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REPORT

Impacts of Surface Gold Mining on Land Use Systems in Western Ghana

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Abstract Land use conflicts are becoming increasingly apparent from local to global scales. Surface gold mining is an extreme source of such a conflict, but mining impacts on local livelihoods often remain unclear. Our goal here was to assess land cover change due to gold surface mining in Western Ghana, one of the world's leading gold mining regions, and to study how these changes affected land use systems. We used Landsat satellite images from 1986–2002 to map land cover change and field interviews with farmers to understand the livelihood implications of mining-related land cover change. Our results showed that surface mining resulted in deforestation (58%), a substantial loss of farmland (45%) within mining concessions, and widespread spill-over effects as relocated farmers expand farmland into forests. This points to rapidly eroding livelihood foundations, suggesting that the environmental and social costs of Ghana's gold boom may be much higher than previously thought.

Keywords Ghana LUCC · Surface gold mining impacts · Farmland displacement · Resource curse · Participatory analysis

INTRODUCTION

Land use has already altered more than half of the planet's terrestrial ecosystems, mainly for increasing the provision of a few ecosystem services, such as food production (Ellis and Ramankutty 2008; Foley and DeFries et al. 2005). Since not all services can be maximized simultaneously, every land use decision involves trade-offs, often resulting in competing interests and substantial conflicts about the desired use of land among stakeholders (Rodriguez et al. 2006; Turner et al. 2007). Economic land use theory suggests that markets resolve such conflicts via differences in land rents that will lead to the most profitable land use allocation (Ricardo 1817; Walker 2004). The problem is that ecosystem services are often difficult to value in economic terms and remain externalities. Degradation of such services may lead to conflicts among land users (Wunder 2005). Surface mining is an extreme example of a land use practice that can lead to such conflicts. Mining is an important component of the economy of many nations, particularly in the developing world. For example, 25% of Guinea's and 5.9% of South Africa's GDP as well as the majority of foreign revenues of these countries are mining related (Aryee 2001). However, local livelihoods rarely profit from mining activities, although mining has widespread and drastic environmental and social effects on them (Kumah 2006).

Surface mining, for example, removes vegetation and soils, interrupts ecosystem service flows, and results in inevitable and often permanent farmland loss. Mining activities also frequently result in toxic waste that causes water pollution and health problems (Akabzaa and Darimani 2001; Habashi 1996). Likewise, dust pollution from heavy traffic on mining dirt roads affects neighboring communities (Ayine 2001), and soil erosion is common around mines (Akabzaa and Darimani 2001). Overall, surface mining in the developing world often erodes livelihood foundations, forcing populations to relocate and farmers to develop alternative income strategies (Kumah 2006). As a consequence, conflicts between communities and mining operators over land use rights are common in many regions worldwide (Hilson 2002a, b) and can become a serious threat to development and security (Maconachie and Binns 2007).

Gold mining has become increasingly attractive during the last decades due to soaring gold prices (Hammond et al.

2007). This has triggered a gold boom, both in industrialized countries (e.g., the United States, Australia, and Canada) and in developing nations (e.g., South Africa, Peru, Indonesia, or West Africa). Since gold is often extracted using toxic substances, the environmental consequences of gold mining can be devastating, particularly in fragile tropical ecosystems (Akpalu and Parks 2007; Kumah 2006; Sousa and Veiga 2009). As a consequence, gold mining activities in developing nations often lead to open, sometimes violent, negotiations about the use of land (Müller 2004). To mitigate such conflicts, governments, mining companies, and rural stakeholders sometimes react with resettlement and alternative livelihood programs, and former farmers engage in small-scale artisanal mining (Banchirigah and Hilson 2010). This is problematic, because such small-scale resource use is often connected to further environmental degradation and inefficient resource use (Banchirigah and Hilson 2010). Overall, there is a risk that rural livelihoods become unsustainable in such contexts (Adjei 2007; Scoones 1998).

Ghana is Africa's second largest gold producer and gold mining in Ghana has been an economic success story for international investors and the country's economy (Addy 1998). However, the question is how the recent gold rush has affected Ghana's environment and local livelihoods. Existing studies suggest widespread land transformations and degradation (Agbesinyale 2003; Akabzaa and Darimani 2001) and thus fundamentally changed livelihood foundations, but overall, land use changes due to mining remain poorly understood. Moreover, there is increasing evidence that Ghana may face a resource curse dilemma: economic diversification is lacking and the country's economic dependency on mineral resource export revenues grows (Adler and Berke 2006; Akabzaa and Darimani 2001; Aryee 2001).

In Ghana, gold is mined in two fundamentally different ways. Small-scale miners (so-called galamsey) mostly open pits by hand and sell gold through regional marketers. On the other hand, large-scale surface- and underground mining enterprises operate with industrialized production chains and direct ties to international markets. Small-scale mining and large-scale mining differ markedly in their environmental and social implications (Hilson 2002a, b). The environmental consequences of small-scale mining, especially the effects of mercury in the refining process, and the competition between large- and small-scale miners have received some attention (Amankwah and Anim-Sackey 2003; Hilson 2002a, b). Yet, to our knowledge, the environmental and social impacts of large-scale gold mining in Ghana, and all of West Africa for that matter, have only been addressed by two studies (Amankwah and Anim-Sackey 2003; Hilson 2002a, b). Conflicts between large-scale mining enterprises, galamsey, and local farmers were strongest where mining enterprises excluded small-scale miners from mining concessions (Hilson 2002a, b). Another study analyzing employment benefits of small-scale gold and diamond mining in Ghana suggests that these benefits are achieved largely at the cost of environmental degradation (Amankwah and Anim-Sackey 2003). While these studies provided interesting insights into mining-related land use conflicts at a general level, neither of them analyzed spatial patterns of landscape changes due to surface mining and linked land cover changes to socio-economic surveys on the local perception of livelihood changes. This is unfortunate, because such an approach could provide novel insight into the environmental consequences of gold mining and help better understand mining impacts on coupled human–environment systems in Ghana and elsewhere.

