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Mining-induced changes in ecosystem services value and implications of their economic and relational cost in a mining landscape, Ghana

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ABSTRACT

The surge in mining operations to meet the global demand for mineral resources adversely impacts ecosystem services and dependent households, but the issue barely attracts attention. This study evaluated the dynamics of mining-induced changes in the value of ecosystem services (ES) and the consequent economic and relational cost to rural households in the Ahafo region of Ghana. Face-to-face structured interviews with 200 householders were conducted in three mining communities. We determined relational values in the landscape through focus group discussion and the economic cost of the ecosystem services lost by applying replacement and contingency cost estimations. Old-growth forests, degraded forests, teak plantations, cultivated land, wetlands, and grassland were ecosystems identified in the mining landscape. The most valued ecosystem was old-growth forest, while the least was grassland. Provisioning service was the most valued ES, while supporting service was the least. Provisioning ES was rated the most impacted by the mine, whereas cultural services were the least affected. Mining activities caused a significant loss of 14 ecosystem services (including crops, livestock, capture fisheries, wild food, bush meat, biomass fuel, and freshwater) that were of priority to the communities. The affected households experienced relatively high monthly economic costs, approximating $300 per household, from the loss of priority ecosystem services. Canonical correspondence analysis revealed connections between ecosystem services valuation and the socio-demographic characteristics of the respondents. There was a perceived mine-adverse effect on the relational values of the people relating to cultural identity, sovereignty, symbolic value, security, subsistence and livelihood, sense of place, social cohesion, social memory, female emotional/mental health, and womanhood training opportunities. Actors in the mining industry should consider policies and management interventions that will limit ecosystem services loss, widely ascertain ecosystem benefits, and comprehensively mitigate the impact of their loss on households.

1. Introduction

Ecosystem services (ESs) are the ecological functions and processes of ecosystems that are passively or actively utilized by humans

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for their well-being [1]. Ecosystem services are grouped into provisioning, regulating, supporting, and cultural services [2]. Provisioning services are yields of ecosystems such as water, food, timber, and fuels. Regulating services encompass regulating ecosystem processes like water purification and flood control. Supporting services are ecological functions like nutrient cycling and soil formation essential in producing all other ecosystem services. Cultural Services cover non-materials such as spiritual and recreational benefits obtained from ecosystems [2,3]. Recent are also the concepts of knowledge services [2] and geosystem services [4]. These concepts allow for consideration of surface ecosystem and subsurface geosystem services to ensure sustainable use of the natural environment [5]. The conceptual development of ecosystem service and understanding of ecosystem functioning have progressed steadily over the years [6–8].

The deepening in the knowledge of ecosystems has contributed to establishing that there is a continual deterioration of ecosystems and connected services across the globe [1]. Human activities such as the expansion of agriculture, population growth, and livestock are noted as anthropogenic disturbance affecting terrestrial ecosystems [9,10]. Constant and widespread impacts of human activities on terrestrial ecosystems such as fragile rainforests reduce their area coverage, productivity and biodiversity [9]. In tropical regions, these activities and many others lead to forest cover loss [11,12], which in turn leads to a decline in several ecosystem services [13–16]. However, studies on ecosystem services are infrequent in Africa, of which most cover provisioning ES [17,18]. Even rare in the continent is data on land-use-land-cover dynamics and connected consequences on ecosystem services [19]. For instance, in Ghana, a few scientific investigations have recently looked into land use disturbance in relation to the stock and flow of ecosystem services to the dependent communities [12,20].

Mining is an important human activity that serves as a significant source of income, and catalyst in broader economic development, particularly in terms of national revenues and jobs [21]. Mining contributes appreciably to the global economy - accounting for 1.2 % of the world's total GDP [22]. However, mining activity can have significant negative impacts and dependencies on ecosystem services [23]. Though mining is a transitory land-use type, it requires an extensive network of industrial infrastructure that can disrupt the surrounding land and stretch far beyond the comparatively small footprint of the mine or exploration site [24]. Indeed, ecosystems are affected by the physical perturbations and chemical alterations of mining operations. For instance, mining converts tropical forests with multiple ecosystem services to a landscape with limited services [25]. Unfortunately, the devastating influence of development projects such as mining on ecosystem services is often overlooked by development managers and policymakers.

The mining disturbance on the ecosystems and their services may economically cost dependent households. This is particularly true in rural Africa where local community dependence on natural resources and ecosystem services can be exceptionally high [6]. Paradoxically, mining benefits such as quality employment and businesses, export earnings, tax and royalty payments are known to accrue at the national level at the expense of costs at the local level [26,27]. This scenario suggests a case of mining disturbance and dependence on ecosystem services and local community benefits dislocation. Despite this imbalance in the distribution of mining benefits and disturbance of stock and flow of ecosystem services in the mining context, few studies have assessed impacts of mining on ecosystem services [25,28–30]. Indeed, the studies on the impacts of mining on ecosystem services are scanty, focused on a limited set of ES, and devoid of linkages between the ES impacts and human wellbeing [18]. Thus, to date, there is virtually no comprehensive, systematic, and integrated study of the effects of mining on ecosystem services and the consequential economic and relational cost to the dependent households and their wellbeing.

Ghana has remained a region of intensive mining businesses and is presently the largest producer of gold in Africa (25) (26). The country is consolidating strategies to maintain this mining leadership and increase the visibility of other resources for commercial exploitation [31]. The current resource exploitation leaning of the nation suggests further biodiversity and ecosystem services disturbance with consequent impact and environmental injustice [32–34] that may affect human well-being in the country. Accordingly, understanding the impacts of mining on the socio-ecological well-being of rural households [35,36,36] and the cost of ecosystem services loss to them due to mining in Ghana is crucial to inform mining policies and interventions that will ameliorate the impacts. Thus, our findings would contribute towards the attainment of socio-environmental or socio-ecological justice in the face of mining. The paucity of such information may inhibit the implementation of ecosystem conservation and ecosystem service management strategies in the region. The dearth of aforesaid data may make economic and relational cost of ecosystem service loss due to mining elusive to both mining operators and the local community and consequently impairs possible compensation schemes. The situation could also engender misunderstanding and conflict between mining operators and the affected communities over deprivation of relational values, sustenance, and livelihood. In recent times arguments have been made to support the inclusion of ecosystem services in Environmental Impact Assessment. This is because ecosystem services mirror ecosystem functioning and also reflect the socio-economic wellbeing of people [37] and could be an effective indicator of ecosystem changes due to mining. For ecosystem service integration into Environmental Impact Assessment to become well accepted in a mining context, there should be adequate information on the extent of the influence of mining on ecosystem service changes. To this end, our findings would be informative for policies on ecosystem service integration in Environmental Impact Assessment. Based on the existing research gaps, we sought to 1) assess the impacts of mining on ecosystem services in a mining landscape in Ghana, 2) determine the economic cost of ecosystem services lost to the dependent rural households as a consequence of mining, and 3) evaluate the mining-induced adverse effect on relational values in the landscape and 4) establish ecosystem services association with ecosystems and socio-demographic characteristics. The study will increase our understanding of mining impacts on ecosystem services to help manage mining land access practices that could worsen ecosystem service for dependent households. And make stakeholders understand and align expectations in estimating adequate compensation and mitigations for ecosystem services disturbed through mining.

2. Materials and methods

2.1. Study area description

The study covers areas around Newmont Ghana Gold Limited's (NGGL) Ahafo South mining operation in the Asutifi North District of the Ahafo Region of Ghana (Fig. 1). The area is located within 7° 5′ 59.7″ N and 2°25′ 33.9″ W to 6° 56′ 43.3″ N and 2° 17′ 19.3″ W. Newmont is a multinational large-scale mining company in gold exploitation. The company has mining and prospecting licenses covering 774 square kilometers of land [38]. Between 2005 and 2018, the Ahafo Mine has compulsorily taken approximately 5000 ha of land for mining activities [39], leading to forced relocation or displacement of thousands of residents [40]. The mineral revenue from the NGGL Ahafo mine was 793,670,767 and US$889,522,223 in 2013 and 2019, respectively [31].

The District where the mine is located has a population of 73,556, with 51.2 % males and 48.8 % females [41]. The rural residents form over 90 % of the population, and work primarily in agriculture [42]. Aside from agriculture, other economic activities in the District are commerce and mining. Forests, plantations, water bodies, and cultivated land constitute the dominant ecosystems in the area [12]. The District lies within the wet semi-equatorial zone marked by double rainfall maxima, June and October, with a mean annual rainfall between 125 cm and 200 cm. The highest point of the district is located within a chain of mountains in the northeast, reaching a height of 1400 feet above sea level, while the lowest part is located along river basins and is around 650 feet above sea level.

These mountains form watersheds for the many tributaries of the Tano River and other streams. Tano River is the main watershed that drains the studied region with its seasonal and perennial tributaries, including the Amama, Subika, Atensu, and Subri. This basin is proximal to the southwest corner of Ghana and flows into the Gulf of Guinea near the Cote d'Ivoire-Ghana border. The Tano River is Ghana's third-largest river, with a length of 512 km and a drainage area of around 16,060 km^2 [43].

The study region is part of the early Proterozoic Birimian Formation, which is made up of broad, parallel, and evenly spaced volcanic belts (Upper Birimian) and sedimentary basins. The Birimian-age rocks have undergone regional metamorphism, producing meta-volcano-sedimentary rocks in the study area. Weathering typically reaches up to depths of over 50 m. This weathered zone consists of red lateritic clay and saprolite and covered at the ground surface by duricrust, composed of alluvial fragments and iron pisoliths held together with iron oxide. Saprock is generally considered the uppermost aquifer in the study area. The saprolite is regarded as an aquitard because of its clay content but does contain weathered quartz veins that can serve as conduits for infiltration and groundwater flow. Under the saprock is competent bedrock where the unit is well fractured to hold and transport groundwater [44].

