highest levels of institutional sustainability (0.69), followed by the non-resettled site (1.33) (Table 8). The non-resettled site had a hostile relationship with the mining company and this affected any negotiation to address community concerns over mining impacts. On the other hand, both resettled sites had an open channel of communication with the mining company and this helped to an extent to reduce tension and build trust between the company and the communities. This notwithstanding, the lack of politically influential person and the partial loss of authority of local chiefs in resettled site I affected its negotiating and lobbying power (Table 7). On the contrary, the paramount chief within the area pays homage to the chief of resettled site II, and therefore, this community is able to draw more support from both the mining company and other organizations.

Total community sustainability

Resettled site I had the lowest total community sustainability score (1.17), which suggests that it experienced the lowest overall negative sustainability impacts from mining. Non-resettled site (1.49) and resettled site I (1.67) seem to have experienced higher negative sustainability impacts from mining. The better score of resettled site I can be attributed to its relatively better scores for the environmental, institutional, and economic sustainability pillars. The low sustainability score of resettled site II is largely attributed to its poor performance in the economic and social sustainability pillar. The non-resettled community had the best score for social sustainability (Table 8).

Discussion

Community-level sustainability analysis

Mining is a significant driver of environmental, socioeconomic, and institutional change in the study communities.

Table 7 Sustainability indicator scores (higher scores denote higher negative impacts)

Sustainability Index category and indicators	Communities		
	Resettled site I	Resettled site II	Non-resettled
Environmental sustainability ($t = 10$ indicators)			
Soil contamination	0.33	0.33	1.33
Vegetation regeneration potential	1.33	3.00	0.33
Destroyed/sedimented watercourse	1.33	1.33	3.00
Water pollution	0.33	1.33	3.00
River bank protection	0.67	0.67	1.50
Richness/diversity of animals	0.33	1.33	3.00
Richness/diversity of plants	1.33	3.00	1.33
Habitat diversity	0.17	1.50	0.67
Forest loss	3.00	1.33	1.33
Soil erosion	0.67	1.50	0.17
Social sustainability ($t = 6$ indicators)			
Farmer-miner economic mobility	3.00	3.00	1.33
Loss of cultural landscape (e.g., shrines)	0.33	3.00	0.33
Loss of aesthetic values (e.g., due to landscape fragmentation)	3.00	0.33	1.33
Migration from affected areas	1.33	3.00	0.33
Access to social services (e.g., secondary education)	3.00	3.00	3.00
Vulnerable population	1.33	3.00	3.00
Institutional sustainability ($t = 6$ indicators)			
Politically influential person in community	1.50	0.17	0.17
Implementation of afforestation schemes	0.67	0.17	0.17
Stakeholder organizations/CBOs	0.33	0.33	3.00
Loss of authority of local chiefs	0.67	0.67	0.17
Relations between NGGL and community leaders	0.33	1.33	3.00
Local community participation in restoration activities	0.67	1.50	1.50
Economic sustainability ($t = 6$ indicators)			
Community capacity development	1.33	3.00	1.33
Livelihood diversification	0.33	3.00	1.33
Loss of farmland area	1.50	0.67	0.67
Loss of forest benefits	1.33	0.33	1.33
Decrease in agricultural yields	0.33	1.33	3.00
Access to potable water	1.33	3.00	1.33

Table 8 Total community sustainability scores (higher scores denote lower overall sustainability)

Sustainability pillar	Resettled site I	Resettled site II	Non-resettled site
Environmental	0.95	1.53	1.57
Social	2.00	2.56	1.56
Institutional	0.69	0.69	1.33
Economic	1.03	1.89	1.50
Total Community Sustainability (25% Weight)	1.17	1.67	1.49

Our analysis provides a comprehensive assessment of the local sustainability impacts of mining across different environmental, social, institutional, and economic dimensions, which is typical in many mineral-rich local communities across Africa (Twerefou 2009; Kemp 2010a, b; Mnwana 2015).