Remote sensing is a powerful tool to assess the extent and environmental impacts of mining activities on landscapes. For example, analyses of Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) images quantified forest loss due to oil sand mining (Latifovic et al. 2005), and dust pollution from Russian ore mines (Rigina 2002). Similarly, land cover change mapping based on multi-date Landsat images allowed quantifying deforestation and flooding due to surface mining in Sierra Leone between 1967 and 1995 (Akiwumi and Butler 2008). Remote sensing is also the key technology for monitoring land use changes (Turner et al. 2007). For instance, satellite images showed land use changes caused by artisanal and industrial diamond mining in West Africa (Pagot et al. 2008). In Western Ghana, one study used remote sensing to show rapid deforestation and urban expansion between 1986 and 2002 (Kusimi 2008). This study analyzed land use changes in the Wassa West District and identified farmland and built up/surface mines as rapidly expanding land use types. To our knowledge though, remote sensing has so far not been used to map land cover and land suse changes within and around gold mining concessions in West Africa to quantify mining impacts on livelihoods.

While remote sensing can map the rates and spatial patterns of land change, relating these changes to a suite of environmental and socio-economic variables is necessary to understand the consequences of land use change for local livelihoods (Fox et al. 2002; Liu et al. 2007; Turneret al. 2007). Fine-scale data gathered via participatory mapping and household surveys have considerable potential to understand land systems, because such data are collected at the scale where land use decisions are made (Liu et al. 2003; Müller et al. 2009; Reenberg 2001). Linking land cover information and socio-economic data is not easy because the latter rarely exists as spatial layers (Liverman et al. 1998; Veldkamp and Lambin 2001).

Several strategies exist to overcome such challenges, for example disaggregating socioeconomic data to the pixel level, comparing aggregated measures of land change and socioeconomic data, or linking people and land via participatory approaches (Castella and Verburg 2007; Lambin 2003). Unfortunately though, no such study linking survey and land change data for assessing gold mining impacts in West Africa has been carried out.

Here, we report on research that explores the environmental and social setting of gold mining-related land use conflicts in Ghana. Our overarching goals were to use satellite images to map land cover change due to gold mining in three large-scale mining concessions in Ghana, and to link observed changes to field surveys to better understand the consequences of mining for local livelihoods. As a study region, we chose Ghana, because of the country's recent gold boom and because Ghana exemplifies many developing nations in the global south (e.g., economic role of mineral exports, investment policies (Agbesinyale 2003)). Within Ghana, we selected the Wassa West District, Ghana's primary gold mining region. Specifically, we were interested in answering:

1. How did land cover change due to surface gold mining affect the Wassa West District between 1986 and 2002?
2. What are the environmental consequences of these land cover changes?
3. How did gold mining-related land cover and environmental changes affect local livelihoods in the Wassa West District?

STUDY REGION

Wassa West District in Ghana's southwest covers 2,354 km^2 and is the country's oldest and arguably most important gold mining region (Fig. 1). The hilly topography is characterized by gentle slopes and wide valleys. Elevation ranges from 30 to 200 m above sea level. The climate is tropical with an annual precipitation of 1,900 mm and year-round day temperatures between 26–29°C. Ferralsols are the dominating soils in the region. Wassa West District belongs to the Eastern Guinean Forest ecoregion. Natural vegetation is wet evergreen rainforest with canopy heights of up to 60 m and dominating tree species of the genera *Lophira*, *Heritiera*, and *Cynometra* (Lebbie 2009).

Land use has substantially altered the region's natural vegetation communities, and today rainforest covers less than 20% of the district, mostly within the Bonsa (210 km^2), Ekwumi (173 km^2), and Neung (158 km^2) forest reserves (Agbesinyale 2003; Wassa West District Assembly 2004). About 46% of the district is used for agriculture, mostly oil palm and other cash crop plantations as well as some subsistence farming (Wassa West District Assembly 2004). Wassa West District has a total population of about 254,100 (in 2002) and annual population growth is estimated at 2.9% (Wassa West District Assembly 2004). Roughly 64% of the population lives in rural areas and the rest in the two large cities (Tarkwa and Prestea). Agriculture provides income for 48% of the total working force and the average farm size is about 1 ha (Wassa West District Assembly 2004).