2.2. Study design and data collection

Three settlements were selected purposively for the study: the Ntotroso Resettlement Community, the Kenyasi #1 Resettlement Site, and the Kenyasi #2 Resettlement Camp. Respectively, 200 respondents were distributed among the communities as 80, 60, and

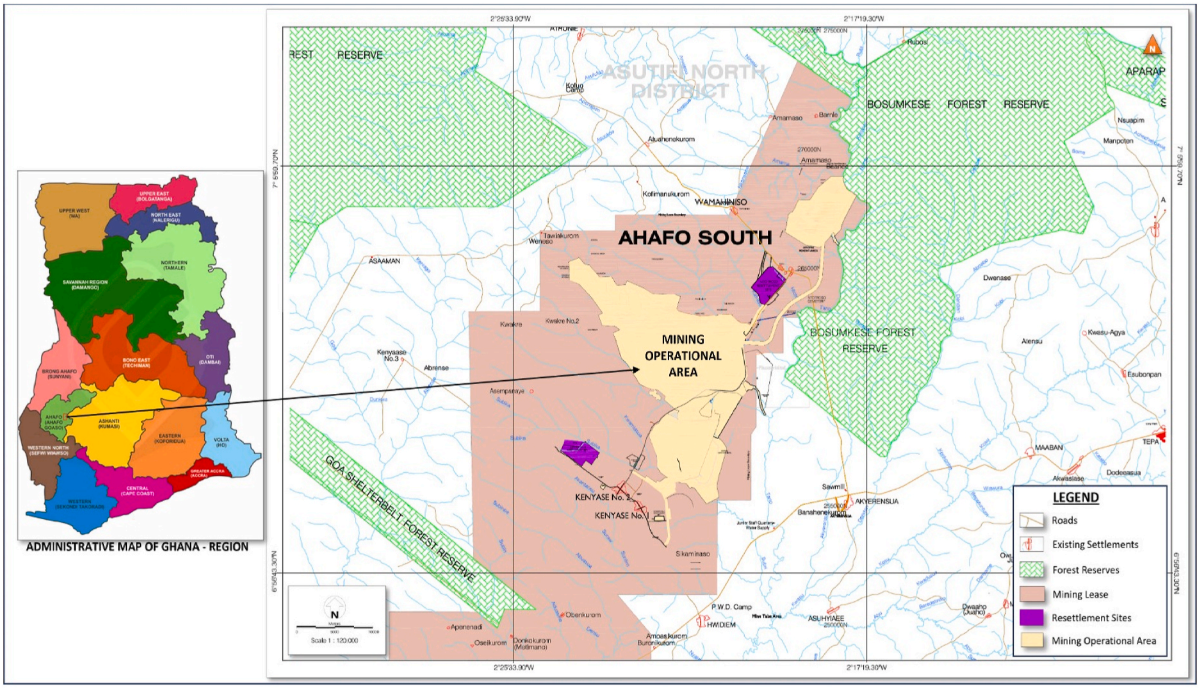

Fig. 1. Map indicating the study area and location of Newmont Ahafo mining operational areas.

60, based on the population size of the communities. The sampled communities comprise resettlement households - thus, people displaced by the project and resettled in the current locations and had experienced varying mining impacts, including loss of ecosystem services. The communities were proximal to the mine and remained the subjects of the mine's operational impacts. Using the Millennium Ecosystem Assessment guide on classes of ecosystem services, and a reconnaissance survey on the landscape, a list of ecosystems and services was generated for the study. After pre-testing questionnaires and incorporating feedback, face-to-face interviews using semi-structured questionnaires were conducted on 200 randomly sampled householders in 2022. The questionnaire was designed according to the Ecosystem Service Review approach [45] and sectioned to cover (i) the socio-demographic characteristics of the respondents (i.e. formal education, age, gender, indigenous and impact status), (ii) the respondents' evaluation of the ecosystem services delivered to people in the area, (iii) the respondent's determination of the levels of ecosystem services dependencies and impact by the mining company and the community and (iv) the respondents' determination of the ecosystem services yield and economic cost of the service's loss to the people following mining. The respondents were asked to indicate the percentage loss of the various ecosystem services and associated costs. All quoted losses and costs that appeared over-inflated were checked or confirmed by leaders of the affected people, experts (valuers/land economists), and a review of land access documentation (eg acreage of land lost to the mine). For 'marketed services,' that's ecosystem goods and services that can be sold in the market such as firewood, the cost of loss was determined with the households using market price or replacement cost. To determine non-marketed services like reduced air quality or flood control, we estimated the cost the households incurred or contributed in managing the damage or the maximum amount they were willing to pay (donate) to control or accept to give up a specific environmental service (contingency valuation method). Prices of all ecosystem services, were quoted in Ghanaian Cedis (GH₵).

The questionnaire administration was followed with four focus groups discussions which comprised of: i) a group of affected householders/farmers and local leaders, ii) a group of leaders from the mining company, including those from social and environmental departments; iii) a group of market women and restaurant operators, and iv) the regional forest managers and biodiversity experts. Their consultations were critical for the richness of the data. The focus group discussions were held in groups of 5–7 to establish the collective view of landscape-related values affected by the mine, capture the 'voices' that's the narrative or explanations [46] relating to services impacted and to reach a consensus on matters of divergence on cost evaluations. Thus, the discussions were used to establish the context and validate some of the monthly quantities or cost/value of some ecosystem services/goods quoted by some households during the interviews. No interpreters were used in the data collection because the researchers could communicate with the stakeholders in either English or the local language.

2.3. Statistical analysis

Thresholds of importance ranging from 1 (least rank) to 5 (highest rank) were set for the range of ecosystems and the evaluation of their services in the study area. We used the aov function in the stats package of R programming to run one-way ANOVA to compare the

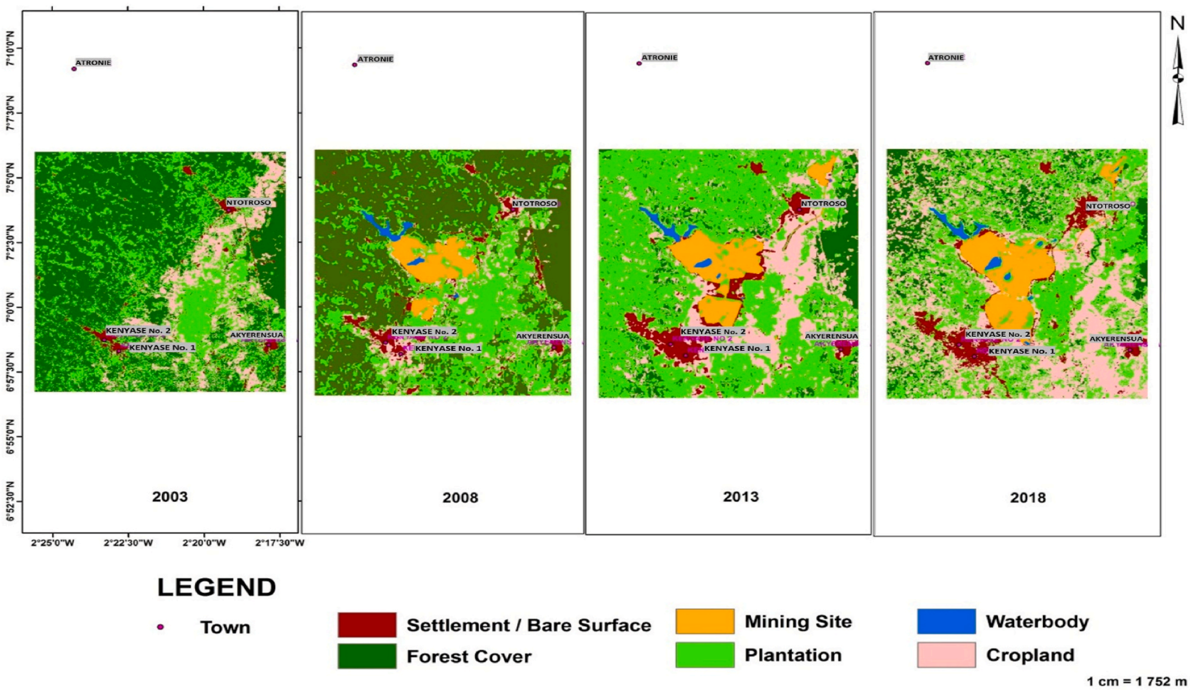

Fig. 2. Map of LULC of the study area, 2003–2018 (Source: Kumi et al., 2021).

various ecosystem services evaluation values among the identified ecosystems [47]. The differences in ecosystem services evaluation among the ecosystems were tested with the Tukey HSD test using the TukeyHSD function in stats package. Canonical correspondence analysis (CCA) is a multivariate statistical technique used for exploring and understanding the relationship between two sets of variables, a set of explanatory variables and a set of response variables. CCA is used primarily in ecological studies. However, in recent times, CCA has been used in studying environmental variables in social context including ecosystem service associations [48,49]. We conducted canonical correspondence analysis (CCA) to determine the relationships between the various ecosystems and their ecosystem services [48], using the former as the explanatory factors, whereas the latter was used as the dependent variables. We also ran the CCA to explore the associations of the demographic characteristics of the respondents with the ecosystem services. The CCA was performed using the cca function in the vegan package in R.

