The Extractive Industries and Society 3 (2016) 450–463

Contents lists available at ScienceDirect

The Extractive Industries and Society

journal homepage: www.elsevier.com/locate/exis

Original article

Evaluating conflict surrounding mineral extraction in Ghana: Assessing the spatial interactions of large and small-scale mining

Kayla Patel*, John Rogan, Nicholas Cuba, Anthony Bebbington

Clark Graduate School of Geography, Clark University, 950 Main Street, Worcester, MA 01610, USA

ARTICLE INFO

Article history:
Received 18 October 2015
Received in revised form 22 January 2016
Accepted 22 January 2016
Available online 19 February 2016

Keywords:
Ghana
Extractive industry
Conflict
Small-scale mining
Large-scale mining

ABSTRACT

Since implementation of its Economic Recovery Program in 1983, Ghana's extractive industries have come to account for 40% of the total value of the country's exports. An adverse impact of this increase, however, has been increased extraction-related conflict due to heightened competition between large and small-scale operators over mineral-rich lands. This paper characterizes these conflicts in the south-central section of the country by mapping the spatial overlaps between large and small-scale miners. Classification tree analysis of 2013 and 2015 Landsat-7 and -8 imagery was used to identify small-scale mine sites. The overlaps between these sites and large-scale concessions are examined in the context of reported mining conflicts. Results reveal that there is a large amount of resource competition between the two parties, specifically, more than half (i.e., 52%) of the identified small-scale mining activity occurs within the boundaries of large-scale concessions. The northwest corner of the study area contains 50% of the identified overlaps; the southwest corner contains 40%; and the northeast corner contains 10%. In most cases, these overlaps take place on prospecting concessions. The work illustrates how mapping and quantifying areas of spatial overlap between large and small-scale miners can help stakeholders implement more effective policy solutions.

1. Introduction

This paper identifies areas of small-scale mining (SSM) activities using a classification of remotely sensed Landsat data to determine locations of spatial overlap between SSM and large-scale mining concessions, and contextualizes the areas identified within histories of mining-related social conflict. The maps and visualizations produced provide stakeholders with a better understanding of the spatial dynamics that surround extraction-related conflict in Ghana. Mapping SSM and large-scale mining assists policy makers with identifying where areas of competition between the two branches of the sector is high, helping to focus efforts and leading to strategies which better account for the existing tension and spatial relationships within the extractive industries. Tensions between Ghana's large and small-scale miners have been well-documented in the literature (Hilson, 2001; Hilson, 2002a; Hilson and Yakovleva, 2007; Banchirigah, 2008; Aubynn, 2009; Hilson and Banchirigah, 2009; Nyame and Blocher, 2010; Teschner, 2013; Ayelazuno, 2014; Nyame and Grant, 2014), although the spatial distribution of the sector's activities have yet to be brought to bear in efforts to contextualize these conflicts. Highlighting areas where overlaps between SSM and large-scale mining occur, along with an assessment of the contextual histories of tension in specific regions, can provide a more nuanced understanding of extraction-related conflict. These findings can help to inform policy by drawing attention to the fine spatial scale impacts of different strategies for specific areas.

The paper examines the spatial relationships between small and large-scale miners in Southern Ghana where the Central Region, Western Region, Eastern Region and Ashanti Region intersect (Fig. 1). In Ghana, SSM is largely informal, populated by low-skilled workers who use simple technology, and most frequently takes place in areas with shallow mineral deposits, such as alluvial deposits along river channels (Appiah, 1998; Aryee et al., 2003; Hilson and Yakovleva, 2007; Aubynn, 2009). Large-scale mining is typically carried out by foreign companies which use mechanized equipment and employ comparatively fewer, albeit more skilled, workers (Garvin et al., 2009; Amponsah-Tawiah and Dartey-Baah, 2011). All three types of licenses linked to large-scale mining in Ghana – mining, prospecting, and reconnaissance – are used to geographically represent ownership of rights to extractive activities, and in the case of mining leases, the actual *presence* of activity. Reconnaissance licenses are the first step in the mining

* Corresponding author. Present address: 16 Juniper Ridge Road Acton, MA 01720, USA.
E-mail addresses: kayla.a.patel@gmail.com (K. Patel), jrogan@clarku.edu (J. Rogan), ncuba@clarku.edu (N. Cuba), abebbington@clarku.edu (A. Bebbington).

http://dx.doi.org/10.1016/j.exis.2016.01.006
2214-790X/

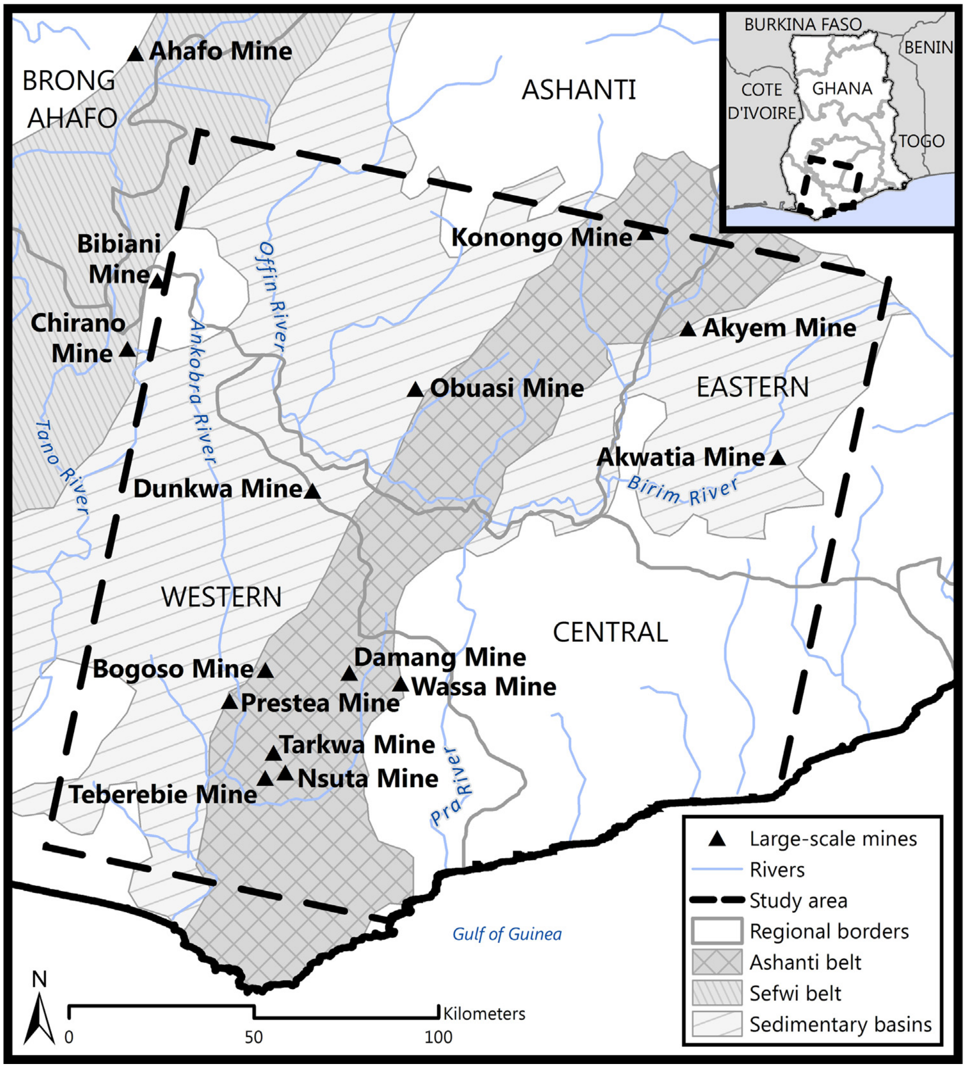

Fig. 1. Study area is shown along with large-scale mines, regional borders, rivers, and the major geological formations running throughout the area.

process, are valid for up to one year, and allow for only aerial and/or field surveys; prospecting licenses are valid for up to three years and allow for sub-surface examination of mineral deposits; and mining licenses allow for extraction and are issued for up to 30 years (Cuba et al., 2014). The three types of corresponding concessions are differentiated to indicate what stage in the mining process an area is in which can influence the amount of extraction-related conflict, as most conflict occurs after periods of surveying (Hilson, 2002b), activity mainly associated with reconnaissance and prospecting concessions (Cuba et al., 2014). Although actual mining occurs on a very small percentage of large-scale concessions, these are used to delineate large-scale mining activity as they represent a right to explore the mineral resources within their boundaries (Cuba et al., 2014) that when encroached upon by small-scale miners can lead to extraction-related conflict (Hilson, 2002a; Hilson, 2002b; Ayelazuno, 2014).

The paper uses a classification of Landsat-7 and Landsat-8 imagery and a set of ancillary variables to map SSM locations in south-central Ghana. The locations of classified SSM are then examined in conjunction with large-scale concession data, unofficial government-designated areas for SSM, as well as information on the existing tensions in specific areas to assess how spatial interactions of the two sectors influence the occurrence of conflict. The amount of tension in an area is represented by records of negative interactions between large and small-scale miners discussed throughout the academic literature, conflict databases, news sources, and publications of some non-governmental organizations. These conflict data range from recorded instances of violence between the sectors, to accounts of tension due to SSM encroachment. The work provides stakeholders with an understanding of the spatial dynamics and relationships between SSM and large-scale mining contextualized within recorded instances of conflict. This information can be used to formulate policy solutions that more effectively decrease or resolve extraction-related conflict.

2. Small and large-scale mining in Ghana

Global material use has increased eightfold over the last century (Krausmann et al., 2009) leading to increased demands for traded commodities, such as food, fuel, water, and timber (Behrens et al., 2007). In response to the greater use of, and demand for, these traded goods, extraction of raw materials has increased by roughly 80% in the last 30 years (Dittrich et al., 2012). The use of non-renewable minerals grew 340% between 1945 and 1973, becoming the most widely-demanded group of resources

Table 1
All recorded conflicts between large and small-scale miners as mentioned in literature, online databases, news sources, and some non-governmental organizations. The region, district, city and/or mine/concession are provided if available, and the date is precise to the month and year if available.