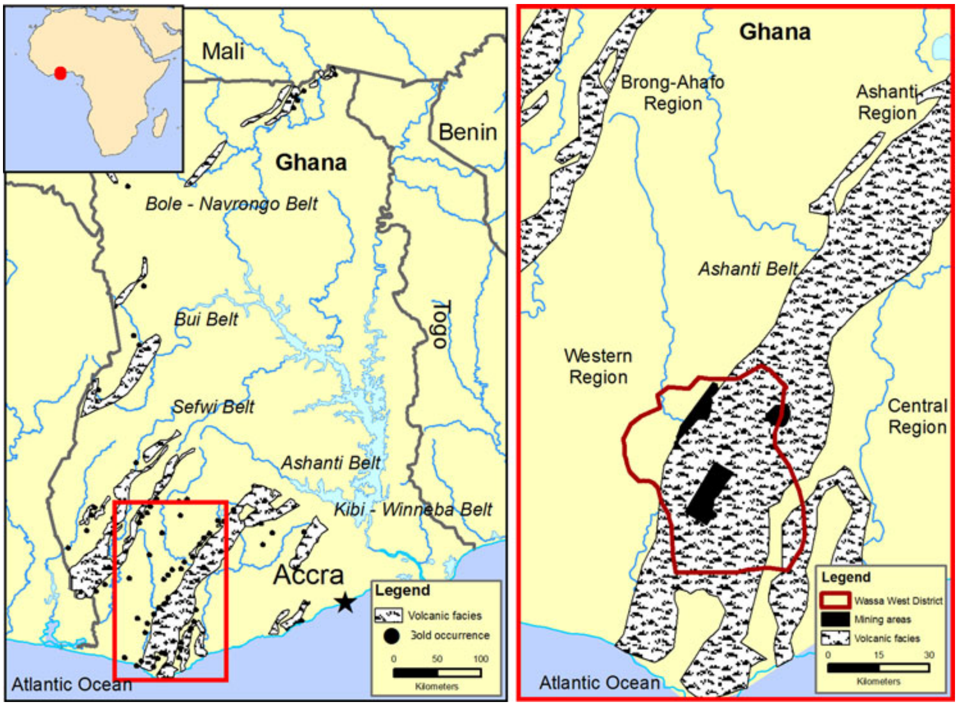

Fig. 1 Wassa West district and major gold deposits and mining concessions considered in Western Ghana (adapted from Hirdes et al. (1993))

About 12% of all land in Ghana is currently under some form of concession for mineral exploration (Ghana Chamber of Mines 2006), with more than 250 companies being engaged in surface mining (E.A.G. 2001). The Wassa West District's geology makes it highly attractive for mining and large areas have been granted to mining companies. Gold deposits are found on various sites, particularly in reef formations or alluvial deposited along riverbanks and in valleys (Hirdes and Loh 1999). The gold boom triggered rapid surface mining development in Wassa West District in the 1980s (Agbesinyale 2003) and today several large surface mining enterprises are extracting gold along the Ashanti belt (Fig. 1). We decided to study the country's oldest surface mining area, the Wassa West District, which includes three of the country's largest surface mine concessions: Bogoso–Prestea, Tarkwa, and Damang. The Bogoso–Prestea concession is mined by Bogoso Gold Ltd. since 1992 and covers an area of about 5,900 ha. Tarkwa, covering an area of 11,400 ha is the oldest gold surface mine in Ghana, dating back to the early 1980s (Agbesinyale 2003). This concession has been mined by different enterprises, most recently AngloGold Ashanti Corp. and Goldfields Ghana Ltd. Surface mining in the Damang area was developed in 1989. The concession is operated today by Goldfields Ltd. and covers an area of 2,000 ha in Wassa West District (the concession extends into the neighboring district).

Gold surface mining concessions are frequently granted for areas dominated by settlements and farmland, resulting in substantial conflicts between mining enterprises and local communities (Aidara 2008; National Coalition on Mining 2006). Thus, due to the region's long gold mining history (30 years) and widespread conflicts, the Bogoso–Prestea, Tarkwa, and Damang concession (Fig. 1) offer unique opportunities to better understand gold mining effects on local livelihoods and land use systems.

DATASETS USED AND METHODS

Satellite Images and GIS Data

To map gold mining-related land cover changes in Wassa West District, we acquired two Landsat images from NASA's GeoCover dataset (http://glcf.umiacs.umd.edu): one Thematic Mapper (TM) image from December 29, 1986 and one Enhanced Thematic Mapper Plus (ETM+) image from January 15, 2002 (both path/row 194/56). Both images were cloud-free and orthorectified with a positional accuracy of <30 m (Tucker et al. 2004). We only retained the six multispectral bands for both images. Differences in atmospheric conditions among images were removed using a dark object subtraction (DOS) method (Song et al. 2001). As a dark object, we used a deep-water spectra from the Gulf of Guinea.

District boundaries were digitized from the administrative map of the Environmental Protection Agency of the Wassa West District in Tarkwa, produced by the Centre for Remote Sensing and Geographic Information Services (CERGIS) at the University of Ghana Legon, Accra. An area of about 20 km^2 in the south of Wassa West District was outside of the Landsat footprint. We excluded this region from our analyses because field visits confirmed that surface mining had not taken place until 2006.

Field Mapping

Ground truth data for training and validation of the image analyses were gathered in the field from July to October 2006. Mapping was carried out with a non-differential Global Positioning System (GPS) receiver and field sites were selected in coordination with community representatives, non-governmental organizations (e.g., Wassa West Association of Communities Affected by Mining), and mining companies. All field visits were accompanied by local translators.

We carried out two types of field mappings: (a) transect mapping within mining concessions, and (b) polygon mapping in farmland areas and forests. Eight transect walks, on average 1.8 km long (longest and shortest transects of 2.5 and 0.4 km, respectively), were carried out within the mining concessions. During these walks, land cover types were photo-documented and georeferenced. We overlayed these photos as well as district planning maps on screen with the Landsat images for reconstructing land cover patterns. Transect walks were accompanied by residents of the cities of Bogoso, Prestea, and Tarkwa, who pointed out boundaries between concessions and settlements.