The market price valuation approach involved computing the average market prices of the ecosystem services. In determining the economic cost of ecosystem services lost to the households, the following assumptions were made:

1. The average quantity of ecosystem services collected by households monthly was used as monthly total on the assumption that the quantity fairly represents the household yield per month.
2. The monthly cost per household was built on the assumption that every household use or experienced the loss of all of ecosystem services used to generate the total cost per month.
3. The monthly ecosystem service cost was built on the assumption that prices will not change in the month.

3. Results

3.1. Land cover dynamics of the study area

A study by [8] indicated drastic changes in the land cover of the area due to mining activities. The land use land cover map (Fig. 2) shows notable land use/cover changes in the studied landscape between 2003 and 2018. There was an intense transformation of the forest cover of over 80 % to plantations, cropland, mining site, settlement/bare surface, and waterbody. This was attributable to the mining establishment in 2005 as well as other anthropogenic disturbances brought about by the mining-induced influx of people into the area. Later there was marginal forest area added or recovered due to the resettlement of displaced farmers farther from their farms, and as a result of the remoteness of their new homes to the farms, lands were abandoned to fallow along with concurrent reclamation programme instituted by the mining company. There was noticeable expansion of settlement/bare surface due to influx of people into the mining communities and the resettlement of the displaced inhabitants in the wake of the mining. It reflects the demand for dwellings to meet the population growth in the area. The sharp and substantial expansion in cropland after an initial drop in the landscape was driven by the high demand for food as a result of population growth due to the mining-induced influx of people to the area. The initial decline of cropland reflected four socio-ecological drivers. Firstly, in the initial phases (2003–2008) of the mine development, there was a mad rush of community members converting cropland into plantations and other cash crops within the proposed mining area in order to get high compensation when the mine expands to take such lands. Secondly, people hurried to plant on their bare/fallow land to attract compensation since the existing mineral and mining law had no provision for payment of deprivation of land use or fallow areas. Thirdly, to permit the mining project to develop, crops in the mining area were destroyed. Fourthly, it was initially difficult for the displaced settlers and dispossessed landowners/farmers to obtain farmlands due to the limited land in the surrounding areas.

Table 1
Comparison of respondents' evaluation of identified provisioning ecosystems services among the various ecosystems in the mining landscape in Ghana. Mean values (±SD) in a row with different superscripts are significantly different ($P < 0.05$).

Ecosystem services	Forest Reserves	Degraded Forest	Inland Wetlands	Teak Dominant	Cultivated Land	Grassland
	Mean(S)	Mean (SD)	Mean(S)	Mean (SD)	Mean(S)	Mean (SD)
Bush meat	$4.72^{a}\pm0.5$	$2.9^{b}\pm1.04$	$1.06^{e}\pm0.2$	$1.92^{d}\pm0.95$	$2.4^{c}\pm0.7$	$2.72^{b}\pm0.7$
Crops	$3.92^{b}\pm07$	$3.45^{c}\pm0.79$	$2.1^{d}\pm1.4$	$1.52^{e}\pm0.78$	$4.24^{a}\pm0.4$	$2.14^{d}\pm1.0$
Wild foods	$4.08^{a}\pm0.7$	$3.32^{b}\pm1.0$	$1^{e}\pm0.0$	$1.38^{d}\pm0.48$	$2.56^{c}\pm0.6$	$1.6^{d}\pm0.8$
Livestock	$3.18^{b}\pm0.6$	$2.97^{bc}\pm0.6$	$2.92^{c}\pm1.5$	$1.46^{e}\pm0.7$	$1.96^{d}\pm0.7$	$3.68^{a}\pm0.8$
Capture fish	$1.54^{b}\pm0.8$	$1.24^{c}\pm0.55$	$4.6^{a}\pm0.6$	$1.06^{d}\pm0.24$	$1.24^{c}\pm0.6$	$1.06^{d}\pm0.2$
Aqua culture	$1.24^{b}\pm0.9$	$1.18^{bc}\pm0.6$	$3.2^{a}\pm1.4$	$1.01^{c}\pm0.0$	$1.24^{b}\pm0.7$	$1^{c}\pm0.0$
Timber	$4.04^{a}\pm0.9$	$2.51^{c}\pm0.79$	$1^{e}\pm0.01$	$3.24^{b}\pm0.81$	$1.54^{d}\pm0.7$	$1.06^{e}\pm0.0$
York plant	$1.9^{a}\pm1.5$	$1.46^{b}\pm0.8$	$1^{c}\pm0.0$	$1^{c}\pm0.0$	$1.06^{c}\pm0.2$	$1^{c}\pm0.0$
Fibres/resins	$3.14^{a}\pm0.5$	$1.54^{b}\pm0.9$	$1.07^{c}\pm0.3$	$1.12^{c}\pm0.3$	$1.16^{c}\pm0.6$	$1.02^{c}\pm0.1$
Animal skin	$1.54^{a}\pm1.2$	$1.24^{b}\pm0.7$	$1^{c}\pm0.01$	$1^{c}\pm0.01$	$1^{c}\pm0.01$	$1^{c}\pm0.01$
Sand & Clay	$1.28^{a}\pm0.4$	$1.15^{b}\pm0.4$	$1.18^{ab}\pm0.7$	$1.18^{ab}\pm0.4$	$1.06^{b}\pm0.2$	$1.12^{b}\pm0.5$
Ornamental Resource	$1.12^{a}\pm0.5$	$1.0^{b}\pm0.0$	$1.0^{b}\pm0.01$	$1.0^{b}\pm0.0$	$1.0^{b}\pm0.0$	$1.0^{b}\pm0.0$
Biomass fuel	$4.78^{a}\pm0.4$	$2.95^{b}\pm0.8$	1.0^{d} 0.0	$2.8^{b}\pm0.8$	$2.14^{c}\pm0.7$	$1.12^{d}\pm0.3$
Freshwater	$2.74^{b}\pm1.5$	$1.33^{c}\pm0.7$	$4.76^{a}\pm0.9$	$1.42^{c}\pm0.8$	$1.06^{d}\pm0.2$	$1.06^{d}\pm0.2$
Traditional Medicine	$4.72^{a}\pm0.5$	$2.99^{b}\pm0.9$	$1.0^{e}\pm0.0$	$1.6^{c}\pm0.9$	$1.6^{c}\pm0.8$	$1.24^{d}\pm0.7$
Ranking	1st	2nd	3rd	4th	5th	6th

Note: very high = 4.5–5; high = 3.5–4.4; moderate = 2.5–3.4; low = 1.5–2.4; very low = 1–1.4.

3.2. Socio-demographic characteristics of the respondents

Out of 200 respondents sampled, 48 % were males and 52 % were females. Most (76 %) respondents were aged between 36 and 60 years and were married. Again, the results show that the majority (84 %) of the respondents were the mining project impacted people. Thus, people who have been resettled by the mines or whose land or property or dependent natural resources or ecosystem services are affected by the mining activities. Nearly half of the respondents had no formal education. Those with basic/secondary education represented half the sample, while those with tertiary education were less than 10 %. Further analysis of the educational background of the project-impacted respondents with no formal education showed that 67 % of them were non-indigenous people while 33 % were indigenes. Regarding occupation, half of the respondents were subsistent farmers, while the rests were petty traders (29 %) and unemployed (21 %).

3.3. Ecosystem services evaluation

We identified six ecosystems from the field survey: They included forest reserves, teak dominant/plantation, degraded forest, inland wetlands, grassland and cultivated land. Generally, the respondents' ratings of the value of the six identified ecosystems around the mine were significantly different (Table 1). Forest reserves were much associated with the highest value for the bundle of provisioning services. Respectively, inland wetlands and cultivated land were rated very high for freshwater/fisheries and crops specifically. However, generally, Teak Dominant/plantation, Degraded Forest, Inland Wetlands, and Cultivated Lands were appraised as moderate for the supply of provisioning services. Grassland was evaluated high for livestock provisions but was generally associated with the lowest bundles of provisioning services compared to all the ecosystems identified.

The study respondents evaluated the regulating services supplied by the six identified ecosystems around the mine operational area (Table 2). The respondents ranked the forest high for fire control, flood control, air quality regulation, soil regulation, erosion regulation, water purification, water quality regulation, and climate regulation. The forest reserves were also moderately rated for waste assimilation, pest control and disease regulation, while recording low value for pollination. Teak dominated ecosystem was moderately rated for erosion regulation, air quality regulation, fire control and climate regulation, whilst the values for the other regulating services were low to very low. Degraded forests were rated moderate for air quality regulation and soil regulation, with low scoring for the rest of the regulating services considered. Inland wetlands was reported to have moderate value for soil regulation, and generally had low to very low ratings for the remaining regulating services. Grasslands and Cultivated lands were generally considered to have low to very low regulating services.

For supporting services, the study considered only habitat support services. The respondents evaluated forests to have a high support service followed by inland wetlands. Degraded forests and teak dominated followed with statistically equal values while cultivated land and grasslands had very low values. The respondents generally rated all the six identified ecosystems as having less or very low importance for cultural services (Table 3). One interviewee commented on cultural services as:

> 'My fathers, grandparents, and most of the aged here hesitated to relocate because they believe they get spiritual protection from river gods in our previous village. However, now most of the youth in this area are Christians and Muslims and do not worship the rivers and creeping plants like 'Ahomakyem' as our fathers used to do. We know the custodians of the river gods and a few other fetish priests cherish those things. (Interview with one household head, 2022).

From the above comment, it appears some community members, the aged, have a relational value attached to spiritual protection

Table 2
Comparison of respondents' evaluation of identified regulating and supporting ecosystem services among the various ecosystems in a mining landscape. Mean values (±SD) in a row with different superscripts are significantly different ($P < 0.05$).

