Spatial Analysis of Artisanal and Small-Scale Mining in the Tarkwa-Nsuaem Municipality of Ghana*

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Abstract

In recent times there have been lots of public outcry on the environmental and public health and safety effects of Artisanal and Small-scale gold Mining (ASM) and the need to monitor ASM activities for reclamation purposes. To effectively develop and deploy policy responses to the environmental and human health effects of ASM, knowledge of the locations and distribution of ASM sites is a prerequisite. However, information regarding ASM hotspots and spatial distribution, the scope and types of ASM operations are hard to find. Therefore, this research was designed to use satellite-based data to map out ASM sites, focusing on the Tarkwa-Nsuaem municipality as the study area. Several image processing techniques were applied on a Landsat 8 satellite image downloaded from the US Geological Survey website. The image processing resulted in the identification of 221 clusters of ASM sites, representing 12.72% of the total size of the study area. To further explore the effects of these ASM sites, Areas of Interest (AOI) including forest reserve, rivers, large-scale mines and urban settlements were defined. By selecting and analysing the location and distribution of the ASM sites in relations to the AOI, the study was effective in identifying environmentally sensitive and critical areas warranting the urgent attention of society to mitigate the health, safety and ecosystem service effects of ASM in the study area. By identifying the environmental sensitive areas being affected by ASM, the findings could support the prioritisation of reclamation efforts.

Keywords: Artisanal Small-Scale Mining, Satellite Image, Environmental Effect, Public Health and Safety

1 Introduction

Artisanal and Small-scale Mining (ASM), which has been practiced in Ghana for close to a century (Aryee *et al.*, 2003; Hilson, 2003; Owusu-Nimo *et al.*, 2018) has been defined by scholars as an occupation involving the use of traditional and rudimentary tools such as pickaxe, hammer, shovel and chisel to dig for gold (Thomas *et al.*, 2002; Hilson, 2009; Bansah *et al.*, 2016b). ASM operations have however evolved over the years from a rudimentary operation to a more sophisticated approach involving the use of heavy mining equipment such as bulldozer, excavators, crushers, processing plants, dredging machine and trucks (Bansah *et al.*, 2016b; Bansah *et al.*, 2018). Over the years, ASM has been identified as a major contributor to the Ghanaian economy and particularly the economy of the local areas where they are practiced. For instance, according to Bansah *et al.* (2018), the Minerals Commission of Ghana estimates that the artisanal small-scale gold mining operations in Ghana employs over a million people excluding those who are engaged in illegal ASM. Again, several scholars recognise ASM in Ghana as a major source of livelihood support to the inhabitants of the communities where they are practiced, by way of direct employments and the indirect jobs (such as direct supplies and suppliers of suppliers) that are created (Hilson, 2003; Hilson, 2009; Bansah *et al.*, 2016b; Amoah and Stemn, 2018; Bansah *et al.*, 2018). It has been reported that the ASM sector's contribution to gold production in Ghana increased from 2.2% in 1989 to 35.4% in 2014 (McQuilken and Hilson, 2016), suggesting an astronomical increase in ASM activities in the country. This rise in ASM activities has been attributed to its poverty-driven nature, serving as a source of livelihood to several rural folks. Globally, ASM has been recognised as a key contributor to world mineral production, contributing 80%, 20% and 20% of the world's sapphire, gold and diamond respectively (Hentschel, 2003; Siegel and Veiga, 2009; Amoah and Stemn, 2018). Thus, ASM continues to be a key aspect of mining in Ghana and an essential part of the country's economic growth (Akabzaa, 2009; Amoah and Stemn, 2018).