In addition to the transect walks, a map of 67 fields inside the Bogoso–Prestea concession was constructed in cooperation with residents of the village Twiyaa. Two nature reserves in the region were visited to map three polygons (GPS based) where forest cover had not changed between 1986 and 2002. We also mapped three polygons in areas that were mined in 2006, but had still been forested in 1986 (these areas were identified based on the Landsat images). We furthermore mapped two polygons that where already mined in 1986, four polygons farmed in 1986 and 2002, and seven polygons of former farmland that had been converted to mines. Additional areas where land cover had changed due to mining were identified in the participatory mapping by the help of local residents (see below). In total, our mapping covered an area of 1732, 75 ha covered by transect walks, and 1,675 ha covered by 19 polygons mapped during field visits and from the Landsat imagery.

Table 1 Overview of classification scheme

Class	Description
Deforestation [D]	Forest sites converted to surface gold mining pits : forest cover in 1986 mining pits 2002
Farmland loss [F]	Regions dominated by agricultural land use converted to surface gold mining pits: farmlands in 1986 mining pits in 2002
Permanent forest [PFo]	Areas where forests remained unchanged: land covered by forests 1986 and 2002
Permanent mine [PMi]	Land cover constantly mined over the observation period: mining pits already established before 1986 remaining by 2002
Permanent farmland [PFa]	Constantly used by farmers, mostly in the form of shifting cultivation: farmland by 1986 and in 2002
Farmland expansion [FaE]	Agricultural expansion into forest: forest in 1986 and farmland in 2002

All ground truth data were categorized into the classes “deforestation”, “farmland loss” (both due to mining), “permanent farmland”, “permanent forest”, “permanent mine” and “farmland expansion” (Table 1).

Interviews and Participatory Data Collection

To better understand the environmental, economic, and social implications of surface mining in Wassa West District, we conducted interviews and organized a participatory workshop (Kitula 2006). In total, 35 interviews with representatives of governmental institutions, private companies, and stakeholders in the agricultural sector were carried out (a list of interview partners can be obtained from the authors). The participatory workshop was held in the village of Twiyaa inside the Bogoso–Prestea concession. Twiyaa had been identified in a survey held in several villages of the Wassa West District as a typical village regarding mining impacts on local livelihoods, including reallocation of farmland and related compensations, surface water pollution, and noise disturbance (Agbesinyale 2003; Akabzaa and Darimani 2001). In the participatory workshop, local farmers outlined a historic map delineating land use around the village in 1990 (before mining started) as well as major landmarks that allowed us to overlay the map with the satellite images and field data.

To better understand the social and environmental implications of surface gold mining and to link the observed changes in land cover and land use mapped from satellite images to the livelihoods these changes impact, we conducted a survey based on structured interviews. We assessed the perception of 40 farm representatives from three villages who were affected by the expansion of the three surface mines. Participants where chosen from the villages of Twiyaa (Bogoso–Prestea concession), Tebrebi (Tarkwa concession), and New Atuabo (resettlement area in the Wassa West district). In Tebrebi and Twiyaa, experts from the Wassa Association of Communities Affected by Mining were consulted to select a group of farmers affected by farmland loss and covering the range of smallholder farm sizes (0.4–4 ha). In Twiyaa, wealth ranking was used during the participatory workshop to select a group of farmers based on farm size. The assessment was based on a questionnaire designed to collect data on conditions prior to the farmland loss (lost farm size, crops cultivated, and legal status of farm), the process of farmland loss (type of compensation agreement, negotiating partners), and the consequences of the farm loss (perception of livelihood and income changes). Current farming activities and land management patterns of each interviewee were assessed at the beginning of an interview. Recall techniques were used to describe historic land use patterns, particularly in regards to farmland losses. All summaries of interviews were crosschecked with the interviewees.

Land Cover Change Mapping

To map mining-related land cover changes in Wassa West District, we stacked both satellite images and carried out a multi-temporal classification (Coppin and Bauer 1996, i.e. composite analysis). Such an approach typically results in more robust and accurate change maps than traditional post-classification map comparison (Coppin et al. 2004). All ground truth polygons were randomly split into a training (75%) and validation (25%) data set. We used a two-stage, hybrid classification to categorize our image stack into our six multi-temporal classes (see “Field Mapping” section). Hybrid classification approaches combine advantages of unsupervised methods (i.e., little a priori knowledge needed) with the better discriminative power of supervised classifications (Kuemmerle et al. 2006). First, we clustered all training data into 70 spectrally homogeneous sub-classes. All clusters were checked visually with the field maps and the Landsat images and only unambiguous clusters were retained. Second, we used the remaining clusters as training data for a supervised maximum-likelihood classification and generated a land cover change map for our study region. To eliminate the salt-and-pepper effect common to pixel-based classifications, all patches <4 pixels (0. 36 ha) were assigned to the surrounding dominant land cover class.

To validate our land cover change map, a stratified random sample of 330 points was collected within the 25% of ground truth polygons not used for training. We constrained our random sample to a minimum number of 30 points per class to ensure representativeness (Congalton 1991). We calculated an error matrix, overall accuracy, producer's and user's accuracy, and the kappa statistics. To analyze land cover changes, we summarized the change map for each of the three mining concessions.