Ecosystem services	Forest Reserves	Teak Dominated	Degraded Forest	Inland Wetlands	Grassland	Cultivated Land
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
Regulating Service Air-quality	4.1^{a}±0.3	2.64^{b} ± 0.7	2.66^{b} ± 0.5	1.12^{d} ± 0.3	1.7^{c} ±0.8	1.74^{c}± 0.8
Climate regulation	3.7^{a}±0.6	2.56^{b} ± 0.49	2.09^{c}±0.3	1.54^{d} ± 0.8	1.4^{d} ± 0.5	1.48^{d} ± 0.5
Water quality	3.72^{a} ±0.5	2.26^{b} ± 0.4	2.13^{b} ± 0.6	1.68^{cd} ± 0.7	1.74^{c}±0.7	1.52^{d} ± 0.5
Erosion regulation	3.98^{a} ±0.5	2.96^{b} ± 0.9	2.22^{c}±0.6	1.72^{e} ±0.8	1.96^{d} ± 0.9	1.48^{f} ±0.5
Water purification	3.88^{a}±0.3	1.74^{bc} ±0.8	1.89^{b} ± 0.9	1.56^{cd} ± 0.8	1.28^{e}±0.6	1.4^{de} ± 0.6
Waste assimilation	3^{a}±0.91	1.9^{b} ± 0.7	1.96^{b} ± 0.9	1.44^{cd} ± 0.8	1.62^{c}±0.8	1.28^{d} ± 0.5
Disease regulation	2.91^{a}±1.3	2.03^{b} ± 0.73	1.7^{c} ±0.6	1^{e} ±0	1.3^{d} ± 0.5	1.06^{e} ±0.2
Soil regulation.	4.04^{a} ±0.8	2.24^{d} ± 0.42	2.54^{c} ±0.5	3.12^{b} ± 1.0	1.86^{b} ± 1.1	2.06^{de} ± 0.8
Pest control	3.04^{a}±0.8	1.24^{d} ± 0.4	1.54^{c} ±0.5	2.12^{b} ± 1.0	0.86^{b} ± 1.1	1.06^{de} ± 0.8
Pollination	1.96^{a}±0.7	1.16^{d} ± 0.36	1.67^{b} ± 0.5	1.06d ± 0.2	1.06^{d} ± 0.2	1.3^{c}±0.5
flood control	4.06^{a}±0.9	2.08^{c}±0.8	2.34^{b} ± 0.7	1.74^{d} ± 0.7	1.58^{de} ± 0.9	1.46^{e}±0.5
Fire control	4.06^{a}±0.8	2.62^{b} ± 0.7	2.2^{c}±0.5	1.76^{d} ± 0.7	1.28^{f}±0.5	1.56^{e}±0.5
Ranking	1st	2nd	3rd	4th	5th	6th
Support Service						
Habitat support	4.08^{a} ±0.8	1.74^{c} ±0.7	1.86^{c} ±0.4	2.195 ± 1.3	1.22^{e}±0.4	1.48^{d} ± 0.5

Note: very high = 4.5–5; high = 3.5–4.4; moderate = 2.5–3.4; low = 1.5–2.4; very low = 1–1.4.

Table 3
Comparison of respondents' evaluation of the identified cultural ecosystems services among the various ecosystems in a mining landscape. Mean values (±SD) in a row with different superscripts are significantly different ($P < 0.05$).

Cultural services	Old-growth forest	Teak dominated	Degraded forest	Inland wetlands	Grasslands	Cultivated land
Recreation	$1.36^a±0.9$	$1.06^b ± 0.2$	$1.12^b ± 0.3$	$1.1\ 2^b ± 0.3$	$1.1\ 2^b ± 0.3$	$1.12^b ± 0.$
Spiritual value	$1.12^a±0.4$	$1.00^b ± 0.0$	$1.00^b ± 0.0$	$1.00^b ± 0.0$	$1.00^b ± 0.0$	$1.00^b ± 0.0$
Ethical value	$1.00^b ± 0.0$	$1.00^b ± 0.0$	$1.00^b ± 0.0$	$1.00^b ± 0.0$	$1.00^b ± 0.0$	$1.18^a±0.7$
Inspiration	$1.00^a±0.0$	$1.00^a±0.0$	$1.00^a±0.0$	$1.00^a±0.0$	$1.00^a±0.0$	$1.00^a±0.0$
Cognitive	$1.24^a±0.0$	$1.12^b ± 0.0$	$1.00^c±0.0$	$1.00^c±0.0$	$1.00^c±0.0$	$1.00^c±0.0$
Ranking	1st	2nd	3rd	4th	5th	6th

Note: very high = 4.5–5; high = 3.5–4.4; moderate = 2.5–3.4; low = 1.5–2.4; very low = 1–1.4.

from the river gods and a traditionally known mysterious or magic plant called "Ahomakyem" in the previous location. The creeping plants are found in forest reserves or sacred forests.

Generally, the respondents assessed the identified ecosystems to supply provisioning and regulating services more than cultural and supporting services (Fig. 3). Forest reserves, degraded forests, and inland wetlands were the topmost ecosystems valued for provisioning and regulating services. Cumulatively across the landscape, provisioning services were the highest valued ES, whereas supporting services were the least valued or supplied (Fig. 4).

3.4. Relational value assessment of the landscape

Focus group discussions during the study revealed specific relationships people hold with non-human nature or artifacts in the landscape that have been affected due to mining (Table 4). As a people, the physical presence of some archaeological facilities, streams, and other landscape elements appeared to serve spiritual and religious value and give assurance of protection, power for existence, and pursuits in life. Reported displacement also seems to affect their sense of place, sovereignty and power. Again, the community appeared to have lost to the mining activities cultural identity and resilience, symbolic values, ecological resilience, land productivity and livelihood, social memory, social cohesion, counseling, and communal training opportunity for young females (womanhood education).

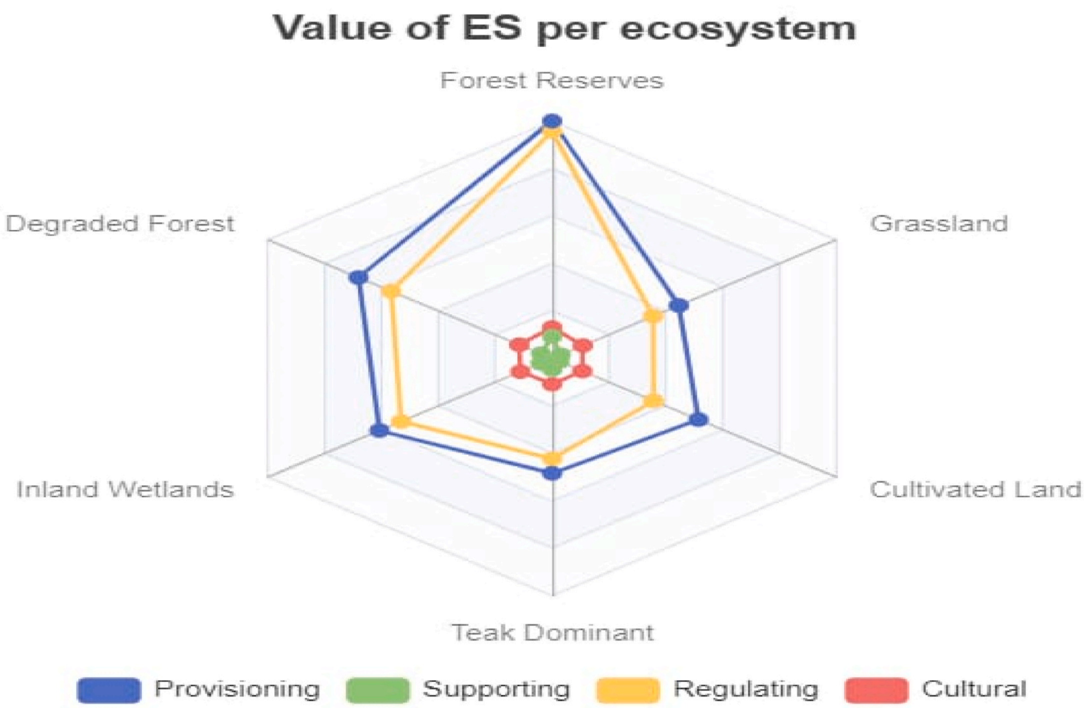

Fig. 3. Comparison of respondents' evaluation of ecosystems services supply among the various ecosystems in the mining landscape.

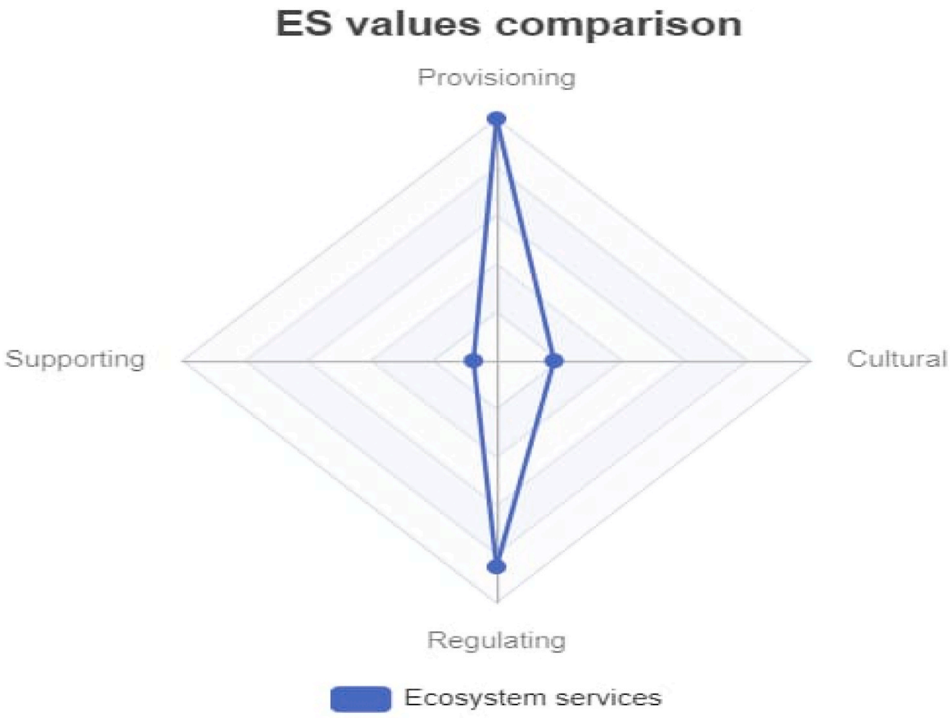

Fig. 4. Comparison of respondents' evaluation of the values of ecosystem services in the studied landscape.