However, despite these contributions of artisanal and small-scale gold mining to Ghana's economic growth, the sector has come under intense public criticisms and was until recently completely banned (Hilson, 2017; Bansah, 2019; Zolnikov, 2020). These public criticisms come as a result of the visible effects of ASM on various key environmental receptors including surface water bodies, ecologically protected areas such as forest reserve and high conservational areas such as cultural heritage sites. Specifically, ASM has resulted in widespread wastelands, which are abandoned, flooded and un-reclaimed (Ontoyin and Agyemang, 2014; Owusu-Nimo *et al.*, 2018), presenting public health and safety risk to inhabitants, particularly the vulnerable ones such as children and women. It has also been reported recently that ASM activities has resulted in extensive destruction of farm lands, forest reserves and pollution of surface water bodies such as rivers

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and streams (Mantey *et al.*, 2017; Owusu-Nimo *et al.*, 2018; Bansah, 2019). These problems associated with ASM raises concerns particularly due to the recent introduction of heavy mining equipment in ASM and the involvements of Chinese nationals who come with most of the highly sophisticated mining equipment (Armah *et al.*, 2013; Hilson *et al.*, 2014; Aidoo, 2016; Crawford *et al.*, 2017; Crawford and Botchwey, 2017). In providing response to addressing the environmental issues associated with ASM, the general public has called on government to monitor the activities of ASM operators and reclaim the abandoned mines to minimise the risk these abandoned mines present to the public (Nyame and Grant, 2014; Bansah *et al.*, 2016a; Owusu-Nimo *et al.*, 2018).

To effectively develop and deploy policy responses to reclaim ASM sites, an understanding of the locations and spatial distribution of the ASM sites is a necessary prerequisite. However, information regarding ASM hotspots and spatial distribution, the scope and types of ASM operations are hard to find. Our literature search resulted in only one research paper that focus on mapping the distribution of ASM sites in Ghana, that is the work of Owusu-Nimo *et al.* (2018). However, their work presents a number of limitations that this work seeks to address. Specifically, the work of Owusu-Nimo *et al.* (2018) adopted GPS ground surveys to map out ASM sites in the selected districts of the Western Region. The GPS ground surveys used is not only laborious, expensive and time consuming, it is also ineffective in identifying most ASM sites as it relies heavily on local knowledge of the existence of ASM sites. Additionally, their work only presents the location of ASM sites and their spatial distribution pattern without considering the area extent of the ASM sites to understand the extent of degradation to guide reclamation initiatives. This current research contributes to addressing these gaps by employing satellite remote sensing to determine the location, spatial distribution pattern and area extent of ASM in the Tarkwa-Nsuaem Municipality of the Western Region of Ghana. Therefore, this research presents a meaningful contribution to the literature by investigating the use of satellite remote sensing in mapping ASM sites. The obtained results could also contribute to prioritising reclamation efforts of authorities.

2 Materials and Methods Used

2.1 Study Area

The study area for this research is the Tarkwa-Nsuaem Municipality of the Western Region of Ghana. It is located between latitudes 4° 54' 30" N and 5° 22' 20" N and longitudes 2° 10' 50" W and 1° 45' 30" W, respectively. The study area is bounded to the north, south, east and west by the Prestea Huni-Valley, the Ahanta West, Nzema East and Mpohor Wassa East Districts, respectively. The municipality consist of a total of 1045.65 km^2 land size and has been divided into six area councils, namely Benso, Nsuaem, Nsuta, Pepesa East, Pepesa West and Tarkwa, with the Nsuaem and Tarkwa area councils being the largest.

The Tarkwa-Nsuaem municipality was selected for this study as it represents one of the most active gold mining districts in Ghana. The municipality accommodates two large-scale gold-producing multinational companies namely, AngloGold Ashanti, Iduapriem mine and Goldfields Ghana Limited, Tarkwa mine. The Ghana Manganese Company Limited, which has been in operation for over a century is also located in the municipality, indicating the resource-rich nature of the study area. Apart from Large-Scale Mining (LSM), registered and regulated small-scale gold mining also abounds in the municipalities. Again, the literature suggests that illegal artisanal small-scale gold mining is ubiquitous in areas with registered ASM and LSM operations (Owusu-Nimo *et al.*, 2018). Therefore, illegal ASM is expected to proliferate in the study area. All these influenced the choice of the study area. Fig. 1 is a map of the study area, and its adjoining districts.