RESULTS

Land Cover Changes

Gold mining in Wassa West District resulted in widespread land cover change between 1986 and 2002 in all three mining concession that we studied (Fig. 2). In 1986, only a small area was used for surface mining (0.2% of the mining concessions area, representing 33 ha, Table 2), but in 2002, mining areas had expanded into 41.9% of the concession areas (Table 2). Our satellite-based analyses confirmed that conversions from forest and farmland to mining pits were

Fig. 2 Land cover change between 1986 and 2002 within the Damang, Bogoso–Prestea, and Tarkwa mining concessions. Background image: Band 5 of the Landsat ETM+ from January 15, 2002

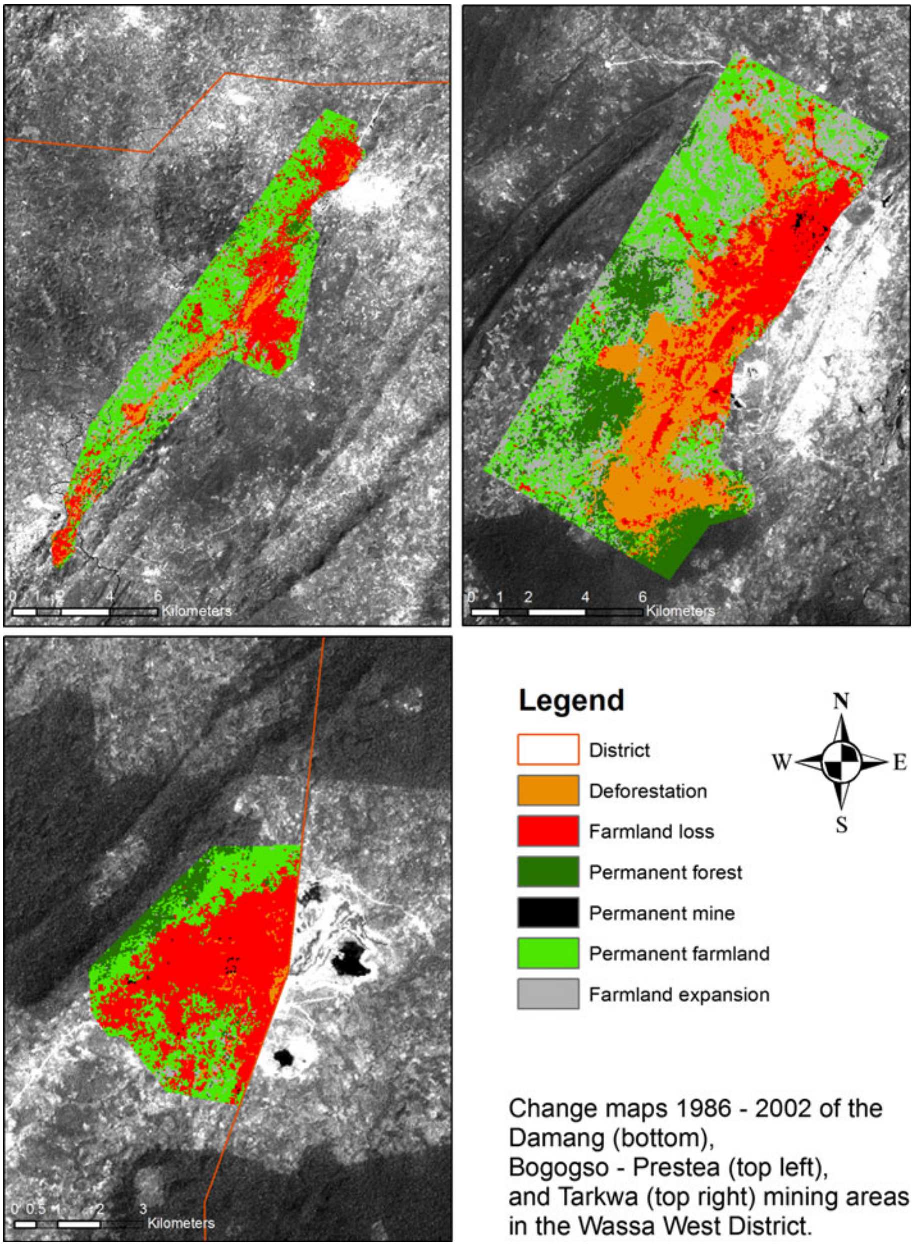

Table 2 Land cover changes between 1986 and 2002 in the Damang, Bogoso–Prestea, and Tarkwa mining concessions

	D	F	PFo	PMi	PFa	FaE	Sum per concession
Damang	51.3 ha	1099.0 ha	166.6 ha	5.7 ha	649.6 ha	38.3 ha	2010.5 ha
	(2.55%)	(54.66%)	(8.29%)	(0.28%)	(32.31%)	(1.90%)	(100%)
Bogoso–Prestea	449.2	1739.8	282.8	1.8	2735.3	729.8	5938.7
	(7.56%)	(29.30%)	(4.76%)	(0.03%)	(46.06%)	(12.29%)	(100%)
Tarkwa	2667.1	2096.6	1775.3	25.5	2545.2	2298.7	11408.4
	(23.38%)	(18.38%)	(15.56%)	(0.22%)	(22.31%)	(20.15%)	(100%)
Σ	3167.6 ha	4935.3 ha	2224.8 ha	33.0 ha	5930.2 ha	3066.7 ha	19357.5 ha
MCP	16.36%	25.50%	11.49%	0.17%	30.63%	15.84%	(100%)

MCP Mean class proportion across all three concessions; all other acronyms see Table 1

the two most widespread land cover changes (Fig. 2, Table 2). Overall, about 3,168 ha of forests were cleared for gold mining pits between 1986 and 2002 within the three concessions (16.4% of the total mining concessions), mostly due to the expanse of forest remnants. Farmland loss affected 4,935 ha (25.5% of the districts' mining concessions). Most of the land within the mining concessions that had not yet been converted to mining pits was used as farmland in 2002 (Table 2). About 30.6% (5,930 ha) of the total land inside the three mining concessions was farmed in 1986 and 2002, whereas 34.1% (3,067 ha) of the total land inside the concessions was converted from forest to farmland between 1986 and 2002. Unchanged forest accounted for 11.5% (2,225 ha) of the mining concessions (Table 2).