Region, district, mine/concession	Date of incident	Description of events
Ashanti Region, Amansie Central District, AngloGold Ashanti concessions	September 2014	The Ashanti Regional Anti-Galamsey Taskforce seized illegal small-scale miners in the Amansie Central district, where illegal mining is prevalent and operators have invaded AngloGold Ashanti concessions (Owusu-Akyaw 2014, September 2).
Ashanti Region, Obuasi, AngloGold Ashanti concession	October 2013	“Armed illegal gold miners last Saturday attacked some members of the anti-galamsey security team of AngloGold Ashanti (AGA) on the company’s concession in Obuasi” (Arku 2013, October 4).
Ashanti Region, Obuasi, AngloGold Ashanti concession	August 2011	“Illegal miners shot and killed by AngloGold Security” (Okoh, 2014; p. 55).
Ashanti Region, Obuasi, AngloGold Ashanti concession	April 2011	“Demonstration against the arrest of 150 illegal miners by the police and military turned violent” (Okoh, 2014; p. 55).
Ashanti Region, Obuasi, AngloGold Ashanti concession	May 2010	“Artisanal miners attacked and seriously wounded two AngloGold Ashanti Ltd. security personnel who were on patrol duties on AngloGold concession” (Okoh, 2014; p. 55).
Ashanti Region, Obuasi, Ashanti Gold Mine	2008	“So virulent has been the activities of the illegal miners that the company's own security men and law enforcement officials from the army and the police are now being forced to stand by helplessly as the galamsey operators, sometimes armed to the teeth, go about their activities . . . ” (Aubynn, 2009; p. 64).
Ashanti Region, Obuasi, Aduaneyede, AngloGold Ashanti	June 2004	“A galamsey suspect was arrested by the security of AngloGold Ashanti and he died while in custody. His family believes he was beaten to death by mine personnel” (WACAM, 2014).
Ashanti Region, Ashanti Goldfields Obuasi Mine	March 2002	Guard dogs released on galamsey miners (WACAM, 2014).
Ashanti Region, Ashanti Goldfields Obuasi Mine	October 2002	Guard dogs released on galamsey miners (WACAM, 2014).
Ashanti Region, Ashanti Goldfields Obuasi Mine	December 2001	Guard dogs released on galamsey miners (WACAM, 2014).
Ashanti Region, Ashanti Goldfields Obuasi Mine	April 2000	“Police killed one man after illegal miners attacked a mine owned by Ghana’s giant Ashanti company” (Salehyan et al., 2012).
Ashanti Region, Obuasi, AngloGold Ashanti's Mine	since 2000	“Since 2000, numerous clashes have occurred between ASM operators and staff at the Bogoso mine, now owned by US-based Golden Star Resources, and Anglo-Gold Ashanti’s Obuasi mine” (Aubynn, 2009; p. 66).
Ashanti Region, Obuasi, AngloGold Ashanti concession	2000	“Artisanal miners set ablaze a poultry farm belonging to AngloGold Ashanti and made away with valuable assets and livestock of the company” (Okoh, 2014; p. 55).
Ashanti Region, Ashanti Goldfields Obuasi Mine	1997	Galamsey operator killed by police, mine security, and military personnel (WACAM, 2014).
Ashanti Region, Obuasi, Ashanti Goldfields concession	1997	“Ashanti Goldfield Company security severely brutalized and set out their security guard dogs on 16 artisanal gold miners” (Okoh, 2014; p. 55).
Ashanti Region, Ashanti Goldfields Obuasi Mine	December 1996	Galamsey operator killed by police, mine security, and military personnel (WACAM, 2014).
Ashanti Region, Obuasi, Ashanti Goldfields concession	1996	“Violent clashes erupted between artisanal miners and Ashanti Goldfield Company security cum state security forces resulting in over $1 million damage to [Ashanti Goldfields Corporation] property” (Okoh, 2014; p. 55).
Ashanti Region, Obuasi, AshantiGold Mine	1996	“a major clash occurred between galamsey operators on the AshantiGold Mine lease area and the state security forces at Obuasi, during which properties estimated at about US$ 10 million were destroyed” (Aubynn, 2009; p. 66).
Ashanti Region, Ashanti Goldfields Obuasi Mine	February 1994	Galamsey operator killed by police, mine security, and military personnel (WACAM, 2014). “Ashanti Goldfield Company (now AngloGold) security in conjunction with military and police killed a total of 3 artisanal miners” (Okoh, 2014; p. 55).
Ashanti Region, Obuasi, AngloGold Ashanti Mine		A galamsey miner was shot by police at AngloGold Ashanti mine in Obuasi. Reports of mine officials saying they will shoot galamsey operators onsite (WACAM, 2014).
Ashanti Region, Obuasi		“The general state of enmity is illustrated by incidences of conflicts that surface periodically between the two main competing groups – artisanal miners and mining communities versus large-scale mining firms and the government – in recent years at Bibiani in the Western Region, Obuasi in the Ashanti Region, and Noyem in the Eastern Region” (Nyame and Grant, 2014; p. 82).
Eastern Region, Akwatia	November 1991	“A riot broke out last week in Akwatia, 80 kilometers (50 miles) northwest of Accra, after one of 30 policemen investigating illegal mining by foreigners fired his pistol into an angry crowd, killing one resident” (Salehyan et al., 2012).
Eastern Region, Noyem		“The general state of enmity is illustrated by incidences of conflicts that surface periodically between the two main competing groups – artisanal miners and mining communities versus large-scale mining firms and the government – in recent years at Bibiani in the Western Region, Obuasi in the Ashanti Region, and Noyem in the Eastern Region” (Nyame and Grant, 2014; p. 82).
Eastern Region, Noyem/Nyafoman, Newmont Mining Corporation		“Newmont Mining Corporation continues to hold onto what appears to be land that is uneconomical to mine on a large scale” (Banchirigah, 2008; p. 32).
Western Region, Gold Field's Damang Mine	2011	“ASM operators invade the central areas of concession and are forcibly evicted” (Teschner, 2013; p. 333).
Western Region, Gold Field's Damang Mine	2008	“ASM operators invade Damang’s Rex pit and are forcibly evicted” (Teschner, 2013; p. 333).
Western Region, Abosso Goldfields concession	1990	“In 1990, seven cooperative groups of small-scale miners had been registered in an area of 155 acres within the same concession awarded to the Ghanaian mining company Abosso Goldfields Ltd. (AGL). Some 600 small miners, many of whom claimed to be amongst the first occupants of the region, encroached on the exploration trench areas of AGL. It became extremely challenging and laborious for AGL to chase small gold miners off “their” exploration area, and after the army and police were called upon to intervene, violent clashes erupted” (Hilson, 2002a; p. 67).
Western Region, Bibiani, Anhwiaso/Bekwai, Ashanti Goldfields concession	2000	“Illegal miners attacked Ashanti Goldfields. Police intervened and killed one attacker” (Raleigh et al., 2010).
Western Region, Bibiani	since 2000	“Since 2000, numerous clashes have occurred between ASM operators and staff at the Bogoso mine, now owned by US-based Golden Star Resources, and Anglo-Gold Ashanti’s Obuasi mine, which have received extensive coverage in both local and international media outlets” (Aubynn, 2009; p. 66). “The general state of enmity is illustrated by incidences of conflicts that surface periodically between the two main competing groups – artisanal miners and mining communities versus large-scale mining firms

Table 1 (*Continued*)

Region, district, mine/concession	Date of incident	Description of events
		and the government – in recent years at Bibiani in the Western Region, Obuasi in the Ashanti Region, and Noyem in the Eastern Region" (Nyame and Grant, 2014; p. 82).
Western Region, Bibiani, Ashanti Goldfields concession		At Ashanti Goldfields' smaller Bibiani property, "management reports needing police help in Kumasi to control resident galamsey" (Hilson, 2001; p. 19).
Western Region, Bogoso, Golden Star Resources Bogoso Mine	March 2005	Galamsey miners operating on Golden Star Resources Bogoso Mine concessions. In March 2005, the government issued an order for the workers to abandon their mines and were met with much resistance (Hilson and Yakovleva, 2007).
Western Region, Bogoso		"Similar circumstances exist in gold mining communities in other parts of the country, notably, Tarkwa and Bogoso in the Western Region, and Kenyasi in the Brong Ahafo Region, where migrant artisanal miners are competing with existing large-scale mines over land" (Okoh, 2014; p. 57).
Western Region, Prestea, Barnex Ltd. concession	July 1996	"Clash between artisanal miners and a contingent of police on the concession of Barnex Ltd., Prestea" (Aubynn, 2009; p. 66).
Western Region, Tarkwa, Gold Fields Ghana Mine	1997	"The populations of two villages were relocated to a resettlement village on the outskirts of Tarkwa and all farmland in the central portion of the concession was compensated to make room for the new surface operations. Gold Fields' staff recall that one of the largest sticking points during relocation negotiations was from gold buyers and the ASM operators who were reluctant to move from their illegal sites on the surface. There locations eventually went ahead. Shortly after, some ASM operators attempted to return to the areas and re-start activities, but they were quickly curtailed" (Teschner, 2013; p. 336).
Western Region, Tarkwa, Gold Fields Ghana Mine	1990s	"Gold Fields' operations in Tarkwa were not spared of violent clashes amid preparations to suspend underground operations in favor of the development of surface resources. During one of numerous clashes with encroaching galamsey miners, a senior manager of the company was reportedly brutally assaulted" (Aubynn, 2009; p. 66).
Western Region, Teberebie Goldfields' Mine	since 1991	Several galamsey are still unwilling to leave the area, contending that they have no alternative "source" of livelihood, and although their activities have caused significant environmental damages in various portions of the concession, they refuse to take any responsibility for these damages, and have not taken any necessary safety precautions. (Hilson, 2001).
Western Region, Tarwka		"Similar circumstances exist in gold mining communities in other parts of the country, notably, Tarkwa and Bogoso in the Western Region, and Kenyasi in the Brong Ahafo Region, where migrant artisanal miners are competing with existing large-scale mines over land" (Okoh, 2014; p. 57).

worldwide, as a result of post-World War II population and economic growth (Krausmann et al., 2009). Most mineral extraction takes place in developing nations, led by companies mainly headquartered in the Global North (Bruckner et al., 2012). These companies are drawn to nations with attractive regulatory and fiscal regimes, enacted in many developing countries that seek the investment and economic growth associated with extraction (Addy, 1998; Aryee, 2001; Hilson, 2004; Hilson and McQuilken, 2014).

Encouraged by institutions such as the World Bank and International Monetary Fund (IMF), many developing world governments have lightened regulations governing extraction in an effort to attract investment from foreign mining corporations (Addy 1998; Akabzaa and Darimani, 2001; Britwum et al., 2001; Hilson, 2002c; Hilson and Potter, 2005). The resulting expansion of extractive industries can generate significant economic growth as it increases export earnings, draws in revenue, and augments gross domestic product (Aryee, 2001; Weber-Fahr et al., 2001; Wright and Czelusta, 2007). Despite the macroeconomic benefits associated with extraction, the sector has generally failed to help reduce poverty and mitigate the pressures associated with extraction, such as displacement, job loss, and land and water pollution, in the poor, rural communities around operations (Hilson, 2004; Bulte et al., 2005; Pegg, 2006; Ayelazuno, 2014; Gamu et al., 2015). As a result, social conflict frequently plagues regions of extraction as local communities express frustration over the negative effects of the industry's expansion and compete for access to resources (Bebbington, 2012; Bebbington et al., 2014a).