Table 4
Extracts from focus groups discussion on landscape-related values and relational value expressions perceived impacted by the mine.

Extracts from focus group discussion on landscape -related values affected by the mining operation	Relational value expression perceived/ inferred impacted
The development of mining pits and associated mine facilities resulted in the disturbance of over ten (10) archaeologically significant sites in the area. The sites had Iron Age, historical and religious significance (Focus group discussion, 2022).	Cultural identity Symbolic value Sacredness and religious value
Erasing the archaeological or cultural sites has affected the features or symbolic facilities that were reminding us of our history or aiding the teaching of the younger ones the community history (Focus group discussion, 2022).	Symbolic value Social memory Education
The mine has brought us to this resettlement place and provided borehole water, but we buy the water. Sometimes we are unable to afford so we go down there to fetch water from the 'remaining' Subri River that has been 'spoiled' by the mine, the water is not good, but we are forced under the circumstance to drink it or use it for washing. (Focus group discussion, 2022).	Ecological resilience Mental and physical Health
The damage and apparent disappearance of our major streams like Subri due to mining have affected our spiritual strength as a community. Subri is a deity Those damaged water bodies were symbols of authority to the community, protecting us, averting our curses, and inflicting curses on our enemies (Focus group discussion, 2022).	Spiritual protection/security Symbolic value Sacredness/religious value
Our caretaker chiefs lost their power and sovereignty as chiefs and people when displaced by the mine (Focus group discussion, 2022).	Identity Sovereignty
We had rich land to farm from which we were harvesting a lot compared to the new land we have now. Some of us own those land (Focus group discussion, 2022).	Subsistence and livelihood Meaningful occupation
The land we farm now is hired and is not good at all. We wish we were on our old land (Focus group discussion, 2022).	Sense of place
In the village, women move in groups with our little girls to fetch water from the riverside and sometimes wash there. In such moments we discuss marriage and domestic issues and counsel each other, and use that means to informally educate our daughters on how to handle marital and domestic issues in the future (Focus group discussion, 2022).	Social cohesion, Mental health (counseling) Womanhood Education

3.5. Associations of ecosystems and ecosystem services in the study area

The CCA highlights the association between ES categories and specific ecosystem types on one hand (Fig. 5) and the association of ESs with the respondents' characteristics on the other hand (Fig. 6). The provisioning service was associated with forest and teak dominated ecosystems. Also, in the association were regulating services, cultivated land, and grassland. Cultural services were

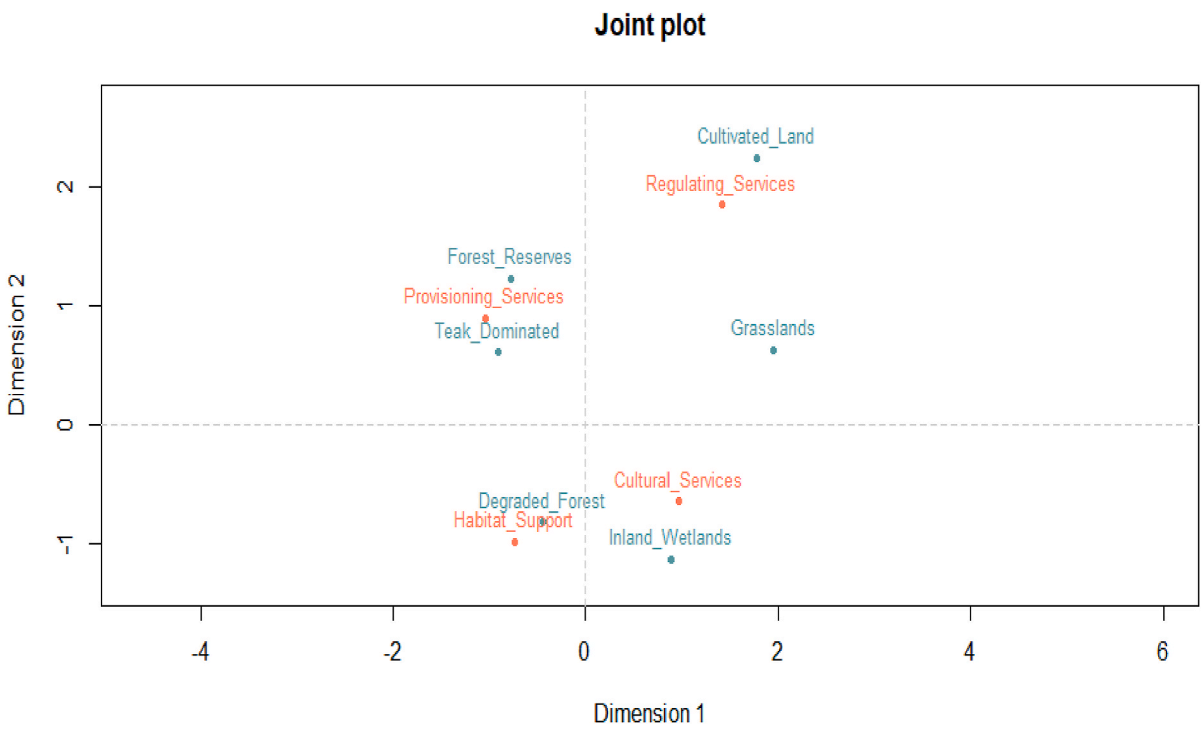

Fig. 5. Canonical correspondence analysis biplot showing the relationships among the six ecosystems and their services.

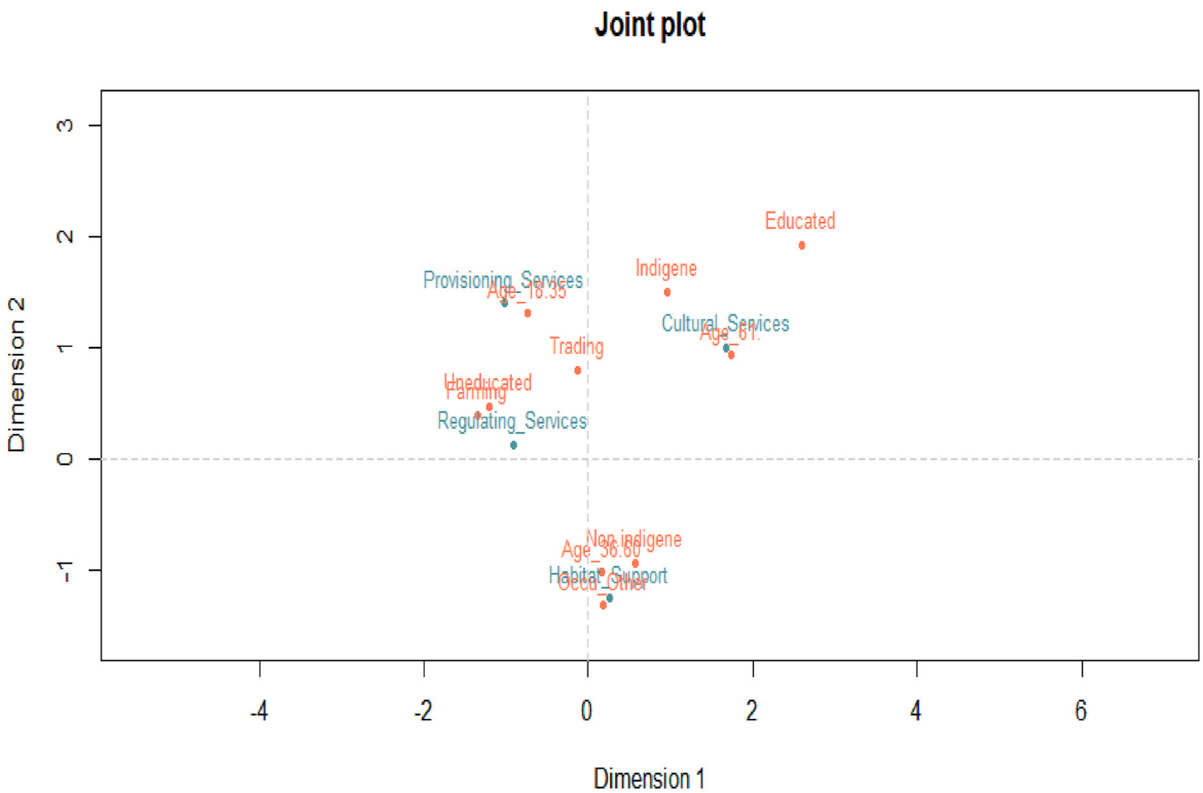

Fig. 6. Canonical correspondence analysis biplot showing the relationships among the four ecosystem services and variables related to respond respondents' characteristics.

associated with wetlands, while degraded forest correlated with support services. The dimensions 1 and 2 explain 0.55 and 0.32 of the total inertia, respectively (Table 5). The chi-square values of the CCA clearly indicate a statistically significant association between the relative values of ecosystems and their ESs. The CCA corresponds to cumulative totals of 0.87 % of total inertias retained by the 2 dimensions. This is acceptably large percentages that add to the reliability of the analysis.