2.2 Data Used

In this study, a combination of both raster and vector data were acquired. Two recent Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) satellite images captured on January 09, 2020 was acquired from the US Geological Survey website (https://earthexplorer.-usgs.gov/) using two different paths and rows. One image had a path and row of 194 and 057, with the other image having 194 and 056 as its path and row respectively. Acquiring two different satellite images with two different paths and rows was necessary because the study area is located within those two paths and rows. The images were cloud-free and geo-rectified and projected to the Universal Transverse Mercator (UTM), zone 30N for easy use in the GIS environment. Additionally, GPS surveys were conducted for image classification, ground truthing and accuracy assessment of the classified image. Vector data consisting of ASM and LSM sites were digitised from Google Earth to facilitate the image classification activities. Also, an existing land cover map of the study area was obtained. Table 1 summarises the data used together with their respective sources.

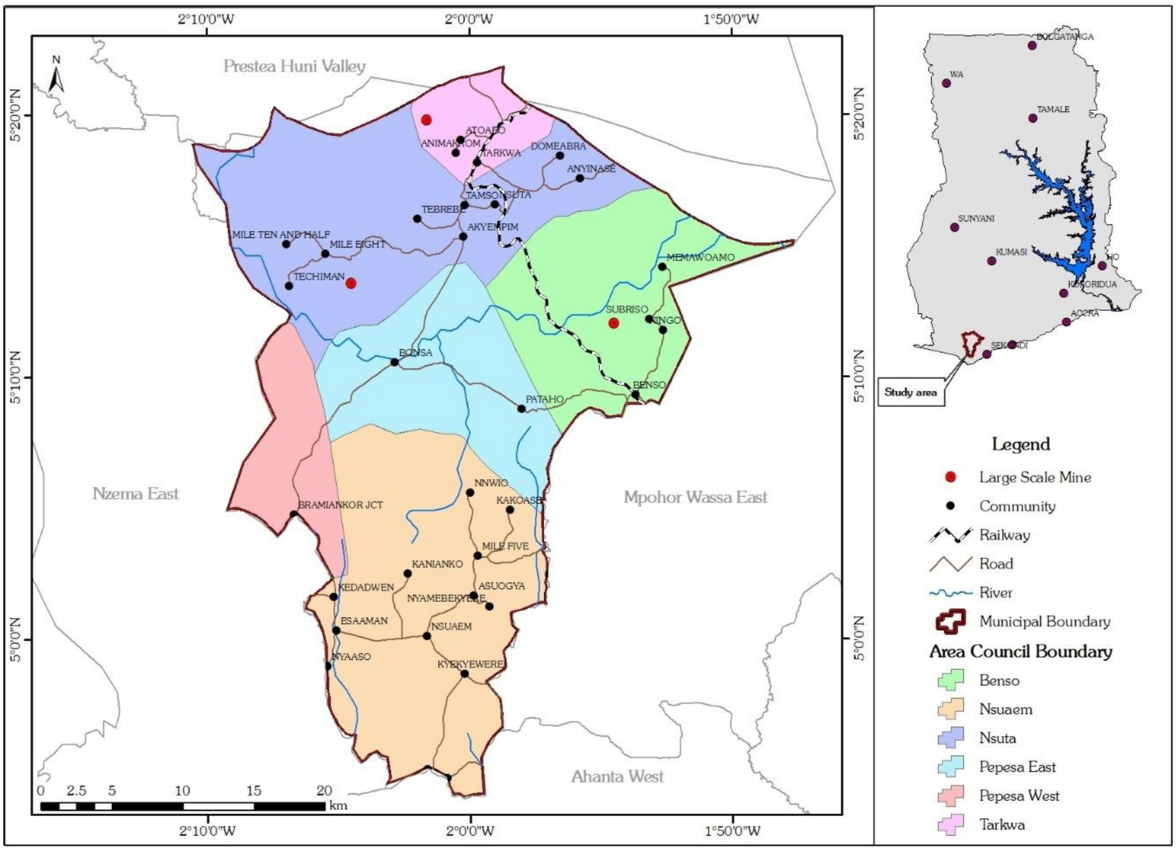

Fig. 1 Map of Study Area

Table 1 Dataset Used for the Study

Data	**Source**
Landsat 8 satellite image	US Geological Survey Website
ASM and LSM sites	Google Earth
Landcover map	Forestry Commission and Land Commission of Ghana
GPS locations	Field surveys

2.2 Method Used

The study was implemented following four major steps. First was the acquisition of data, which has been described in the preceding subsection. This was followed by the actual data analysis, consisting of three steps, namely, image pre-processing, image processing and post-image processing analysis. Details of how each step was practically implemented have been provided in the subsequent subsections and Fig. 2 is a flowchart summarising the entire study methodology.

2.3.1 Image Pre-processing

Image pre-processing of the downloaded Landsat satellite images was undertaken using the Erdas Imagine software. The purpose of the pre-processing was to correct for image sensing, atmospheric effect and earth's curvature errors on the acquired image. Firstly, the different bands of the acquired satellite images were combined to obtain two multi-band images using the "Layer Stack" tool. Since the study area laid between two different paths and rows, the two layer stacked images were then masked into a single image, before actual image pre-processing began. Specifically haze on the south eastern part of the image was removed following the de-dehaze tool of Erdas Imagine. After this, GPS locations of road intersections, railway crossing and permanent monuments such as bridges were used to verify the rectification of the image. Finally, the "Extract By Mask" tool of ArcGIS was used to extract an image of the study area for onward image processing. This ensured that the image processing excluded other locations and was very specific to the study area.