Differences in the characteristics of each community, as well as their location in relation to active mining operations, were important determinants of the overall community sustainability. In terms of environmental sustainability, resettled site I was the least sustainable having low vegetation regrowth and ecosystem diversity, and high forest degradation compared to the non-resettled community and resettled site I. While the spatial analysis at the landscape level reveals a little variation of the environmental sustainability pillar between study communities, we observe a high level of fragmentation and low species diversity across all communities, and especially at resettled site I. Interviews with community leaders revealed that extensive areas of forest reserve were cleared to allow mining operations at resettled site I, which led to land degradation, and the loss of agricultural land and forest cover. For instance, Conservation International (CI) surveyed the effect of NGGL's operations on plants of economic importance in the resettled communities, and acknowledged the negative impact of mining on the access to (and use of) forest resources. It should be noted that even though our study assesses species richness and diversity in the study communities, the lack of a systematic documentation of species abundance and distribution in baseline surveys (i.e., before the commencement of mining activities by NGGL) has curtailed our ability to identify the true impact of mining on environmental sustainability.

Our social sustainability assessment employed six indicators. While these indicators are not by any means exhaustive of the social impacts that mining can have at the community level, the selected indicators reflect irreparable social changes that can have long-term consequences on community sustainability. For instance, the removal of cultural landscapes, farmer-miner economic mobility, and migration from affected areas reflect long-term social changes in the resettled communities compared to the non-resettled site. On the other hand, resettled communities (as is the case in our study) tend to benefit more from social infrastructure compared to the non-resettled community. For instance, resettled site I and II benefited more in the form of community planning, access to infrastructure (e.g., schools and clinics), and access to social services. In rural community settings where mining is a key driver of social change, access to such infrastructure can enhance community resilience to the impacts of mining (Hilson 2002).

As pointed above, in most studies related to the local impact of mining, institutional factors have received less attention. However, our findings suggest that the institutional strength of a community can directly or indirectly affect how communities are impacted by mining, or are able to mitigate the impact of mining. Mining has severely affected local institutions in all communities. The local chieftaincy institution, in particular, does not command the same level of authority as before the introduction of mining in the resettled communities. For instance, in resettled site I, decline in the authority of local chiefs has affected the ability of local leaders to negotiate with mining companies on the type of development projects that would be more beneficial to the community (cf. Amponsah-Tawiah and Dartey-Baah 2011). Furthermore, the lack of local political representation has affected collaborative planning as mining companies operate in a top–down fashion. This has implications for decision-making and the political activism that is needed to bring pressure on authorities to enforce the existing regulations (Campbell 2003, 2009). Community-based organizations have sprung up in the resettled communities to fill the void left by the breakdown of the local political system. A downside to this new institutional regime is that the CBOs are externally driven and tend to be more sympathetic towards the mining company. We also identified a communication breakdown between the mining company and the local community in the non-resettled site due to the hostile relationship that arose from disagreements concerning the social responsibility of NGGL. This hostility effectively took a toll on any form of community development, including social responsibility projects. It also explains to an extent why NGGL's social responsibility projects benefitted resettled communities more than the non-resettled communities. Again, in terms of community involvement in restoration activities such as afforestation programs, the non-resettled site reported a little involvement beyond a few locally connected individuals, compared to the wider involvement of community leaders and individuals in the two resettled communities.

In terms of economic sustainability, the resettled site II appears to perform better than the other communities. Although both resettled communities received more support such as capacity building to enhance farming and livelihood diversification, the decline in farmland area and the fewer benefits received from forest resources seem to have had negative effects on local sustainability. However, it is important to point out that all communities were performing poorly on indicators related to access to agricultural land, micro-credit schemes, and agricultural extension services. For instance, the loss of agricultural land due to mining as discussed in the previous section affects access to arable land and agro-ecosystems. Although the mining company anticipated that the construction of the Ahafo South Mine (and its ancillary facilities) will disturb more than 50% of agricultural land in the area, not much was done to address these anticipated problems as our study revealed. These economic effects highlight in many ways the need for mining companies to plan community development initiatives in a way that consider rural livelihoods and community perspectives (Kemp 2010a, b; Amponsah-Tawiah and Dartey-Baah 2011).