In Ghana, with its extensive mineral reserves (Hilson and Potter, 2005) and struggling economy (Hilson, 2004), policy makers were eager to benefit from opening the extractive industries to foreign investment in the early 1980s (Akabzaa and Darimani, 2001; Hilson, 2002c; Hilson and Potter, 2005). In 1983, with World Bank/IMF assistance, Ghana implemented the Economic Recovery Program (ERP), an initiative that would reduce government control over the extractive industries and led to considerable increases in both large-scale mining and SSM activity throughout the country (Tsikata, 1997; Aryee, 2001; Hilson and Potter, 2005). In 1986, seven large-scale gold mines existed in Ghana, whereas by 1998, 15 years after implementation of the ERP, the country's total mine count had doubled to 14 (Aryee, 2001). By 2004, Ghana's gold outputs had experienced a five-fold increase (Hilson, 2004), surpassing cocoa as the country's most important export commodity (Wan, 2014).

Ghana's extraction-friendly economic environment also extends to SSM, which experienced rapid growth after its legalization in 1989 following passing of the Small-scale Gold Mining Law (Hilson 2001; Amankwah and Anim-Sackey, 2003). Before the ERP, SSM was largely ignored by the government (Hilson, 2002b), but increasing poverty due to the lack of job opportunities in the years following its implementation pushed people into the sector as it held the promise of quick economic rewards (Hilson and Potter, 2003; Hilson and Garforth, 2012). By 2001, the sector had shown visible signs of growth, having produced over U.S. $117 million worth of gold and over U.S. $98 million worth of diamonds (Hilson, 2001). Between 2000 and 2010, SSM grew faster than its large-scale counterpart, as evidenced by the 519% increase in ounces of gold produced compared to a 13% increase in the large-scale sector (Nyame and Grant, 2014). Many rural inhabitants turned to SSM to supplement their seasonal farming earnings or as their primary source of income (Hilson and Garforth, 2012; Hilson and Garforth, 2013; Nyame and Grant, 2014): today, the sector currently employs at least 200,000–300,000 people, more than half the country's mining labor force (Hilson, 2001; Aubynn, 2009; Nyame and Blocher, 2010).

Despite the creation of legal modes of SSM, about 85% of the sector currently operates illegally (Hilson and Potter, 2003;

Teschner, 2012). These ‘galamsey’ miners, as they are often referred to, have failed to register with the relevant government authority, specifically, the Minerals Commission, and often operate illegally on concessions awarded to large-scale miners (Hilson, 2002b; Aubynn, 2009). Despite being referred to differently on paper, the distinction between registered and unregistered SSM operators is often difficult to determine in practice, as many registered individuals continue to conduct illegal activities through informal exporters and intermediary buyers (Aubynn, 2009; Teschner, 2012) or the overuse of mercury and explosives (Aryee et al., 2003; Babut et al., 2003; Teschner, 2012). The main reason for the high levels of illegal SSM is poor government coordination in regulatory efforts (Hilson, 2002b; Hilson, 2002d; Hilson and Potter, 2003). Miners have little incentive to get licensed, as the lengthy and tedious registration process takes too long for the fast-paced, nomadic small-scale miner (Hilson and Potter, 2003). Additionally, the Precious Minerals Marketing Company (PMMC), established in 1989 and tasked with purchasing minerals extracted by small-scale operators, will buy gold from both registered and unregistered actors, therefore potentially undermining the power that a license from the Minerals Commission provides (Hilson and Potter, 2003; Banchirigah, 2008).

Increases in both large-scale mining and SSM activity have led to an intensification of conflict in areas surrounding operations over access to mineral-rich lands (Hilson, 2001; Hilson, 2002a; Hilson, 2002b; Hilson and Potter, 2005; Hilson and Yakovleva, 2007, Teschner, 2013; Gamu et al., 2015). The Government of Ghana continues to work to attract foreign investment to develop large-scale mining, which has led to a decrease in the amount of land available for SSM (Hilson, 2002b; Hilson and Potter, 2005). Of Ghana’s total land area, about 25% has been demarcated for prospecting, reconnaissance, or mining activities (Cuba et al., 2014); the concentration of concessions is even higher in regions containing substantial proven mineral deposits. In some cases, land legally granted to registered SSM operators is later re-zoned as a large-scale mine concession area (Hilson and Potter, 2005; Aubynn, 2009), increasing confrontation and conflict (Aubynn, 2009). As a result of these overlaps, conflicts between large-scale mining and SSM have consistently accompanied the growth of Ghana’s extractive industries (Hilson, 2002b; Aubynn, 2009; Okoh, 2014). Specific instances of conflict between large-scale mining and SSM mentioned throughout the literature, conflict databases, non-governmental organizations, and local news sources are presented in Table 1.

In an effort to address this conflict, some large-scale mining companies have entered into agreements with the SSM operators on their concessions, permitting them to work on company land (Hilson, 2001; Hilson, 2002b; Aubynn, 2009). The Akwatia diamond mine, when under the ownership of Ghana Consolidated Diamonds Ltd., was one of the first large-scale operators to permit small-scale miners to work on their concession (Hilson, 2001; Hilson, 2002b; Yelpaala and Ali, 2005). While these agreements are deliberate attempts to reduce extraction-related conflict in Ghana (Hilson, 2001), tensions remain in many locations due to complex histories of conflict and increasing large-scale mining activity (Hilson and Potter, 2005; Aubynn, 2009; Nyame and Grant, 2014). In 1996, after many failed attempts to forcibly prevent SSM, Abosso Goldfields Ltd. provided company identification cards to the operators in the area surrounding its Damang Mine, permitting them to operate on the property and to sell their gold to the company at near-market prices (Appiah, 1998; Hilson, 2002b). Despite this agreement, in 2008 and 2011, other small-scale miners invaded the central areas of the mining concession and were forcibly evicted (Teschner, 2013). On the Bogoso Gold Ltd. concession, there have also been numerous clashes between small-scale operators and mine security forces since the 2000s as a result of illegal SSM (Hilson and Yakovleva, 2007; Aubynn, 2009), and despite the company allocating 5% of its concession to SSM, encroachment beyond sanctioned areas continues (Hilson, 2002b). In some instances, corporations are more reluctant to enter into agreements, as in the case of Newmont Mining Corporation in Noyem, in the Eastern Region, which is currently withholding concession land considered unsuitable for large-scale mining instead of allowing SSM to occur (Banchirigah, 2008).

Long-term solutions for decreasing extraction-related conflict have historically revolved around reducing the extent of illegal SSM through initiatives such as alternative livelihood projects, relocation efforts, or police raids of operations (Hilson and Yakovleva, 2007; Banchirigah, 2008). But as these solutions have proved to be generally ineffective (Hilson and Yakovleva, 2007; Hilson and Banchirigah, 2009) more recent discussions have centered around acknowledging SSM’s role as an important rural livelihood and focusing on the increased formalization of operations, along with the demarcation of more lands to enable licensed activities to take place (Hilson and Potter, 2003; Hilson and Yakovleva, 2007; Aubynn, 2009; Teschner, 2012; Hilson and Garforth, 2013; Hilson and McQuilken, 2014; Okoh, 2014). The SSM licensing process has long been unfeasible for the majority of operators as it can take up to a year to complete the necessary paperwork and is known to be an extremely cumbersome and bureaucratic process (Hilson and Potter, 2003; Bush, 2009; Teschner, 2012). As SSM continues to be an important source of income to increasing numbers of people, helping to alleviate rural hardships (Hilson and McQuilken, 2014), the need for the Government of Ghana to gain control over the sector so that it can be productively incorporated into development strategies has become clearer (Hilson and Yakovleva, 2007; Aubynn, 2009; Teschner, 2012). In addition, the lack of land available for facilitating legalized SSM could be addressed through policies that would lead to more mining companies relinquishing parts of their concessions, so that overlap between the sectors becomes less common and competition is reduced (Hilson and Potter, 2003; Hilson and Yakovleva, 2007; Aubynn, 2009). A contextualized understanding of the spatial dynamics and relationships between large-scale mining and SSM, as presented in this paper, could help target such reallocations of mining rights and anticipate areas of possible future conflict and collaboration between the two forms of mining. It could also inform any future decisions on allocations of mining rights such that they are less likely to catalyze conflict. More generally, making such spatially explicit data available in the public sphere can only help to inform and enhance public and policy debates on how best to manage relations between SSM and large-scale mining.

3. Study area and data

The study area was located in Southern Ghana, encompassing parts of the Central Region, Western Region, Ashanti Region, and Eastern Region, where the Ankobra, Pra, Offin, and Birim rivers run through (Fig. 1). The region is demarcated by the footprint of the Landsat-8 scene: path 194 and row 56. The scene was selected because of the high volume of large-scale mining and SSM within its boundaries around proximal mineral-bearing rock formations (Hilson, 2001; Aryee et al., 2003; Babut et al., 2003; Banchirigah, 2008; Nyame and Grant, 2014). The Birimian Supergroup and Tarkwaian Group, both part of the Paleoproterozoic supracrustal formation and forming between 2195 Ma and 2072 Ma, are the main groups of mineral-bearing parent material in Ghana. The sedimentary basins running through the study area consist of sedimentary rocks from the Birimian Supergroup. The Ashanti belt, which runs through the middle of the study area is comprised of rocks from the Tarkwaian Group, and the Sefwi belt, located to the northwest of the study area, is comprised of volcanic rocks from the Birimian Supergroup (Ghana Geological Survey, 2013).

Due to persistent and typically-heavy cloud cover in the study area, no single Landsat image from 2013 to 2015 contained valid, cloud-free observations for more than 67% of the study area. However, valid observations were available for 95% of the study area through aggregation of observations from three images: a Landsat-8 image, captured 11 January 2015, a Landsat-7 image, captured 3 January 2015, and a Landsat-8 image, captured 23 December 2013. The image dates fall within the northern hemisphere winter season, when cloud cover tends to be lower thus making more pixels available for classification analysis.

All of the data products used in the analysis are presented in Table 2, with source information, format, and a description for each. The ancillary geospatial data used in the land-cover map classification include a Digital Elevation Model (DEM), slope, distance to rivers, distance to roads, location of forest reserves, and location of areas suitable for SSM. The 90 m spatial resolution DEM comes from NASA's Shuttle Radar Topography Mission (SRTM) and was used to derive the slope map. Both the rivers and roads datasets come from DIVA-GIS (Hijmans et al., 2012), and 30 m gridded distance maps were created for each of these datasets to be used in the analysis. The forest reserves were provided by Ghana's Ministry of Land and Natural Resources (MLNR) and mark the locations of protected forest areas in 2012 using a binary 30 m gridded map. The suitable SSM locations layer is also a binary 30 m gridded map and highlights river basins that overlap mineral bearing rocks, capturing areas in which productive SSM is more likely to occur based on geological information from the Ghana Geological Survey.