Land cover change differed markedly among the three concessions during the 16-year period we studied (Table 2). In Bogoso–Prestea, deforestation for mining expansion occurred on 7.6% of the area (449 ha) and farmland loss on 23.9% (1,740 ha). Permanent mines occupied a relatively small area in this region (1.8 ha). Unlike in the other two mining concession, the spatial pattern of mining pits in Bogoso–Prestea was relatively dispersed, with clusters of pits stretching along a >20 km long trench (Fig. 2). Forests persisted only in a small area (283 ha) and most unchanged areas represented permanent farmland (2,735 ha, equaling 50.8% of the concession's area). About 12.3% (730 ha) of all land in the Bogoso–Prestea concession was converted from forest to farmland (Table 2).

In the Tarkwa concession (Fig. 2), the largest of the three mines we analyzed, only 25.5 ha (0.2%) of mining pits were found in 1986 (Table 2). In contrast to the other two mines, deforestation for mining expansion was widespread in Tarkwa and exceeded all other land cover changes (23.4% of the concession's area, equaling 2,667 ha). Thus, the deforestation rate in Tarkwa due to mining activities was nine times higher than in Damang and three times higher than in Bogoso–Prestea. Farmland gave way to surface mines on 2,097 ha (18.4% of the mining concession) and most of the unmined areas represented farmland (22.3% or 2545 ha). Permanent farmland accounted for 22.3% of the mining concession (2,545 ha) and 2,298 ha of forest were converted into farmland. The Tarkwa concession also still had sizable forests in 2002 (15.6% of the area on 1,775 ha) (Table 2).

In the Damang mine, the most widespread land cover change was the replacement of farmland by mining pits, occurring on 54.6% of the concession and equaling 1,099 ha (Table 2). Only a small proportion of forests were lost (2.6% of the concession, equaling 51.3 ha). Among the unchanged areas, farmland was almost four times more extensive than forest (167 and 650 ha, respectively, Table 2). Only a miniscule proportion (0.3%) of the Damang area was constantly mined between 1986 and 2002 (Table 2 and Fig. 2). Farmland expansion was not extensive in Damang, affecting less than 2% of the area (Table 2).

Our change detection approach yielded a reliable change map with an overall accuracy of 83.3% and a kappa coefficient of 0.79 (Table 3). Most classes had high producer's and user's accuracies, particularly the permanent farmland, permanent mine, and permanent forest classes that all had accuracies of >88%. The main source of uncertainty was confusion between the deforestation and farmland loss classes, resulting in a lower user's accuracy of the deforestation class and a lower producer's accuracy of the farmland loss class. Minor uncertainty was also connected to the farmland expansion class, which had a lower producer's accuracy (73%).

Gold Mining Impacts on Land Use Systems

The interviews we conducted indicated that there is a severe lack of knowledge regarding the consequences of surface mining among farmers. For example, the process of compensation and the valuation of land were reported in six different ways and information regarding the

Table 3 Error matrix for the land cover change classification

	Classified data						Σ	UAC
	D	F	PFo	PMi	PFa	FaE		
Reference data								
D	**48**	25				1	74	64.86%
F	1	**48**		5	3	3	60	80.00%
PFo			**33**				33	100.00%
PMi				**25**			25	100.00%
PFa	2				**86**	9	97	88.66%
FaE		1	1		4	**35**	41	85.37%
Σ	51	74	34	30	93	48	**330**	
PAC	97.96%	63.16%	97.06%	83.33%	92.47%	72.92%		

PAC producer's accuracy, *UAC* user's accuracy, *AC* overall accuracy; all other acronyms see Table 1

compensation was brought to affected farmers in no case by a governmental institution such as the Land Valuation Board, whereby 88% were informed by the company and 12% by traditional authorities. Likewise, our interviews suggest that no common understanding among different stakeholder groups (i.e., farmers, traditional authorities, government institutions, and mining companies) exists regarding the compensation of farmland loss. For instance, interview partners mentioned area- and crop-based compensation methods, 63% of the interviewees mentioned compensation was realized by a mining company without any negotiation. Spatial planning was considered very important by almost all interview partners, but our interviewees also emphasized a marked lack of information (e.g., 25% of all interviewed farmers did not know the current legal status of their land). The combined information of all interviews did not provide a clear picture whether and if so which spatial planning practices have been conducted in the study area. Apart from different types of mining concessions and forest areas which are mapped and equipped with certain land use right, no cadastral or planning base was mentioned by any of the interview partners. Smallholder farmland allocation, which we discussed with the district agricultural department and NGO representatives, also appears to suffer from a substantial lack of spatial planning.