Implications for restoring mine damages

A key concern of the local communities affected by mining is how to address the multiple impacts brought by mining, and how to put the communities towards more sustainable trajectories. The methodology adopted in this study can offer a comprehensive assessment of mining impacts, as a first step towards proposing restoration goals that are community- and/or area-specific.

When it comes to restoration actions related to environmental sustainability, more attention should be paid on the non-resettled site, since it has experienced the most severe impacts among the three communities. Key environmental sustainability priority areas for all local communities include the need to address sedimented watercourses, decreased forest area, soil erosion, and lack of riverbank protection. In relation to erosion, communities should be supported to introduce erosion control measures in households, public spaces, and in agricultural fields (e.g., tilling, ploughing, and use of cover crops). At the landscape level, the key environmental concerns such as landscape fragmentation and biodiversity loss could be mitigated through a series of measures such as the local re-colonization of species, the creation of open habitat mosaics that incorporate native species, and the use of shelter wood practices. To improve access to forest resources, community tree plantation programs, reforestation using nitrogen-fixing plants, and formation of green clubs in communities should be encouraged and supported.

Options to address the social impacts of mining should focus on addressing migration and access to social services. In terms of access to social services, the government of Ghana needs to compliment the efforts of the mining company in expanding access to services such as education and health, particularly in the resettled communities. The local government in particular should take an active interest in expanding and maintaining existing social infrastructure. On the other hand, the mining company should consider building the capacity of the local communities to maintain the provided infrastructure. While the factors driving migration in the study communities are complex and dynamic (and possibly extend beyond mining), expanding local livelihood opportunities on- and off-the-farm could help to limit outmigration and loss of local labour.

Related to the above, to improve the economic sustainability, supporting agricultural livelihoods and expanding access to potable water could be priority restoration goals. Improving access to new agricultural land (especially in resettled communities), encouraging the youth to go into farming, and improving access to farm input to increase productivity can be some of the possible interventions. Improving access to farm inputs so as to increase productivity will require the direct provision of seedlings and fertilizer. Enhancing the interest of youth in farming as a means of moving away from mining can be a long-term goal which may require support and the provision of appropriate incentives from the local and national governments. Livelihood diversification can be another important restoration goal needed in all the communities as towards the end of the mine life cycle, most mine workers are likely to lose their jobs. Alternative livelihood schemes to support ex-mine workers could involve support for livestock rearing activities, cash crop production, and involvement in reforestation support programs. Support for alternative livelihood options can broaden the focus of restoration goals from simple landscape restoration (Limpitlaw and Briel 2014). Overcoming the lack of funding (Hilson 2002; Assel 2006; Amponsah-Tawiah and Dartey-Baah 2011) and commitment from both the government and mining companies could facilitate the transition to comprehensive restoration programs. On the other hand, improving access to potable water across all communities could help to improve the well-being of the local community. In the short-term, restoration goals to improve access to potable water could focus on providing less costly disinfecting water solutions for home use. However, in the long-term, more attention should be focused on tapping underground water sources as practically all the surface water has been polluted by mining (Babut et al. 2003). Funding for such programs can involve a cost-sharing arrangement between the local district assembly, the local communities, and the mining company.

Finally, more attention needs to be paid on how mining affects the local governance structures, especially in non-resettled communities. Mining has often weakened local governance structures, and particularly the authority of local chiefs. In our case this has affected how local communities can collectively address (or lobby to mitigate) the impact of mining. To curb the hostile relations between mining firms and local communities (as well as strengthen local governance institutions), there should be conscious effort to involve local communities more meaningfully in the design and implementation of restoration activities. Local CBOs could play a mediating role to build trust and understanding between mining firms and local communities.