The concession data used in the analysis indicate the status of each large-scale concession as either a mining, prospecting, or reconnaissance plot, and also include unofficial SSM concessions, all of which were obtained from the Minerals Commission of Ghana (Ghana Minerals Commission, 2014). The mining, prospecting, and reconnaissance concessions are dated to July 2012, while the areas unofficially blocked out for SSM are dated to July 2014. The unofficial SSM concessions are locations that have been identified by the Minerals Commission as areas that are yet to become "official" concessions for SSM but in which such mining might potentially be allowed.

Lastly, following a review of relevant literature, social conflict databases, news sources, and non-governmental organizations, conflict data were collected on reports of violence or tension between SSM and large-scale mining operations (Table 1). The conflicts were only included if they happened directly between small and large-scale operators, and the types of events recorded range from large-scale companies refusing to allow SSM on their concession, to riots and violence committed by either sector against the other. The location, actors, approximate date, and a description of events were documented. Geo-referencing the conflicts to latitude and longitude coordinates proved difficult due to the consistent lack of precise location information available for many recorded conflicts. Conflicts were thus linked to the large-scale mine corresponding to the actors involved in an effort to gain a sense of the general tensions defining a particular area.

4. Methods

Classification Tree Analysis (CTA) was used to map SSM locations throughout the study area. CTA is a machine learning approach that can incorporate ancillary data layers and spectral reflectance from Landsat imagery to classify each in-scene pixel among a designated set of land-cover types, and has been used in previous studies involving the detection of SSM (Elmes et al., 2014). CTA accepts both parametric and non-parametric data as inputs, and thus was chosen due to the need to incorporate ancillary data, such as distance to roads and rivers, which can improve the categorical accuracy of map outputs when used in conjunction with reflectance data. CTA also yields information on the specific variables and thresholds that are used to distinguish groups of pixels as different categories, indicating the variables and values key to distinguishing categories (Hansen et al., 1996). The land-cover make-up of SSM tends to be a mix of bare-soil and water areas (Asner et al., 2013), due to the forest clear cutting and standing pools of water associated with the mining process (Hilson, 2001; Aryee et al., 2003; Ayivor and Gordon, 2013). The contrasting spectral properties of the high-reflectance soil and

Table 2
Data used in the analysis with information about the source, format, and a description of each dataset.

Data	Source	Format	Description
Landsat-7 ETM+	USGS	Raster image	Captured January 3, 2015. Path/Row: 194/56. 30 m spatial resolution.
Landsat-8 OLI	USGS	Raster image	Captured January 11, 2015. Path/Row: 194/56. 30 m spatial resolution.
Landsat-8 OLI	USGS	Raster image	Captured December 23, 2013. Path/Row: 194/56. 30 m spatial resolution.
Geology map	GGS	Raster image	Map of geological formations within Ghana.
Roads	DIVA-GIS	Vector lines	Road network within Ghana.
Rivers	DIVA-GIS	Vector lines	River systems within Ghana.
Administrative boundaries	GADM	Vector lines	National, regional, and district boundaries.
Digital elevation model	NASA (SRTM)	Raster image	90 m spatial resolution digital elevation model for Ghana.
Large-scale mining concessions	MLNR	Vector polygons	Digitized from paper maps and recent to 2012.
Unofficial SSM concessions	MLNR	Vector polygons	Digitized from paper maps and recent to 2014.
Conflict data	ACLED, literature review, WACAM, SCAD	Vector points	Collection of reported conflict events between large-scale mining companies and small-scale miners. Conflicts range from reported instances of violence to accounts of tension between the sectors.
Suitable areas for small-scale mining		Raster image	Binary 30 m grid showing location of suitable areas for small-scale mining based on water basins that intersect mineral bearing rock formations. Derived from DEM and geology map.
Forest reserves	MLNR	Raster image	Binary 30 m grid showing locations of protected forest areas in 2012.

ACLED, Armed Conflict Location and Event Data Project; OLI, Operational Land Imager; ETM+, Enhanced Thematic Mapper Plus; USGS, United States Geological Survey; GADM, Database of Global Administrative Areas; SCAD, Social Conflict Analysis Database; MLNR, Ministry of Lands and Natural Resources; GGS, Ghana Geological Survey; NASA (SRTM), National Aeronautics and Space Administration (Shuttle Radar Topography Mission); WACAM, Wassa Association of Communities Affected by Mining.

low-reflectance water produce a speckled pattern of heterogeneity over fine spatial scales (Asner et al., 2013).

Pixels in each of the three Landsat scenes were classified as one of six land-cover categories: water, SSM, forest, light vegetation, urban/bare soil, or agriculture. The process of selecting training sites in order to calibrate the classification tree included delineating 50–60 sites of known land-cover that were each around 300 m^2, for each land-cover category. Separate CTA models were run on each image and map accuracy assessment was conducted using fine spatial resolution imagery from the GeoEye-1, WorldView-1, and Worldview-2 sensors, obtained from Google Earth and dated from late December 2011 to mid-January 2015 (Fig. 2). Fifty pixel sites per land-cover category were used to assess the map accuracy for the classification of each of the three dates, the results of which were used to define how the three classified output maps would be combined into the final SSM map.

The final map is a composite of classified maps for each of the three image dates (e.g., 11 January 2015, 3 January 2015, and 23 December 2013). In instances where the classified land-cover of a pixel differed between dates, the land-cover of the pixel in the most recent image was assigned in the final map. Classified land-cover from earlier images was used in the final map for pixels where clouds or cloud shadows prevented quality observations in later images. A 3×3 pixel modal filter was applied to the final land-cover map in order to reduce speckle, or fine-scale spatial heterogeneity in land-cover. Finally, as a result of over classification of SSM in some areas, particularly in and around the Tarkwa large-scale mine, high spatial resolution reference imagery and the initial Landsat scene were used to identify erroneously classified SSM pixels and manually adjust them to the appropriate land-cover based on the imagery and surrounding pixel classifications. These methods were shown to yield a final map with higher accuracy with reference to high spatial resolution imagery, compared to maps produced using alternative aggregation methods, or without the use of a modal filter.

5. Results

5.1. Mapping small-scale mining sites

The SSM activity mapped using CTA, the locations and extents of the unofficial SSM concessions, the existing large-scale mining

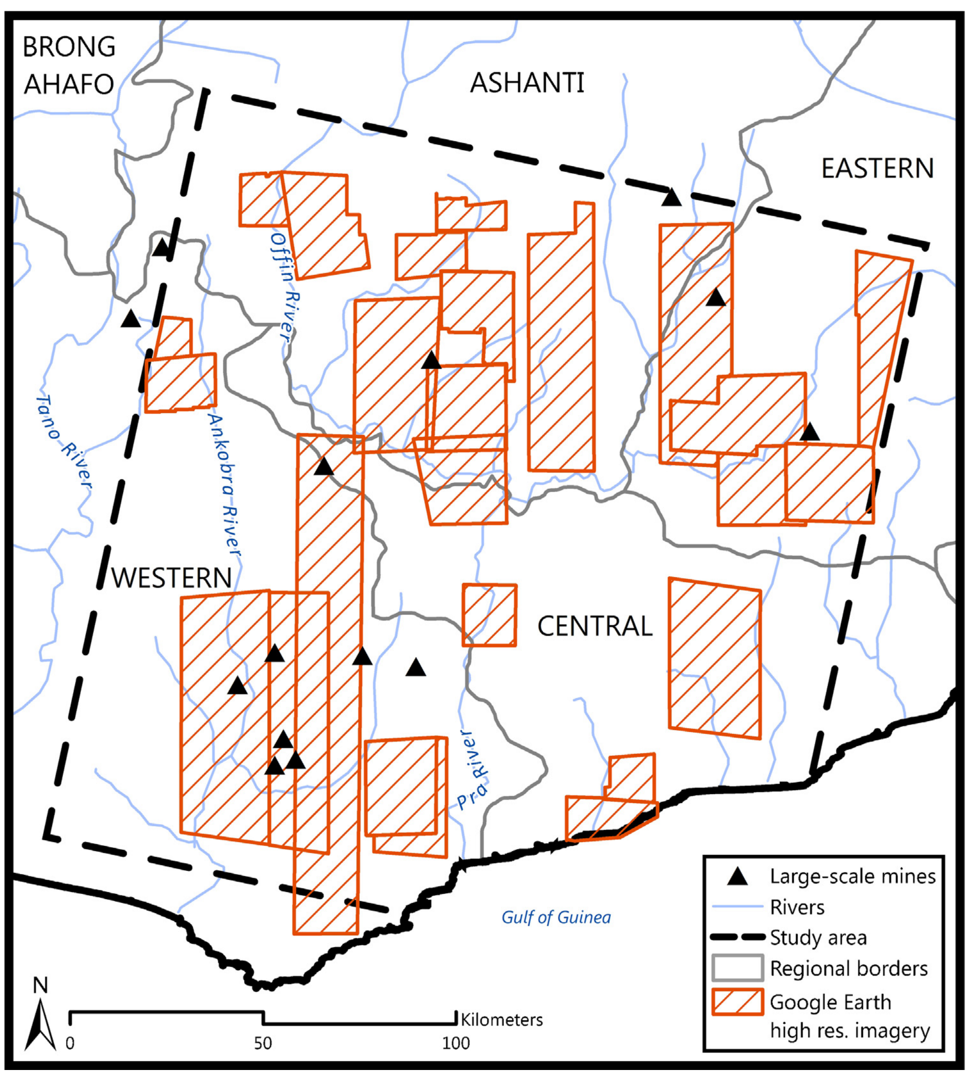

Fig. 2. Locations of high spatial resolution imagery from GeoEye-1, WorldView-1, and WorldView-2 used to perform map accuracy assessment on the small-scale mining maps (Landsat-7 and -8 images).