2.3.2 Image Processing

The pre-processed image of the study areas was subjected through several image processing techniques. First, signature files were generated using the GPS coordinates obtained from ground surveys and vector data digitised from Google Earth. The generated signature files were subsequently used as training samples to classify the extracted satellite image of the study area following the supervised classification technique. The supervised classification was implemented through the maximum likelihood algorithm (Weng, 2001; Otukei and Blaschke, 2010) to classify the image into six land covers, namely, forest, agriculture land, rangeland, wetland, urban areas, LSM sites and ASM sites. After classifying the image, the accuracy of the classified image was assessed to allow a degree of confidence to be attached to the result. After assessing the accuracy of the classified image, the ASM sites land cover was extracted for onward analysis using the "Select by Attribute" tool of ArcGIS. The ASM sites were extracted from the other land cover to allow for a more focused analysis of the spatial distribution of artisanal and small-scale mining in the study area.

2.3.3 Post Image Processing Analysis

Post image processing analyses were carried out to more thoroughly understand the spatial distribution pattern of artisanal and small-scale mining in the Tarkwa-Nsuaem Municipality. First, the number of individual ASM sites obtained from the image classification was determined, followed by computing the area of each of the individual sites and the total area using the "Field Calculator" tool of ArcGIS. For further analysis, the extracted ASM sites were overlaid on the boundary of the Area Councils of the study area to investigate the spatial distribution and extent of the artisanal and small-scale mining in each Area Council. Finally, to further analyse artisanal and small-scale mining activities on key land covers, and identify environmentally critical areas requiring urgent attention, three AOI representing three major land covers of the study area were created. The three AOI are (1) Forest Reserve, (2) Large-Scale Mining, and (3) Urban Settlement. The Forest Reserve AOI correspond to government gazetted forest reserve, and three of such forest reserves are located in the study area, namely, the Bonsa River, Nueng South and North forest reserves. The Large-Scale Mining AOI refers to areas with intense large-scale open-cast mining activities, and the Urban Settlement AOI refers to areas with intense human settlement, often with at least 60% building surface fraction (Stemn and Kumi-Boateng, 2020). The ASM sites were overlaid on the three AOI to determine the number, area extent and proximity of ASM activities to the AOI.