Interview partners at the Wassa West District office of the Ministry of Lands, Forestry, and Mines suggested that illegal logging was common in areas where surface mining expands (e.g. around Twiyaa in the Bogoso–Prestea Concession). Our interviews also strongly suggested that the low input smallholder farming systems that are displaced by gold surface mining are very likely to be reestablished in nearby forest areas, because initial deforestation provides benefits from wood extraction, previously unfarmed soils are more fertile than degrade areas, and fertile farmland is scarce.

Table 4 Surveyed perspectives on livelihood before and after farmland loss and compensation due to surface mining

Conditions prior to compensation	$(n = 35)$[a]
Contract or	13%
Oral agreement or	63%
No regular user rights	25%
Conditions after compensation	
Negative livelihood changes[b]	88%
Income increased or	13%
Decreased or	75%
Effect unknown	13%

[a] Farm representatives with 1.2 ha average farm size, [b] decreasing income, lack of work and lack farmland where mostly mentioned

What are the consequences of gold surface mining-related land cover changes for local livelihoods in the Wassa West District? Our interviews indicate a massive erosion of the region's farming base and a widespread degradation and loss of ecosystem services that local communities depend on (Table 4). Farmland loss was perceived as the major threat to people's livelihoods. Surface mining led to the direct loss of about 5,000 ha of farmland (representing about 5% of the district's total farmland), affecting an estimated 6.8% of the total agricultural labor force (total farmland and total agricultural labor force numbers are based on (Wassa West District Assembly 2004)). Although the status of farmland was heterogeneous prior to compensation, the impact of farmland loss and compensation was unanimously perceived as negative and related to decreasing income and life standard. As a consequence, most interviewed farmers described their livelihood situation after relocation as worse, mainly due to the loss of their traditional farmland and inadequate compensation schemes. It was also frequently pointed out that mostly the illiterate villagers who almost never have written land tenure rights face huge disadvantages when negotiating compensation schemes with entrepreneurial representatives.

During the participatory workshop in Twiyaa, we found much evidence that the community is heavily affected by mining activities: blasting, lack of clean water, and decreasing farmland where identified as most important effects of the Bogoso–Prestea mine during a ranking exercise with the participants in Twiyaa. Degradation and loss of fresh water were the most frequently mentioned direct negative effects of surface mining on ecosystem services by our interviewed farmers. In all the three mining concessions, villagers inside concessions had lost their water resources and now depended on (sometimes contaminated) boreholes or (often unreliable) water supplies by the mining enterprises. For example, approximately 40% of the groundwater resources in the Tarkwa concession were lost due to mining (Kuma and Younger 2004). The rapid expansion of surface mining we found (Fig. 2) supports widespread reports of decreasing water resources in the Wassa West District (Asante et al. 2007; Essumang et al. 2007; Kuma 2007). Moreover, the interruption of natural drainage resulted in widespread water pools, that have in turn been linked to increased Malaria incidents (Akabzaa 2005; Touré 1989). Indirect effects of surface mining on ecosystem services, related to the spill-over effects outline above, are difficult to assess. Yet, it is important to note that field visits and interviews underpinned the various functions that forests fulfill in Wassa West (e.g., non-timber products, soil fertilization, and water filtration), rendering ongoing forest loss an eminent and direct threat to these livelihoods.

DISCUSSION

Surface mining resulted in extensive land cover changes in all three mining concessions we studied in the Wassa West District, mainly leading to the loss of forests and farmland. Our field visits and interviews with farmers and stakeholders suggest that these mining-related land cover changes resulted in widespread land use conflicts, may erode ecosystem services, and compromise nature conservation in our study area. Surface gold mining in Ghana, appears to displace farmers, thereby triggering increased deforestation, agricultural intensification, and land degradation. Thus, surface mining may have additional, substantial indirect social and environmental cost (e.g., spill-over effects, social discontent) in addition to the direct costs of mining that are widely acknowledged (e.g., farmland loss, pollution). These negative consequences of surface mining are often not clear to local stakeholders when concessions are negotiated and compensation schemas are frequently insufficient. Overall, surface mining in Ghana, though economically one of the country's most profitable sources of foreign revenues (Aryee 2001), may erode livelihood foundations.

Farmland loss was the most widespread land cover change, with 4935.3 ha farmland (45% of all farmland within mining concessions) being converted to pits (Table 2). While this has widespread socio-economic consequences, our interviews also suggest that farmland loss within mining concession triggers large spill-over effects, because relocated farmers are often forced to clear adjacent forests for new farmland. Moreover, interview respondents frequently mentioned a growing scarcity of suitable farmland due to surface mining in the region as a direct consequence of mining. This results in land use intensification (e.g., five times shorter fallow periods (13)), often causing biodiversity loss and further degrading ecosystem services (e.g., soil erosion, fertility loss), which in turn leads to additional farmland expansion into forests (e.g., in the north and south of the Bogoso–Prestea concession, Fig. 2).

Deforestation due to surface mining was widespread, resulting in a loss of about 3167.6 ha (58% of all forests within concession areas). Visual interpretation of our satellite maps suggests that forest loss mainly affected small forest patches embedded within farming landscapes. The ongoing loss of small forest patches that fulfill important corridor and stepping-stone functions is, therefore, a concern for the region's forest biodiversity (only small, fragmented patches of native forests remain). The farmland displacement in mining areas we found may exert additional pressure on the remaining forests outside concessions. Ghana also began issuing extraction licenses within protected forest areas in 2003 (Kusimi 2008). Thus, our study not only confirms previously suggested land cover trends in Western Ghana (Kusimi 2008) but suggests that surface mining may be a principal driver of the region's forest loss, both inside and outside mining concessions.