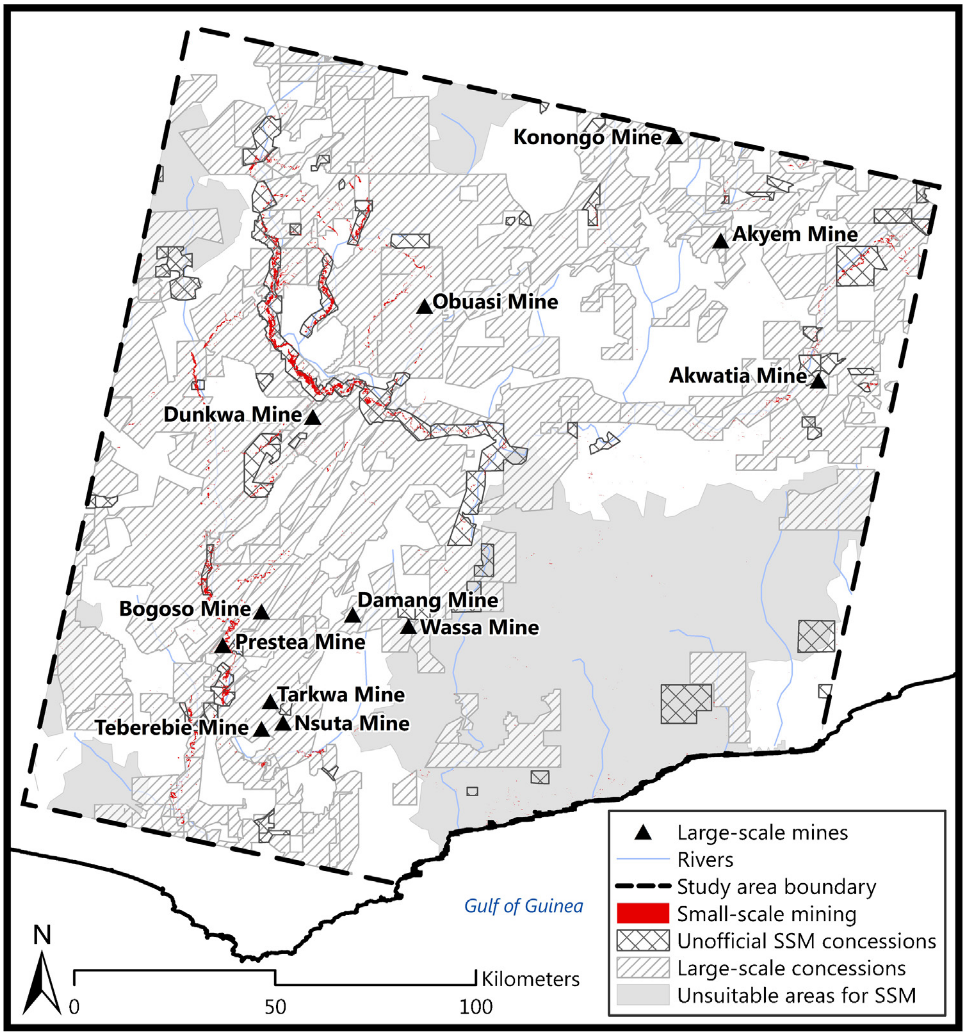

Fig. 3. Map of small-scale mining (SSM) activity derived from the classification of the Landsat-7 and -8 2013 and 2015 imagery in the context of large-scale concessions, large-scale mines, unofficial small-scale mining concessions, and unsuitable small-scale mining areas.

concessions, and the areas deemed unsuitable for SSM are presented in Fig. 3. The final map has an overall accuracy of 87%, and the SSM category has a commission error of 14% and an omission error of 9% (Table 3). Classification confusion in the SSM category occurred most frequently with the urban and light vegetation categories. Important early splits in the classification trees for each of the CTA models indicate that distance to rivers, elevation, and reflectance in the near infrared and shortwave-infrared bands are influential variables in identifying SSM locations correctly.

Area calculations of the SSM land use and the large-scale mining concessions, represented as the sum of pixels and as vector polygons, respectively, are shown for the total study area as well as three sub-regions of interest in Table 4. The analysis classified 183 km^2 of SSM activity, comprising approximately 0.5% of the study area. This mining activity predominately falls along the Offin River in the northwest, the Ankobra River in the southwest, and the Birim River in the northeast of the study area, with the highest density of identified mining occurring in the northwest. These three areas are also where much of the large-scale mining activity

Table 3
Accuracy matrix of the final small-scale mining (SSM) map using a sample of 50 pixels per category and visually comparing the classified land-cover to the corresponding locations on high resolution GeoEye-1, WorldView-1, and WorldView-2 imagery.

	Reference imagery							
SSM map	Agriculture	Built	Forest	Light veg	SSM	Water	Total	Commission error
Agriculture	45	0	1	4	0	0	50	0.1
Built	4	41	0	2	3	0	50	0.18
Forest	0	0	47	3	0	0	50	0.06
Light veg	4	1	2	42	1	0	50	0.16
SSM	1	1	0	4	43	1	50	0.14
Water	0	0	0	0	0	50	50	0.0
TOTAL	54	43	50	55	47	51	268	
Omission error	0.17	0.05	0.06	0.24	0.09	0.02		

Table 4
Area calculations and percentages for the extent of classified small-scale mining (SSM), the extent of large-scale mining (LSM) concessions, the extent of unofficial small-scale mining concessions, the extent of small-scale mining occurring on large-scale concessions, and the extent of small-scale mining occurring on unofficial small-scale mining concessions for the entire study area, the northwest, southwest, and northeast quadrants.

	Total study area		Northwest quadrant		Southwest quadrant		Northeast quadrant	
	Conflicts 37 (km^2)	Agreements 11 % study area	Conflicts 21 (km^2)	Agreements 2 % total in study area	Conflicts 13 (km^2)	Agreements 6 % total in study area	Conflicts 3 (km^2)	Agreements 3 % total in study area
Total area SSM	183	0.5%	111	60.5%	52	28.2%	18	9.7%
Total area all LSM con.	16322	43.7%	5624	34.5%	5243	32.1%	4530	27.8%
Total area mining con.	2673	7.2%	842	31.5%	1058	39.6%	700	26.2%
Total area prospecting con.	10432	27.9%	4034	38.7%	3519	33.7%	2604	25.0%
Total area recon con.	3216	8.6%	749	23.3%	667	20.7%	1226	38.1%
Total area SSM con.	1731	4.6%	750	43.3%	313	18.1%	399	23.0%
Total SSM on all LSM con.	96	0.3%	47	49.5%	38	39.9%	10	10.5%
Total SSM on mining con.	33	0.01%	16	49.1%	12	37.0%	5	13.9%
Total SSM on prospecting con.	61	0.2%	30	49.9%	25	41.5%	5	8.6%
Total SSM on recon con.	2	$<0.01\%$	1	44.7%	1	36.0%	<1	12.8%
Total SSM on all SSM con.	92	0.3%	72	78.5%	14	14.9%	6	6.6%

is located, with the Obuasi Mine and Dunkwa Mine, both located in the northwest, the Tarkwa large-scale mining region in the southwest, and the Akyem and Akwatia mines in the northeast.

Of the classified SSM, 96 km^2 (52% of class) falls within existing large-scale mining concessions, more commonly in prospecting concessions (33% of class) than in mining concessions (18% of class) or reconnaissance concessions (1% of class). About 92 km^2 (50% of class) of the classified SSM is within unofficial SSM concessions. In some instances, SSM activity falls within both a large-scale mining concession and an unofficial SSM concession due to overlaps in the datasets that occur on 365 km^2 within the study area. Additionally, approximately 17% of the total area designated as unofficial SSM concessions, totaling 294 km^2, falls on land deemed unsuitable for SSM activity. These unsuitable areas are predominately in the southeastern portion of the study area and coincide with few large-scale mining concessions, no active large-scale mines, and no identified SSM.

5.2. Locations of SSM

The landscape can be divided into three main regions of mining activity and overlap between large-scale mining concessions and classified SSM: the northwest area (Fig. 4), the southwest area (Fig. 5), and the northeast area (Fig. 6). Patterns in each area are presented below with more detail concerning the specific mining history and the overlaps between large-scale mining and SSM in the quadrant. To enable this sub-regional focus, the study area was divided into four 9330 km^2 quadrants and Table 4 shows the area and percentage calculations for the classified SSM activity, unofficial SSM concessions, large-scale mine concessions, and intersections between these land uses for each of the three quadrants in which mining activity occurs, omitting the south-eastern quadrant of the scene.

5.2.1. Northwest quadrant

In the northwest quadrant (Fig. 4), there are two large-scale mines, the Obuasi Mine and the Dunkwa Mine, and just outside of the study area are the Bibiani Mine and Chirano Mine in close proximity (Fig. 1). This region has been an active large-scale mining area since the early 1900s (Hilson, 2002c), and as a result, the small-scale miners in the area tend to be generational, relying on the sector as their primary form of income (Aubynn, 2009; Okoh, 2014). This area holds the largest concentration of classified SSM activity, with 111 km^2, or approximately 60% of the total classified SSM found in the study area. Much of this SSM activity occurs along the Offin River, to the south and west of Obuasi and north of the Dunkwa Mine. Approximately 50% of the total observed extent of overlaps between the identified SSM and large-scale mining concessions occur in this quadrant, with 47 km^2 of classified SSM directly intersecting large-scale mining concessions. Most of the overlaps are located to the west of the Obuasi Mine and south of Awaso (Fig. 4). Additionally, some classified SSM activity along the Offin River occurs within regions of overlap between unofficial SSM concessions and existing large-scale mining concessions. Classified SSM within this quadrant exhibits the closest correspondence to the unofficial SSM concessions, with about 72 km^2 of the classified SSM (65% of quadrant total) occurring on unofficial SSM concessions.

The northwest quadrant has seen the most recorded conflicts out of all three areas discussed, with 21 recorded incidents of extraction-related tension and conflict between 1994 and 2014 (Table 1). From the mid-1990s to early 2010s, at least 10 small-scale miners were killed by police, mine security, or military personnel on separate occasions, and there were four recorded instances of guard dogs being let loose on small-scale miners (Raleigh et al., 2010; WACAM, 2014). In 2000, illegal SSM operators set a poultry farm on fire in Obuasi and stole livestock that belonged to AngloGold Ashanti, the large-scale company operating the mine at the time (Hilson, 2001; Hilson, 2002a). In 1996, one of the larger clashes between the sectors occurred in the region and resulted in an estimated one million U.S. dollars in damages (Hilson, 2001; Aubynn, 2009). The region's recorded agreements include one in which a group of 10,000 miners was deemed legally able to engage in SSM on a section of the Obuasi concession (Hilson and Garforth, 2013), and another in which the government seized the Dunkwa Continental Goldfields concessions and gave out SSM licenses in the area in the mid-2000s (Banchirigah, 2008).