Another CCA application helped to reveal the socio-demographic bundles of the respondents that affect the evaluation of ecosystem services (Fig. 6). The Dimensions 1 and 2 explain approximately 0.76 and 0.23 of the total inertia respectively. The chi-square values of the CCAs clearly indicate statistically significant association between ecosystem services and the respondents' characteristics. The CCA corresponds to cumulative totals of 0.98 % of total inertias retained by the 2 dimensions respectively (Table 6). This is acceptably large percentages that add to reliability of the analysis. CCA Further reveals differing stakeholders' evaluation regarding ESs and their supplying ecosystems. The young respondents (18–35 years), uneducated (43 %) and into farming and trading positively associated with provisioning and regulating services. The indigenous (43 %), educated and the aged (60+) respondents associated with cultural services.

It was also observed that the respondents within the age 36–60 (76 %), non-indigenous (57 %) and those of other occupations reported high for habitat support services and degraded forest.

3.6. Community dependency and mine impact on ecosystem services and associated cost of loss

Respondents perceived that mining communities highly depend on crops, livestock, capture fisheries, wild food (fruits, nuts, mushrooms), bush meat (including snail, crabs, etc.), biomass fuel (firewood, charcoal, palm kennel, etc.), and freshwater (from rivers and streams) (Fig. 7). The dependency ratings range from 4.80 to 4.12. The mine was also perceived as highly impacting the same services. The ratings of mining impacted ranged from 4.82 to 4.26. The other set of provisioning services rated by the respondents as moderately depended on by the community and impacted by the company are aquaculture, timber, York plant, fibres, animal skin, sand and ornamental resources and traditional medicine. The dependency ratings of this set ranged from 3.66 to 1.00, and the corresponding impact ratings ranged from 4.20 to 1.00. Some community interviewee lamented as:

> ''We cannot get our free bushmeat, fish, fruits, and firewood anymore. All our livestock are lost because the company created no space for them in the resettlement sites. We have lost our crops, and now we do not have reliable land to farm. Oh, all the things that could enable us to feed our family are lost. Even water that was free in our previous villages is paid for here (interview with some community members, 2022).

The company representatives who were engaged also shared their sentiment and challenges on ES loss and cost as:

> We cannot deny the high impact of mines on crops and other benefits the people get from their land because during mine construction and operational phase, we take land, clear vegetation for installation of mine facilities, and sometimes dam, redirect or sediment water courses, cause an influx of people, and all these deprive or reduce access to original things the community obtained from the environment. However, we offer cash compensation for crops, but other benefits like bushmeat and others, they are difficult to compensate or get replacements for them.

Overall, it appears that the community so much depend on these ecosystem services for their sustenance and livelihood, so the mine heavily impacts them adversely and yet administer limited compensation option.

The respondents rated the community dependency on the regulating services from high to moderate and to low score (Fig. 8). The respondents reported high dependence on flood control services from the ecosystems with a rating of a 4. The overall dependency ratings range between 4 and 1. While the corresponding mine impact ratings range from 4.76 to 1 with erosion control services recording the highest impact and pollination the least impact. It appears the community depends, and the mine impacts on the regulating services. This situation seems to produce competition between the community and the mine on the ecosystems' regulating function. The respondents rated the community dependency on the cultural services very low with correspondingly less mine impact on those services. The dependency ratings ranged from 1 to 1.12 while that mining impact was 1.

The respondents valued the ecosystem service loss or mine impacts on the ecosystem service flow, and corresponding cost to the dependent people (Fig. 9). Generally, the most reduced provisioning services recorded correspondingly high costs. It is observed that out of 15 provisioning ecosystem services (PESs) appraised by the respondents, eight (crop, livestock, capture fishes, bush meat, biomass fuel, wild food, animal skin and ornamental resources) were considered to have been lost or reduced by 81–100 % as a result of mining. The respondents valued the corresponding cost of the loss from GHc480 to GHc 2 ($80 to $0.33) per month per household. Crop was reported as impacted provisioning services with the highest cost (GHc480/$80) per household per month followed by bush meat (GHc404/$67.33), capture fisheries (GHc 322/$65.9), wildfoods (GHc133/$22.66), biomass fuel (GHc89/$16.33), Livestock (GHc63/$10.50), animal skin (GHc5/$0.80) and last with least cost was ornamental resources (GHc2/$0.33). Out of the 15

Table 5
Canonical Correspondent Analysis (CCA) on ecosystems and ecosystem services.

Canonical Dimensions	Chisq	Proportion	Cumulative Proportion	Eigen value	Total Inertia
Dimension 1	1432.506	0.554	0.554	0.307	2.386
Dimension 2	818.313	0.316	0.870	0.099	1.363
Dimension 3	336.312	0.130	1.000	0.016	0.560

Table 6
Canonical Correspondent Analysis (CCA) on ecosystem services and respondents'. Characteristics.

Canonical Dimensions		Chisq	Proportion	Cumulative Proportion	Eigen value	Total Inertia
Dimension 1	1980.2	0.758	0.758	0.575	3.268	
Dimension 2	588.11	0.225	0.983	0.051	0.971	
Dimension 3	43.311	0.017	1	0.001	0.071	

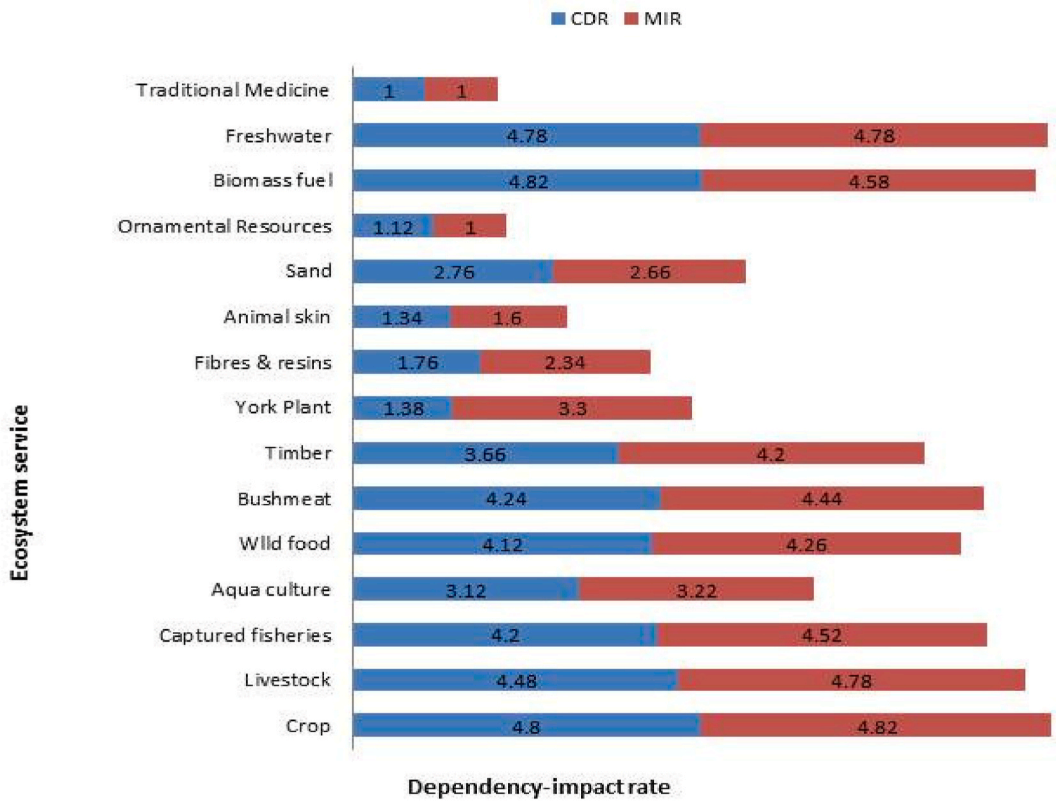

Fig. 7. Evaluation of community's dependence and mine impacts on provisioning ecosystem services. Ratings are based on a scale of 1–5 where 1 is the least and 5 is the highest. CDR = community dependence rating; MIR = mine impact rating.

provisioning services, 6 were evaluated to have been lost or reduced by 61–80 % with corresponding cost ranging from GHc 386 to GHc 5 ($64.33 to $0.8). One (York plant) of the provisioning services fell under 1–20 % lost category with corresponding cost of impact of GHc13 ($2.16). Affected people and community leader's focus group commented as:

> 'The mine compensated for crops and ignored all other things relevant to us. We mentioned the loss of our livestock, fruits, bushmeat, free water, firewood, medicinal herbs, mushroom, crabs, and many more that give us food and medicine in our villages, but we were ignored and insulted during the resettlement negotiations. So no provisions were made for those losses. Because of that, we have to travel long distances with tricycles to look for alternatives or substitutes that tare limited and costly for us as rural households. For instance, in our previous location, we did not buy firewood, but here we have to buy about four bags of charcoal or GHc 100 plus worth of LPG every month to cook. We could stay a whole year without buying meat/fish, but we buy it daily here. We did not pay for water, but here the company has provided us with borehole water and forced us to buy the water. We did not anticipate all these costs. The money we could have used to take care of our children's education is now being used to feed the family. Our children are no more in schools, and the company has sent many of them to prisons because they stole mining pipes and other materials" (affected people focus group, 2022).