Considering the manifold impacts of gold surface mining on local livelihoods, it is perhaps not surprising that substantial land use conflicts have recently become apparent in Wassa West District (Lassey 2002). In the Bogoso–Prestea area, where many people depend on small-scale mining, violent conflicts between galamsey (i.e., small-scale miners) and security personnel of the mining enterprises occur frequently as we observed in 2006. Likewise, in the Tarkwa concession where we found the highest amount of farmlands lost (Table 2), violent conflicts have recently escalated in gun fighting where expelled farmers tried to access their former land (Hausmann and Strohscheidt 2008). Our interviews suggest that land use conflicts due to gold surface mining (especially due to farmland loss) are widespread and may pose serious limitations for the region's development and security. Indeed, similar conflicts are reported across Ghana. For example, several people were shot while demonstrating against different mining enterprises in 2005 and 2006, because mining threatened a local hospital, contaminated surface waters, and destroyed a local well (National Coalition on Mining 2006). Likewise, several villages were resettled and farmers forcefully excluded from their farmland (Aidara 2008).

Local farmers, often illiterate and poorly informed about the social and environmental consequences of surface mining, face a huge disadvantage when compensation schemes are negotiated. Mining licenses in the three concessions we studied are granted by the Ministry of Lands, Forestry, and Mines, yet companies negotiate compensation with land users affected by the mining operations. Depending on a company's policy and the institutional and legal framework when concessions are actually developed, local stakeholders' land tenure and compensation for land loss is dealt very differently. In general though, because no neutral institution oversees compensation negotiations, the strong power imbalance between the negotiating partners, and the low incentive for the mining companies to compensate land loss adequately, negotiation processes are frequently biased and their outcomes are to the disadvantage of local smallholder farmers (Ayine 2001; Tsikata 1997). Thus, although foreign direct investments and economic growth are positive for Ghana's economy, this comes at a serious environmental and social cost, mostly for local livelihoods, that may bear potential for political destabilization in the long run.

How can policy makers address these conflicts and work toward their solution? Based on our results, field visits, and interviews with farmers and stakeholders, we suggest five possible actions for resolving conflicts and stimulating regional development. First, forest protection should be extended and properly enforced, because remaining forests provide local livelihoods with important ecosystem services (e.g., fresh water, non-timber products, etc.) that are lost elsewhere due to mining (Table 2). Second, spatial planning should become a prominent part of mid-term development reporting and district development planning. Spatial planning should aim at mitigating farmland losses and land pressure due to farmland scarcity. For example, participatory management and the establishment of community forest resources have proven successful in managing common-pool resources eslewhere (Gobeze et al. 2009; Sultana et al. 2007). Likewise, policy makers should direct support to the Wassa West District's agricultural sector, and farmers affected by mining in particular (Ademola 2009). An example for such support is micro-finance schemes or a district-level investment agency supporting smallholder agriculture. Third, the perception of decreasing livelihood quality by local stakeholders should lead to a reassessment of the adequacy of mining-related revenue flows. Ideally, such an assessment should affect national- and district-level policy making. Possible improvements to the current legislation could, for example, be revenue reinvestment in regional development, developing alternative income strategies, and supporting the economic diversification of local populations (Agbesinyale 2003).

At a more general level, transparency has to be established when negotiating land use rights between mining corporate and local people (Boas 2007) and legislation needs to be in place that focuses on restoring pre-mining land tenure, ecosystems services, and biodiversity once surface mining ceased. Though these issues due not directly derive from our results, our interviews strongly suggest that transparency and adequate legislation are key to mitigate environmental degradation and social discontent, and ultimately to balance mining and local livelihood need and to transition toward sustainable resource use in general (Boas 2007; Sukhdev 2008).

CONCLUSIONS

Gold surface mining profoundly affected land use systems in the Wassa West District of Ghana. Our analyses of Landsat images showed that the most widespread mining-related land cover changes in the region were farmland loss and deforestation. Since farmers are often forced to relocate, they frequently clear forests for new farmland, suggesting marked spill-over effects of mining into adjacent areas. The interviews with farmers and stakeholders that we conducted suggest that gold surface mining resulted in the widespread loss of ecosystem services (e.g., fresh water, non-timber forest products, and agricultural products, etc.) and environmental degradation (e.g., pollution of surface waters, biodiversity loss), together pointing to rapidly eroding livelihood foundations. Since we found substantial indirect effects of surface mining (via displacement of farming), the environmental and social costs of Ghana's gold boom may be much higher than the often acknowledged direct costs.

Overall, our study showed the weakening effects of gold surface mining on regional development. While Ghana's gold boom has resulted in substantial revenues at the national level, local people are clearly not profiting from this boom, instead experiencing eroded livelihood foundations, lost income opportunities, health problems, and social and cultural alienation. Altogether, this causes substantial, but mostly ignored, environmental and social costs and increasingly brings about violent conflicts over the use of land. Regional development plans must address these problems, for example by ensuring a backflow of gold-related revenues to local people to help develop alternative income strategies, by enforcing fair compensation schemes, and by protecting lands that are key for local livelihoods (e.g., remaining forests). Ignoring the trade-offs of surface mining for local livelihoods may result in substantial destabilization of the region in the future. To avoid this, and to find sustainable futures, both farmers and mining corporations must be considered integral parts of land use systems in Ghana's rural areas.

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