5.2.2. Southwest quadrant

The southwest quadrant contains seven large-scale operations, more than the combined total in the other areas of interest, and 32% of the total extent of large-scale concessions found within the study area. The region has the second highest extent of classified SSM (52 km^2) making up 28% of the total SSM activity identified in the entire study area. Most of the SSM activity is located along the Ankobra River and spans from north of the Bogoso Mine, to directly east of the Prestea Mine, and continues south to west of the Tarkwa Mine and Teberebie Mine along with a limited amount of SSM activity found southeast of the Nsuta Mine (Fig. 5). This region has

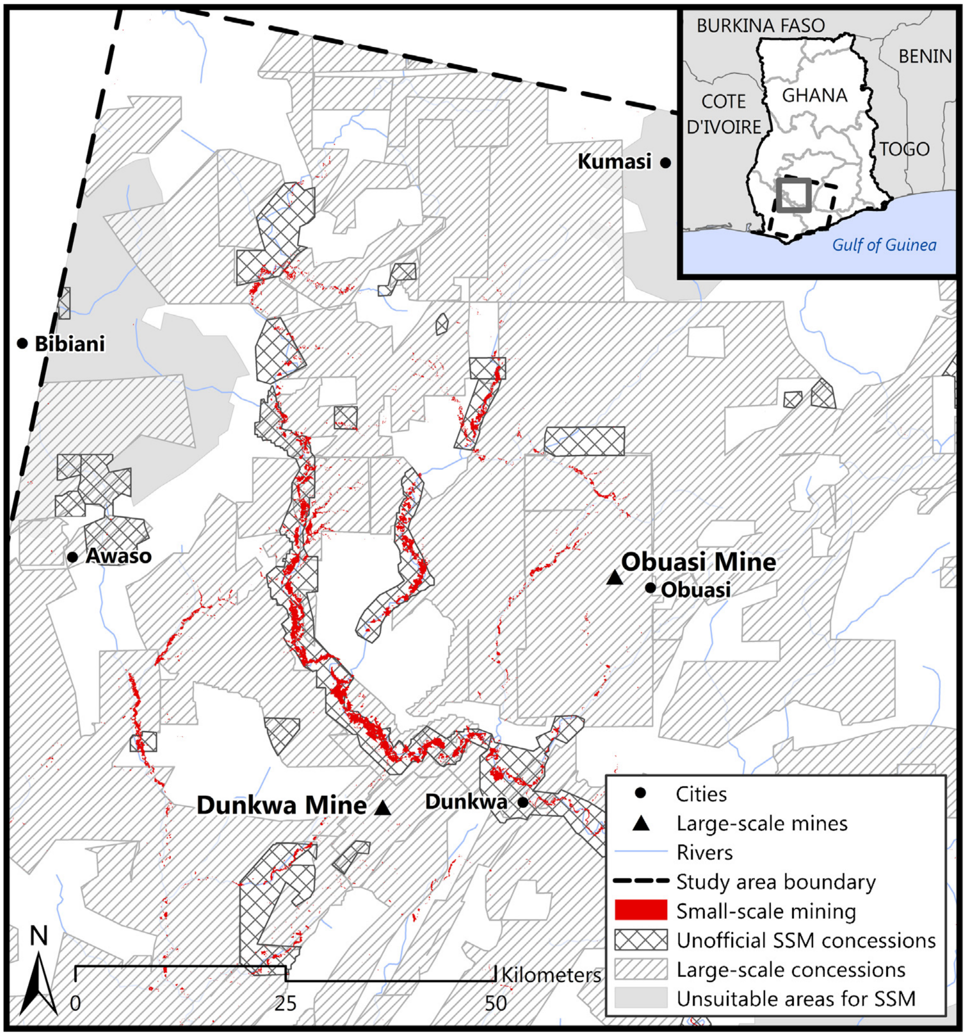

Fig. 4. Northwest region of the study area shown with the small-scale mining (SSM) derived from the 2013 and 2015 Landsat-7 and -8 imagery in the context of the surrounding cities, large-scale mines, large-scale mining concessions, unofficial small-scale mining concessions, and unsuitable small-scale mining areas.

the lowest concentration of unofficial SSM concessions, representing 18% of the total extent of such concessions in the study area, most of which occur to the west of the Tarkwa Mine and Teberebie Mine and northwest of the Bogoso Mine. This quadrant contains approximately 40% of the total overlaps between large-scale mining concessions and classified SSM, which mainly occur north of Bogoso city, between the Bogoso Mine and Prestea, and south of the Teberebie Mine (Fig. 5). About 27% of the SSM found within the quadrant occurs on unofficial SSM concessions, generally in the area northwest of the Bogoso Mine, which also overlaps with an existing large-scale concession, as well as on the unofficial SSM concessions located to the west of the Tarkwa Mine and Teberebie Mine.

Similar to the northwest quadrant, this area has been actively mined since the 1900s, and the small-scale miners here tend to rely on the sector for their primary form of income (Hilson and Banchirigah, 2009). Additionally, the area has experienced intense conflict between large-scale mining and SSM (Table 1), with 13 conflicts recorded, due to histories of maltreatment and poor relations between the sectors (Hilson 2002a; Hilson and Yakovleva, 2007; Aubynn, 2009). As indicated earlier, at the Damang Mine, as recently as 2011, SSM operators invaded the concession and were forcibly removed (Teschner, 2013). Despite a long history of conflict and tension, the area has had more recorded *positive* interactions between the sectors than the other two quadrants discussed here. Revisiting points raised earlier, at Damang, there are reports of Gold Fields Ghana Ltd. adopting a relaxed attitude towards the miners, allowing the activity as long as it does not interfere with the large-scale activities (Aubynn, 2009). Additionally, the closure of the underground mine in Tarkwa in 2000 left many small-scale miners without work, and in response, Gold Fields Ghana Ltd. established a SSM cooperative, the Small-Scale Mining Society, permitting its members to work the previously-suspended ground operation (Hilson, 2001). Lastly, in Prestea, Bogoso Gold Ltd. allowed for the reallocation of approximately 5% of its concession to SSM operators (Hilson, 2002b).

5.2.3. Northeast quadrant

The northeast quadrant has a shorter history of mining than the other two areas discussed (Hilson and Banchirigah, 2009). As a result, the miners here tend to be mostly farmers who engage seasonally in SSM to supplement their farming income (Hilson and Banchirigah, 2009; Hilson and Garforth, 2012). There is the lowest concentration of classified SSM activity identified in this area out of

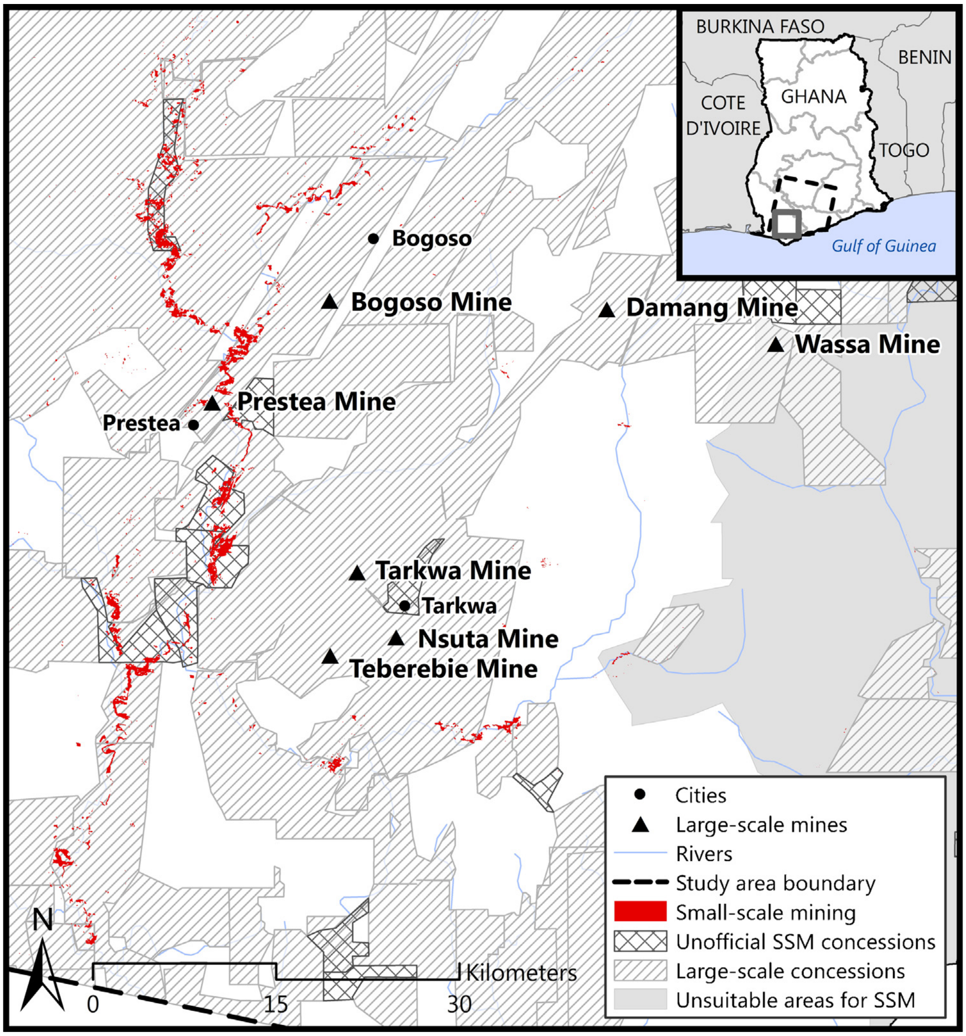

Fig. 5. Southwest region of the study area shown with the small-scale mining (SSM) derived from the 2013 and 2015 Landsat-7 and -8 imagery in the context of the surrounding cities, large-scale mines, large-scale mining concessions, unofficial small-scale mining concessions, and unsuitable small-scale mining areas.

the three discussed (18 km^2), making up 10% of the total SSM found throughout the study area. The majority of this SSM occurs along the Birim River and runs from the northeast corner of the quadrant, to west of the Akwatia Mine, and down to north of Akim Oda, with some additional activity in the northern portion of the quadrant, near the village of Noyem (Fig. 6). The quadrant has the largest concentration of reconnaissance concessions, again, the first stage in the mining process, representing approximately 38% of all reconnaissance concession land throughout the entire study area. In addition, approximately 23% of the total unofficial SSM concessions (399 km^2) are located in this quadrant, and most of these areas fall near the eastern and northern borders of the region along the Birim River, near Noyem, and in the northwest near the Konongo Mine. Between the three regions discussed, the northeast quadrant has the least amount of spatial overlap between large-scale mine concessions and classified SSM, with 10 km^2 of the latter occurring on the former's concessions, approximately 10% of all identified interactions. Of these, the majority occur along the Birim River in the northeastern corner of the quadrant and between the towns of Kade and Akim Oda. About 33%, or 6 km^2, of the identified SSM happening within the quadrant occurs on unofficial SSM concessions, making up almost 7% of the total classified mining occurring on unofficial SSM concessions throughout the entire study area.