Caveats and limitations of the study

We identify four important caveats in our study. First, while the recommendations outlined in the previous section can be appropriate for restoring mine-affected areas in Ghana, they may not be transferable to other areas of Africa due to the different prevailing political, socioeconomic, and environmental conditions. Furthermore, as we used extensively expert opinion and stakeholder insights to identify, weigh, and rate the indicators, several of our methodological decisions are location-specific and require a very good knowledge of the locality.

Second, in our assessment, we assumed that the local sustainability impacts of mining are negative (with low, moderate, or high levels). However, there have been some positive impacts from mining (at least for some segments of the local communities) such as income/employment generation and the provision of some social services. Yet, household surveys and focus group discussions strongly suggested that the negative impacts far outweigh the positive. While our assessment approach was simplified to reflect only these negative impacts, it can be easily adapted to differentiate negative and positive impacts in contexts where trade-offs are more balanced.

Third, the development of composite sustainability indices entails several methodological steps that are subject to subjective decisions (Singh et al. 2012; Gasparatos et al. 2008). For example, the extensive use of expert judgment, the use of qualitative information to measure key indicators, and the lack of a sensitivity analysis reduce to an extent the robustness of our results. To limit such methodological shortcomings, some of the recommended methods for constructing composite indices such as principal component analysis, factor analysis, and distance to target normalization (Singh et al. 2012; OECD 2008) could be used in future studies.

Fourth, the extensive stakeholder consultation during the development of our composite index and its data intensiveness can affect its utility in data-constrained environments or when time/budget constraints are important.

Notwithstanding the above limitations, the transparent process we adopted during the development of the sustainability index and the wide involvement of the local community and experts have provided a good insight of the local sustainability impacts of mining through different perspectives. This framework can be adapted for assessing the local sustainability impact of mining in other African countries. However, future adaptations of this approach can improve its effectiveness by taking serious consideration of the caveats discussed above, as well as involving communities to test whether the recommendations provided in the previous section are socially desirable (as well as what their limitations are).

Conclusions

Reducing the negative sustainability impacts of mining can go a long way towards improving the environmental and socioeconomic condition of local communities, as well as their resilience. Our study developed a composite sustainability index that provided a holistic assessment of the local impacts of mining in three communities surrounding the gold mine of NGGL in the Ahafo South District of the Brong Ahafo region, Ghana. Our study viewed mining activities as a driver of environmental, social, economic, and institutional changes that manifest in multiple local impacts.

Results suggest that despite some between-community similarities for some environmental impacts, the local communities often had radically different scores for social, economic, and institutional sustainability indicators. This implies that in Ghana, and in other mineral-rich African countries, restoration activities in mine-damaged communities need to go beyond simple landscape restoration to include interventions that improve human well-being, infrastructure, and enhance the stability and effectiveness of local governance institutions.

Stakeholders such as local communities, mining firms, civil society, and the national government are key players to tackle the sustainability challenges that mining poses. For instance, mining firms, apart from adopting sustainable production practices during their operation, they can develop restoration goals that consider the complex and multi-faceted damages after their operations are concluded. Mining firms can contribute meaningfully to restoration efforts by moving beyond their narrow adoption of standardized tools such as CSR and environmental impact assessments (EIAs), to consider more meaningfully the local environmental, social, economic, and institutional impacts of their operations.

National governments should be encouraged to act proactively to ensure that all aspects of mining (and its impacts) are given the necessary attention. This is particularly pertinent in Ghana, given the historical focus on putting in place policies to attract mining investments rather than guaranteeing the protection of the environment and human dignity from unsustainable mining. Governments should lead efforts to improve the sustainability of mine-affected communities through multi-sectoral approaches that involve diverse stakeholders such as local communities, civil society, and mining firms.

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