The extent of regulating ecosystem services loss and corresponding cost compared to provisioning services were low (Figs. 9 and 10). Only one (pollination) out of 12 regulating ecosystem services (appraised by the respondents was found to have been lost or reduced by 81–100%with corresponding cost of GHc1.00 ($0.16). Also, erosion control services fell in 61–80 % lost bracket with corresponding cost of GHc24.8 ($4.10). Seven of the services were perceived to have been reduced by 41–60 % with cost of impact ranging from GHc57.7 to GHc10.1 ($9,61to $1.68). The highest impact cost (GHc57.7/$9.61) was ascribed to soil quality regulation

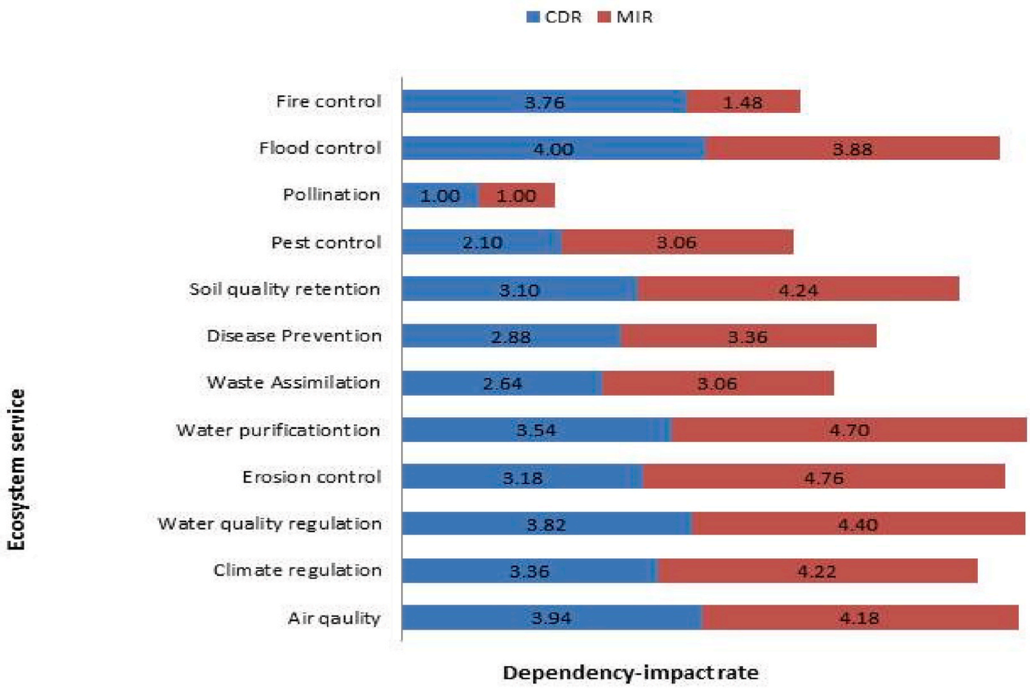

Fig. 8. Evaluation of community dependence and mine impact on regulating ecosystem services. Ratings are based on a scale of 1–5, where 1 is the least and 5 is the highest. CDR = community dependence rating; MIR = mine impact rating.

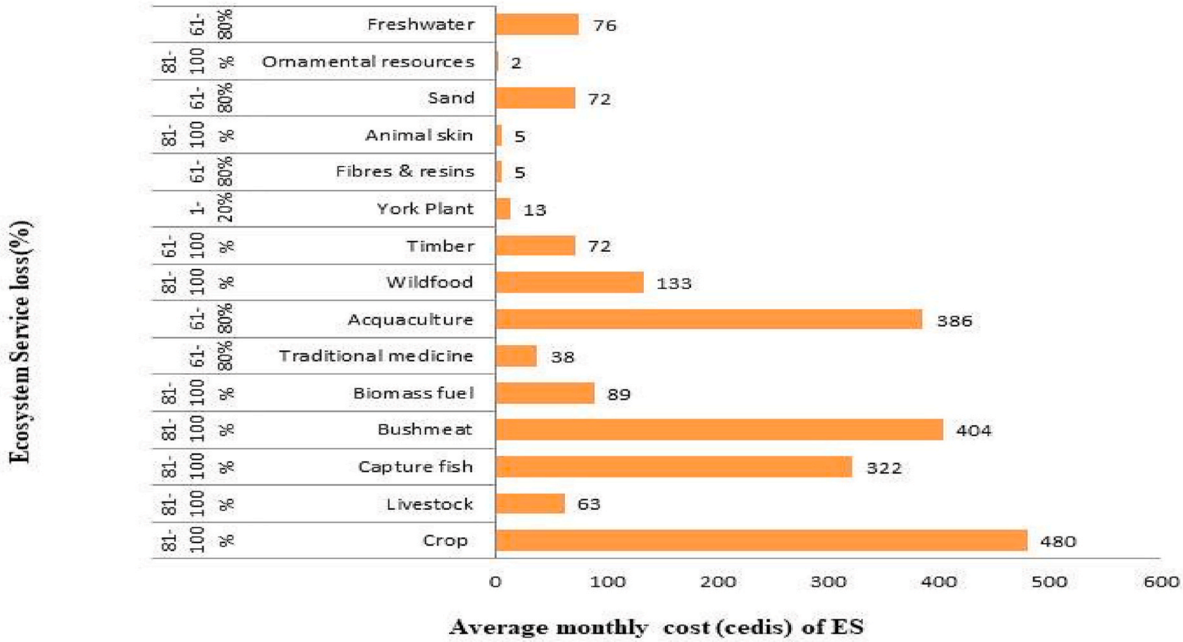

Fig. 9. Estimation of percentage loss and corresponding average cost of provisioning ecosystem services per month per household.

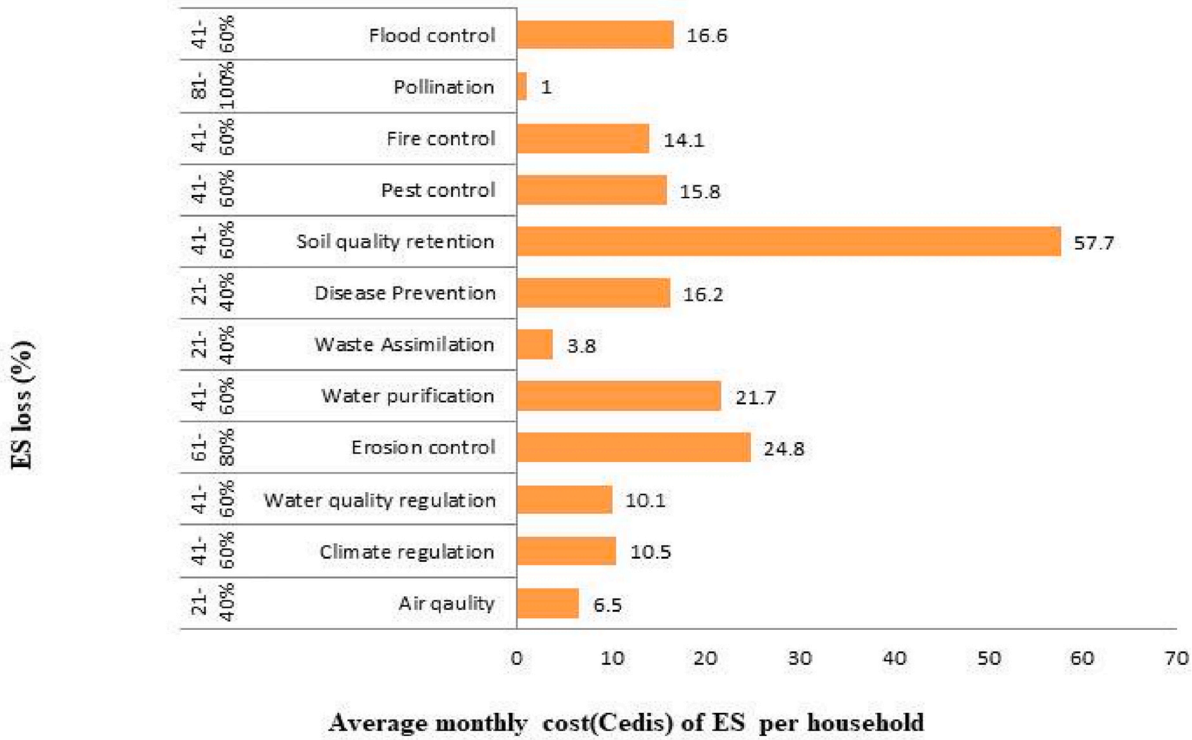

Fig. 10. Evaluation of percentage lost and corresponding cost of regulating ecosystem services.

services and the lowest within this percentage lost category was water quality regulation. 3 regulating services were appraised to have been lost by 21–40 % with corresponding cost range of GHc16.2 to GHc 3 ($2.66 to $0.5) per month per household.

4. Discussion

4.1. Community valuation of ecosystem services

The study highlighted that people value various ecosystems differently based on the quantity and type of services they receive from them. Forest was valued highest in provisioning services. This observation is consistent with reports of previous studies showing that rural people living close to forests depend heavily on forest ecosystem services for their livelihood, particularly provisioning goods [48,50–52]. Our study adds to the evidence of the high dependence of rural livelihoods on forest provisioning ecosystem services [53]. The dependency of rural households on the provisioning services suggests that the studied communities are potentially vulnerable to changes in the forest ecosystem services due to mining and other related human activities [54]. Generally, the majority of the respondents had either no formal or low education, making it difficult to access job opportunities from government or private organizations. This may explain the high dependence of the communities on forest ecosystem services [55]. Again, the forest ecosystem was cited high for its regulating services, reflecting how rural households attach impotence to such ecosystem benefits.