This northeast quadrant has the fewest recorded conflicts between large-scale mining and SSM of the three areas examined. At the end of 2006, there were known to be about 30,000 small-scale miners operating within the Newmont Mining Corporation concession near Noyem (Banchirigah, 2008). Reports show the company tended to ignore this mining (Hilson and Garforth, 2013), but at the same time, held on to land deemed uneconomical to exploit using large-scale methods yet potentially suitable for SSM (Banchirigah, 2008). At the Akwatia Mine, a riot broke out in the early 1990s after a police officer investigating SSM activity fired into an angry crowd and killed a resident (Salehyan et al., 2012). Despite this tension, the Akwatia Mine, formerly owned and operated by Ghana Consolidated Diamonds, was, as noted, one of the first large-scale mines to forge a working relationship with the SSM operators in the area, selling licenses which allowed them to work on their concession legally (Hilson, 2002b; Yelpaala and Ali, 2005). Additionally, in Konongo, the Minerals Commission has worked with large-scale companies to identify unsuitable areas for

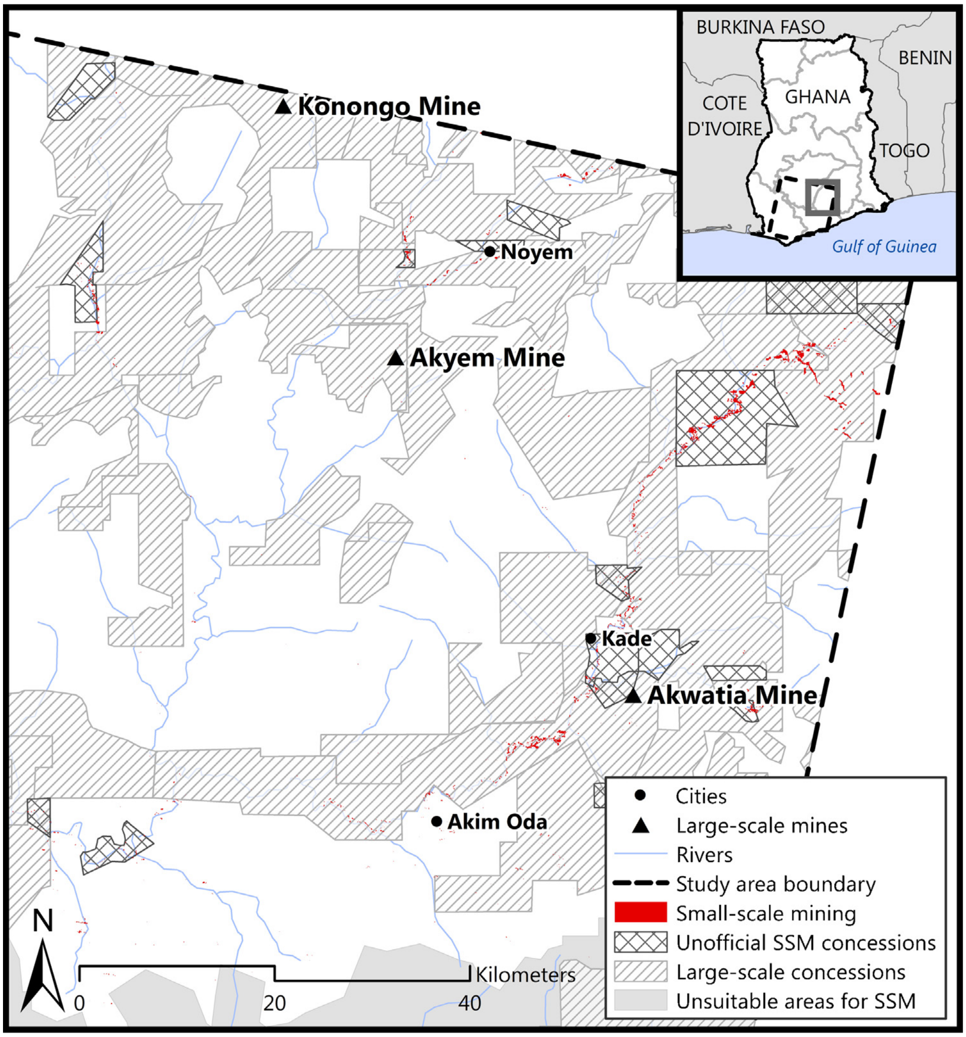

Fig. 6. Northeast region of the study area shown with the small-scale mining (SSM) derived from the 2013 and 2015 Landsat-7 and -8 imagery in the context of the surrounding cities, large-scale mines, large-scale mining concessions, unofficial small-scale mining concessions, and unsuitable small-scale mining areas.

large-scale mining and reallocate them for SSM (Banchirigah, 2008).

6. Discussion and conclusion

Because both SSM and large-scale mining require mineral deposits and water for exploitation, they tend to occur in the same general locations and frequently overlap throughout the study area (Figs. 3–6). The literature supports the general regional patterns seen in the maps, with high amounts of activity for both sectors in the northwest and southwest quadrants and less mining in the northeast (Hilson, 2001; Banchirigah, 2008; Hilson and Banchirigah, 2009; Nyame and Grant, 2014; Okoh, 2014). Mining began in Obuasi in the 17th century and has continued since throughout the northwest area (Okoh, 2014), and the southwest quadrant contains about half the country's large-scale gold mines (Hilson, 2004), making these two areas widely considered the most heavily-mined areas in the country (Akabzaa and Darimani, 2001; Amponsah-Tawiah and Dartey-Baah, 2011). Large-scale mining has been seen to follow and supplant SSM in some areas where SSM demonstrates a potential for high productivity (Aubynn, 2009; Gamu et al., 2015), a transition which likely occurred in the northeast region. Large-scale mining is newer to the northeast region (Hilson and Banchirigah, 2009; Hilson and Garforth, 2012), as evidenced by the larger concentration of reconnaissance concessions and fewer large-scale operations, which has meant less overlap extent between the sectors. However, the SSM activity in the northeast region is more established, engaging about 30,000 individuals in Noyem (Banchirigah, 2008) and around the Akwatia Mine (Yelpaala and Ali, 2005).

Spatial overlaps between different land uses fuel resource competition that frequently morphs into conflict over land use rights and access (Bebbington et al., 2014a; Bebbington et al., 2014b; Cuba et al., 2014). Not only does this research confirm that areas with more spatial overlap between large-scale mining and SSM experience more conflicts, but it also reveals how this relationship between overlaps and conflicts emerges throughout the study area by displaying and quantifying the intersections occurring in each quadrant. The maps reveal that the northwest and southwest quadrants have more instances of recorded conflict and spatial overlap than the northeast region where overlaps and conflict between the sectors are less abundant, giving stakeholders a more detailed understanding of where the competition for access to land that leads to extraction-related conflict occurs. The maps also show the broad spatial extent of large-scale concessions throughout the study area as a result of the Government of Ghana's policy of liberally granting concession rights to large-scale companies (Hilson and Potter, 2005). By displaying these in the context of the identified SSM, unofficial SSM concessions and suitable areas for SSM, the results provide deeper understanding of how this widespread allotment of land to large-scale mining concessions has left little space available for other land uses, specifically SSM.

The unofficial SSM concessions dataset offers an opportunity to examine a potential policy solution to Ghana's extraction-related conflict within the context of the spatial overlaps and relationships revealed by the analysis. The dataset comes from the Government of Ghana and delineates areas that could become sanctioned SSM concessions in the future. These unofficial SSM concessions capture about 50% of the classified SSM activity in the entire study area, but within the specific quadrants examined, the overall effectiveness of the unofficial SSM concessions varies. In the northwest quadrant, over half of the identified SSM activity in the area is captured by the unofficial SSM concessions (65%), showing potential for fairly successful incorporation of the existing SSM activity into policy and planning processes. At the same time, in the southwest and northeast quadrants, the unofficial SSM concessions only capture a little over a quarter and a third, respectively, of the classified SSM within each area, evincing less consideration of the current conditions into the policy solution. The maps allow for potential strategies to be developed and examined simultaneously at varying scales, throughout the entire study area and within specific regions, producing a more nuanced understanding of the effectiveness of the approach.

In addition to illustrating the potential effectiveness of these unofficial SSM concessions at incorporating existing SSM, the maps presented also provide information on the locations of these areas in terms of overlaps between unofficial SSM concessions, areas deemed unsuitable for SSM, and existing large-scale mine concessions. Assessing the potential for a productive mineral yield in sanctioned SSM concessions is an important issue which, in the past, has failed to be undertaken prior to awarding miners sanctioned areas (Hilson and Potter, 2003). Currently, 17% of the existing unofficial SSM locations fall outside suitable SSM areas, generally within the southeast quadrant of the study area where there is little large-scale activity and no classified SSM. In addition, the literature reports instances of SSM operators being sent by the government to mine in areas that overlap large-scale concessions, and subsequently being told to leave by the mining company (Hilson and Potter, 2005; Teschner, 2013); currently, 21% of the unofficial SSM concessions overlap existing large-scale plots. The maps provide initial clues on a potential direction for policy solutions to extraction-related conflict, such as demarcating areas for SSM. The maps also reveal important information about the ways in which possible solutions interact with existing conditions, such as established mining activity and potential mineral yield.

Examining the spatial overlaps between SSM and large-scale mining within the context of their existing tensions and histories of conflict clarifies the conditions under which extraction-related conflict in Ghana occurs, and puts stakeholders in a better position to craft policies that are integrated more effectively with existing spatial relationships. The results support the notion that extraction-related conflict tends to happen more frequently in areas with long histories of mining and frequent overlaps between the sectors. The maps presented illustrate and quantify the spatial relationships that lead to extraction-related conflict and show how the overlaps that result in this type of conflict are experienced differently throughout the study area, providing stakeholders with a more nuanced understanding of the conditions under which extraction-related conflict occurs. In addition, the analysis was conducted with little to no financial expense and could be reproduced at a similarly low cost in relatively short, two-to-three month, time frame. The data used in the analysis were all freely acquired from governmental agencies and other researchers, making the main expense compensation for the data analyst and the use of proprietary software. The work provides a fast, low-cost method that yields visual display of the overlaps between the large-scale mining and SSM, the results of which allow policy makers to better evaluate the way in which potential solutions will affect specific areas.

The results give an initial understanding of the ways in which specific policies will affect certain areas, and where possible the maps should be contextualized with extensive knowledge and experiences from the field to avoid over-simplifying the patterns and relationships found in the results. This research used records of past conflict events, many of which come from previous field work studies, to better understand and contextualize the land use overlaps between large-scale mining and SSM, but only a small percentage of actual conflicts are recorded with varying degrees of success across different regions. In addition, the analysis largely focuses on alluvial SSM, but as mining technologies continue to develop, more SSM will likely take place further underground. Future work would incorporate this type of SSM and look to define areas in which it is occurring and examine how it interacts with large-scale mining. Lastly, the work would be aided by finer-scale imagery to identify SSM areas more accurately and increase the detail of the patterns found in the results, which would enhance the contributions of the research.

Acknowledgments

The authors acknowledge and thank Professor Gavin Hilson for his support and guidance throughout the research process. In addition, special thanks to McKenzie Johnson and Kwame Boamah for their willingness to share important datasets and information, and to Kojo Asante for his guidance and advice in the beginning of the research process. This project is an output from the authors' earlier research on this topic, and are thus indebted to the research team at Oxfam America for their collaboration and support. Finally, thank you to two anonymous reviewers who offered extremely insightful and helpful comments on an earlier draft of this paper.

References

Addy, S.N., 1998. Ghana: revival of the mineral sector. Resour. Policy 24, 229–239.
Akabzaa, T., Darimani, A., 2001. Impact of mining sector investment in Ghana: a study of the Tarkwa mining region. Draft report prepared for SAPRI.
Amankwah, R.K., Anim-Sackey, C., 2003. Strategies for sustainable development of the small-scale gold and diamond mining industry of Ghana. Resour. Policy 29, 131–138.
Amponsah-Tawiah, K., Dartey-Baah, K., 2011. The mining industry in Ghana: a blessing or a curse. Int. J. Bus. Soc. Sci. 2, 62–69.
Appiah, H., 1998. Organization of small scale mining activities in Ghana. J. South Afr. Inst. Min. Metall. 98, 307–310.
Arku, J. (2013, October 4) Galamseyers attack AngloGold Ashanti security. Graphic Online. http://www.graphic.com.gh/news/general-news/551-galamseyers-attack-anglogold-ashanti-security.html (last accessed 12.12.14).
Aryee, B.N., 2001. Ghana's mining sector: its contribution to the national economy. Resour. Policy 27, 61–75.
Aryee, B.N., Ntibery, B.K., Atorkui, E., 2003. Trends in the small-scale mining of precious minerals in Ghana: a perspective on its environmental impact. J. Clean. Prod. 11, 131–140.
Asner, G.P., Llactayo, W., Tupayachi, R., Luna, E.R., 2013. Elevated rates of gold mining in the Amazon revealed through high-resolution monitoring. Proc. Nat. Acad. Sci. 110, 18454–18459.
Aubynn, A., 2009. Sustainable solution or a marriage of inconvenience? The coexistence of large-scale mining and artisanal and small-scale mining on the Abosso Goldfields concession in Western Ghana. Resour. Policy 34, 64–70.
Ayelazuno, J.A., 2014. The 'new extractivism' in Ghana: a critical review of its development prospects. Extr. Ind. Soc. 1, 292–302.
Ayivor, J., Gordon, C., 2013. Impact of land use on river systems in Ghana. West Afr. J. Appl. Ecol. 20, 83–95.
Babut, M., Sekyi, R., Rambaud, A., Potin-Gautier, M., Tellier, S., Bannerman, W., Beinhoff, C., 2003. Improving the environmental management of small-scale gold mining in Ghana: a case study of Dumasi. J. Clean. Prod. 11, 215–221.

Banchirigah, S.M., 2008. Challenges with eradicating illegal mining in Ghana: a perspective from the grassroots. Resour. Policy 33, 29–38.
Bebbington, A., 2012. Underground political ecologies: the second annual lecture of the Cultural and Political Ecology Specialty Group of the Association of American Geographers. Geoforum 43, 1152–1162.
Bebbington, A., Rogan, J., Cuba, N., Slack, K., 2014a. Geographies of Conflict: Mapping Overlaps between Extractive Industries and Agricultural Land Uses in Ghana and Peru. Oxfam America.
Bebbington, A.J., Cuba, N., Rogan, J., 2014b. Visualizing competing claims on resources: approaches from extractive industries research. Appl. Geogr. 52, 55–56.
Behrens, A., Giljum, S., Kovanda, J., Niza, S., 2007. The material basis of the global economy: worldwide patterns of natural resource extraction and their implications for sustainable resource use policies. Ecol. Econ. 64, 444–453.
Britwum, A., Johan K., Tay F.D., (2001). Washington DC: Ghana Country Report. Structural Adjustment Participatory Review Initiative (SAPRI).
Bruckner, M., Giljum, S., Lutz, C., Wiebe, K.S., 2012. Materials embodied in international trade-global material extraction and consumption between 1995 and 2005. Global Environ. Change 22, 568–576.
Bulte, E.H., Damania, R., Deacon, R.T., 2005. Resource intensity, institutions, and development. World Dev. 33, 1029–1044.
Bush, R., 2009. 'Soon there will be no-one left to take the corpses to the morgue': accumulation and abjection in Ghana's mining communities. Resour. Policy 34, 57–63.
Cuba, N., Bebbington, A., Rogan, J., Millones, M., 2014. Extractive industries, livelihoods and natural resource competition: Mapping overlapping claims in Peru and Ghana. Appl. Geogr. 54, 250–261.
Dittrich, M., Giljum S., Lutter S., Polzin C., 2012. Green economies around the world?: Implications of resource use for development and the environment. Vienna.
Elmes, A., Ipanaque, J.G.Y., Rogan, J., Cuba, N., Bebbington, A., 2014. Mapping licit and illicit mining activity in the Madre de Dios region of Peru. Remote Sens. Lett. 5, 882–891.
Gamu, J., Le Billon, P., Spiegel, S., 2015. Extractive industries and poverty: a review of recent findings and linkage mechanisms. Extr. Ind. Soc. 2, 162–176.
Garvin, T., McGee, T.K., Smoyer-Tomic, K.E., Aubynn, E.A., 2009. Community–company relations in gold mining in Ghana. J. Environ. Manage. 90, 571–586.
Geological Survey Department, 2013. Geological Map of Ghana. Hannover, Federal Republic of Germany: Bundesanstalt fur Geowissenschaften und Rohstoffe.
Ghana Minerals Commission, 2014.
Hansen, M., Dubayah, R., DeFries, R., 1996. Classification trees: an alternative to traditional land cover classifiers. Int. J. Remote Sens. 17, 1075–1081.
Hijmans, R.J., Guarino, L., Mathur, P., 2012. DIVA-GIS.
Hilson, G., 2001. A contextual review of the Ghanaian small-scale mining industry. Min. Miner. Sustain. Dev. 76.
Hilson, G., 2002a. An overview of land use conflicts in mining communities. Land Use Policy 19, 65–73.
Hilson, G., 2002b. Land use competition between small-and large-scale miners: a case study of Ghana. Land Use Policy 19, 149–156.
Hilson, G., 2002c. Harvesting mineral riches: 1000 years of gold mining in Ghana. Resour. Policy 28, 13–26.
Hilson, G., 2002d. Small-scale mining and its socio-economic impact in developing countries. Nat. Resour. Forum 26, 3–13.
Hilson, G.M., 2004. Structural adjustment in Ghana: assessing the impacts of mining-sector reform. Afr. Today 51, 53–77.
Hilson, G., Banchirigah, S.M., 2009. Are alternative livelihood projects alleviating poverty in mining communities? Experiences from Ghana. J. Dev. Stud. 45, 172–196.
Hilson, G., Garforth, C., 2012. 'Agricultural Poverty'and the expansion of Artisanal mining in Sub-Saharan Africa: experiences from Southwest Mali and Southeast Ghana. Popul. Res. Policy Rev. 31, 435–464.
Hilson, G., Garforth, C., 2013. 'Everyone now is concentrating on the mining': drivers and implications of rural economic transition in the eastern region of Ghana. J. Dev. Stud. 49, 348–364.
Hilson, G., McQuilken, J., 2014. Four decades of support for artisanal and small-scale mining in sub-Saharan Africa: a critical review. Extr. Ind. Soc. 1, 104–118.
Hilson, G., Potter, C., 2003. Why is illegal gold mining activity so ubiquitous in rural Ghana? Afr. Dev. Rev. 15, 237–270.
Hilson, G., Potter, C., 2005. Structural adjustment and subsistence industry: artisanal gold mining in Ghana. Dev. Change 36, 103–131.
Hilson, G., Yakovleva, N., 2007. Strained relations: a critical analysis of the mining conflict in Prestea, Ghana. Political Geogr. 26, 98–119.
Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K.-H., Haberl, H., Fischer-Kowalski, M., 2009. Growth in global materials use, GDP and population during the 20th century. Ecol. Econ. 68, 2696–2705.
Nyame, F.K., Blocher, J., 2010. Influence of land tenure practices on artisanal mining activity in Ghana. Resour. Policy 35, 47–53.
Nyame, F.K., Grant, J.A., 2014. The political economy of transitory mining in Ghana: understanding the trajectories, triumphs, and tribulations of artisanal and small-scale operators. Extr. Ind. Soc. 1, 75–85.
Okoh, G.A., 2014. Grievance and conflict in Ghana's gold mining industry: the case of Obuasi. Futures 62, 51–57.
Owusu-Akyaw, R. (2014, September 2) Anti-Galamsey Task Force Impounds 15 Excavators . . . As Aga Seeks Regsec's Protection. *The Chronicle*. http://thechronicle.com.gh/anti-galamsey-task-force-impounds-15-excavators-as-aga-seeks-regsecs-protection/ (last accessed 09.09.14).
Pegg, S., 2006. Mining and poverty reduction: transforming rhetoric into reality. J. Clean. Prod. 14, 376–387.
Raleigh, C., Linke, A., Hegre, H., Karlsen, J., 2010. Introducing ACLED-armed conflict location and event data. J. Peace Res. 47, 651–660.
Salehyan, I., Hendrix, C.S., Hamner, J., Case, C., Linebarger, C., Stull, E., Williams, J., 2012. Social conflict in Africa: a new database. Int. Interact. 38, 503–511.
Teschner, B.A., 2012. Small-scale mining in Ghana: the government and the galamsey. Resour. Policy 37, 308–314.
Teschner, B., 2013. How you start matters: a comparison of Gold Fields' Tarkwa and Damang Mines and their divergent relationships with local small-scale miners in Ghana. Resour. Policy 38, 332–340.
Tsikata, F.S., 1997. The vicissitudes of mineral policy in Ghana. Resour. Policy 23, 9–14.
WACAM, 2014. Wassa association of communities affected by mining.
Wan, P.M.J., 2014. Environmental justices and injustices of large-scale gold mining in Ghana: a study of three communities near Obuasi. Extr. Ind. Soc. 1, 38–47.
Weber-Fahr, M., Strongman, J., Kunanayagam, R., McMahon, G., Sheldon, C., 2001. Mining and Poverty Reduction. The World Bank, Washington, DC.
Wright, G., Czelusta, J., 2007. Natural resources: neither curse nor destiny. In: Lederman, Daniel, William Maloney (Eds.), Resource-Based Growth Past and Present. Stanford University Press, Stanford, CA.
Yelpaala, K., Ali, S.H., 2005. Multiple scales of diamond mining in Akwatia, Ghana: addressing environmental and human development impact. Resour. Policy 30, 145–155.