In contrast to the forest, the value of the other ecosystems was generally low except for cultivated land, wetlands, and grassland which were cited highly for only a specific service like crops, capture fisheries, and livestock, respectively. The high recognition of crops, capture fisheries, and livestock may be attributable to their contribution to the local household food security [56,57]. The level of biodiversity of an ecosystem determines the functions and the services of the ecosystem [58,59]. The other ecosystems we studied were less diverse in comparison to the forest. Thus, the low value placed on them by the respondents reflect the lower biodiversity of the ecosystems relative to the forest. Similarly, all the identified ecosystems in the area were valued very low regarding cultural services. This can be attributed to the limited presence of things of cultural importance, possibly due to ecological degradation or changes caused by mining [60]. From our field interaction, we received comments on the youth religious conversion from traditional worship to Christianity and other religions, which may partly explain less valuation for the cultural services [52,61]. This trend has conservation implications in the area since cultural basis for conservation in the communities would be low [62].

4.2. Ecosystem services relationships

Our findings revealed associations of ecosystem services with specific ecosystem types. The observed connectedness of provisioning services to forest and teak dominated ecosystems was expected since rural folks greatly depend on forest provisioning services for household nutrition and income [53,63,64]. It was least expected to find the association of regulating services with cultivated land and grassland. Notwithstanding, the connection may reflect the respondents' acknowledgment of the role of farmland in the provision of regulating services such as soil erosion control, soil quality maintenance and local climate regulation. This is plausible as agro-ecosystems have been found to contribute immensely toward regulating ecosystem services [65]. The association of cultural services with wetlands appears inconsistent with our findings of low values assigned to it compared to other studies that show that wetland offers many cultural services, including spiritual values [66]. This suggests that though the majority of the affected households do not attach importance to the cultural values of the ecosystems, the indigenous people, particularly the aged, still hold the traditional beliefs associated with wetlands, such as protection from river gods. Undeniably, the aged or elderly individuals often have a deep connection to cultural heritage and certain features in the landscape, sense of place and traditions [67].

The socio-demographic characteristics of the respondents appear to have influenced their rating of the categories of the ecosystem services. Expectedly, the uneducated, farming, trading and active age (18–35) respondents positively associated with provisioning and regulating services. This phenomenon which reinforces the dependence of the respondents on ecosystem services in the area reflects a rural community dominated by uneducated and subsistent farmers. This trend is supported by other studies which reported that rural communities with active age and less educated individuals and subsistent farmers depend much on ecosystem benefits, especially provisioning services from forest source [68]. The association of farmers with the regulating services may be due to their appreciation and experience of soil quality maintenance and other regulating services obtained from their farms or agro-ecosystem [65,69]. The relationship of educated individuals with cultural services in our study is in keeping with previous findings which indicated that the educated persons have a preference for cultural services [48,52].

4.3. Impacts of mining on ecosystem services and associated cost of loss

Our analysis depicts a scenario of the heavy community depended versus highly mining-impacted ecosystem services with unaccounted economic costs to the dependent households. Thus confirming that there is environmental injustice in mineral development and in essence, widening inequalities and vulnerabilities in the catchment region [32,34]. This situation foretells mining company-community conflicts on the loss of ecosystem services due to mining [70]. The respondents revealed negative mining impacts on provisioning and regulating ecosystem services, which were highly depended on by the community. This is not surprising since the original forest cover in the area has decreased by 86 % following surface mining [12]. A review of Land use land cover changes in the study area reveals drastic mining-induced land cover conversions within the last two decades, i.e., 2003–2023 [39,66]. Forest area of 30–86 % of the studied landscape has been transformed into mining site, mine water, settlement/bare surface, cropland and plantations [8,67]. The substantial and steady declines of forest cover and the concomitant expansion of the adjoining land cover forms in the mining landscape were attributable to direct and indirect mining disturbances and influences such as the construction of mining facilities, mining-induced influx of people, and high mining-land-compensation expectation driven developments of the surrounding communities (8) (69) (41). Land-use changes involving forest cover loss contribute immensely to the decline in several ecosystem services [13,16]. Our observation provides support for earlier studies that found mining to adversely affect ecosystem services leading to the erosion of the livelihood of the affected people [13,70].

Our study established that the local community depended heavily on 14 ecosystem services. These were crops, livestock, capture fisheries, wild food, bush meat, biomass fuel, and freshwater for provisioning services, and fire control, air quality, soil, erosion control, water purification/quality, and local climate regulations and flood control for regulating services. Those ecosystem services were of priority to communities in the area, given that the respondents claimed the provisioning services constitute critical components of the rural households' livelihood, while the listed regulating services also represent vital safeguards for soil quality maintenance, erosion control, and local climate regulation. But ecosystems supplying the services are drastically lost consequent to the mining operation [12]. The affected services have no easy alternatives or substitutes, yet, the costs of their loss due to mining are ignored. This observation is consistent with the findings that project managers and policymakers overlooked developments' impact on ecosystem services [71]. The justification for excluding the costs of ecosystem services damaged by mines from a compensation claim is that their market value is difficult to assess according to legal principles in monetary terms [72]. Blindly and wholly accepting such compensation principle discourages attempts to explore innovative means to adequately mitigate the loss of ecosystem services due to mining. Ending in perpetuating environmental injustices and adversely affecting the well-being of the rural poor.

Typically, the value of ecosystem services goes unaccounted for in businesses and policy decisions, as they are often perceived as free goods. However, the cost of mining impact on the fourteen (14) 'priority' ecosystem services in the study area amounted to approximately $300 per household per month. This economic cost in the context of a low standard of living of the studied rural households that depend mainly on subsistent farm income [42,73,74] reveals livelihood risks in the communities. The District's average household income per month ranges from $120.23 to $263.84, while the majority of the mining project-affected households earn low monthly income below or equalling $100 [75]. An affected household may have to bear a cost significantly higher than its monthly income, if we consider the household's monthly income and the cost burden per month following the mining-induced ecosystem service loss. This substantial household income-cost difference suggests a massive defect in the economic well-being of the affected people. This observation is in line with studies that concluded that loss of biodiversity and ecosystem services has a material cost to society [76]. Our findings offer further evidence that human well-being has a positive correlation with the supply of ecosystem services [1,69] and that their supply-demand mismatch impact strongly on well-being [69]. We argue that great ecosystem service supply-demand challenge caused by mining and associated environmental injustice widens inequality, vulnerability and ultimately heightens local community impoverishment and unrest.

4.4. Impacts of mining on relational values in the mining landscape

We found out that the communities perceived mining activities have adversely affected the cultural identity and resilience, symbolic values, security, land productivity and livelihood, social cohesion, counseling, and social training opportunities for young females. Determinedly, these impact the fundamental and eudaimonistic values of the people [77–80], giving credence to the need for considerations of plural values or relational value in decisions or environmental impact assessment of projects [81,82]. The community held the perception and was concerned that the mine has disturbed archaeological, heritage, and religious sites. It appears these sites define the cultural identity, serve as symbolic value, and promote enculturation in the community. According to Refs. [83,84], deprivation and disconnection of cultural heritage footprints affect cultural identity, raise human rights issues, and erode knowledge, memories, and landmarks. Thus, compromising the meaningful life of local people.

Our study also revealed the communities' relational connection to the physical presence of the water bodies in the landscape. The local people regarded the perceived mining-induced damage and disappearance of water bodies as dispossession of power and security of the community. This may be due to the sense of physical (discouraging potential attacks of enemies by the mere notion of association with a powerful water god) and spiritual protection obtained from the streams. This reflects the observation by other authors who documented that water welds powerful socio-natural and supernatural and other relational influences on people [81,85]. Again, the purported damaged water bodies appeared to limit social cohesion, emotional and psychological support previously enjoyed among women in the locality, and social training opportunities for young girls to grow into better adulthood. The findings from the study further demonstrated the deprivation of productive land and associated livelihood benefits. This is consistent with the report by Ref. [12], who found that due to mining operations, people are resettled or relocated to places far away from their productive land, discouraging access and utilization of productive land resources and by that affecting the sustainability of the mining communities.

5. Conclusions

This research assessed the value of ecosystem services and the perceived impact of mining on those services and their consequential economic cost to the dependent rural households in Ahafo Region, Ghana. It also examined the perception of the impact of mining on relational values of the people in the landscape. The study found forests as significant stock and flow of provisioning and regulating services relative to wetlands, cultivated land, plantation, degraded forest, and grassland. Based on our observation, the mine is likely to have caused a substantial loss of provisioning and regulating ecosystem services highly depended on by the community. The mining-occasioned ecosystem services loss and put a significant cost burden on the dependent rural households. The mine is perceived to have adversely affected relational values of the cultural identity and resilience, symbolic values, security, land productivity and livelihood, social cohesion, counseling, and social training opportunities for young females. It is crucial for actors in the mining industry, government, the mining company, and the community to consider interventions in the context of sustainability and responsible mining. First, to stem the loss of forest cover and its ecosystem services by evaluating and limiting forest clearance and deprivation to rural households through mining land-take approvals and implementation. This will enhance the environmental performance of the mine and safeguard the sustainability of the rural livelihood. Second, planners and managers of the mining projects and the community should ensure ecosystem services and their economic contribution to the dependent households, as well as relational values in the project area are base-lined, assessed, valued, and compensated (mitigated) during project developments. This could ensure full consideration of rural livelihood and quality of life in project impact assessment for comprehensive cost-benefit analysis. Finally, the mining companies should train and create an opportunity for employment for the affected households as an additional effort to mitigate the cost of ecosystem services loss and potential conflicts to secure the mines' social license to operate.

CRediT authorship contribution statement

Samuel Kumi: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Writing – original draft, Writing – review & editing. **Patrick Addo-Fordjour:** Formal analysis, Project administration, Supervision, Validation, Writing – review & editing. **Bernard Fei-Baffoe:** Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e21156.

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