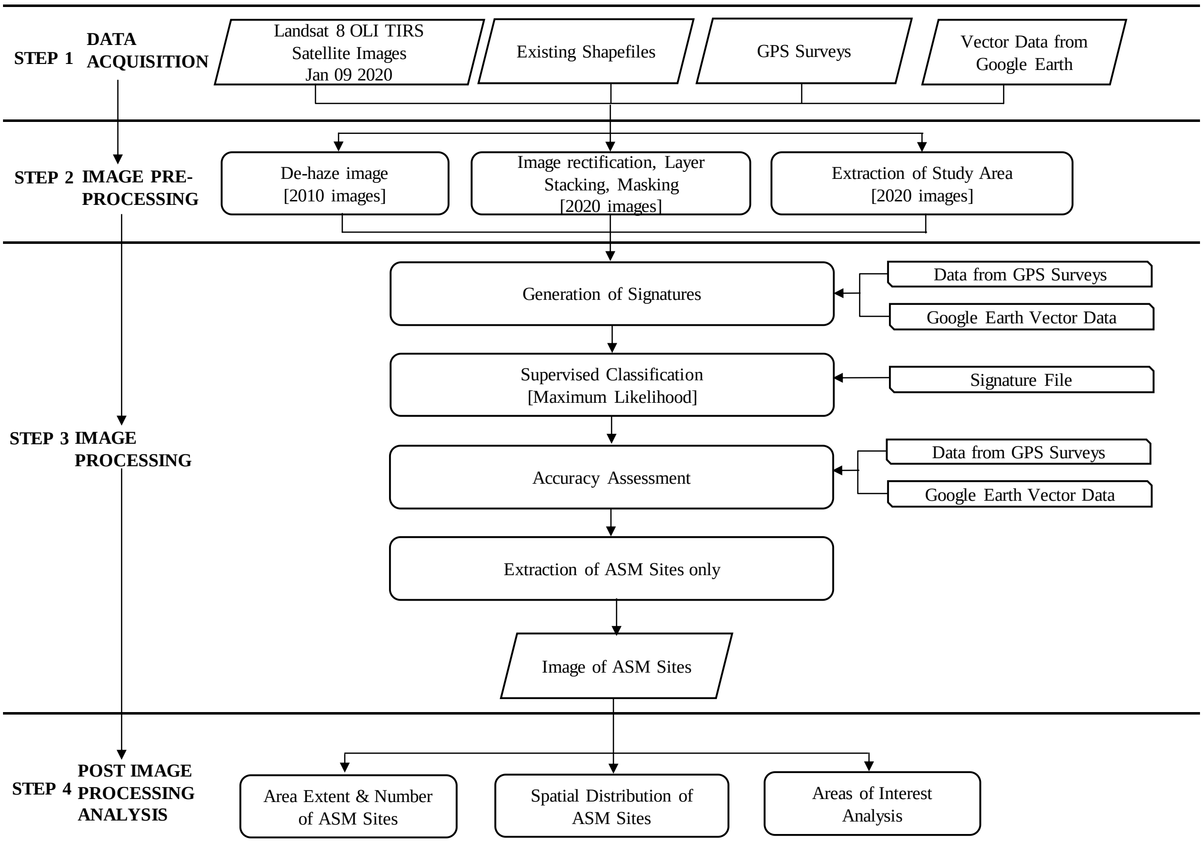

Fig. 2 Flowchart of the Study Methodology

3 Results and Discussion

3.1 Spatial Distribution of ASM Sites in the Study Area

The image classification resulted in the identification of 221 ASM sites in the study area. However, a closer look at the image of the ASM sites and when compared with Google Earth images revealed that most of the identified ASM sites were in clusters. Therefore, the number of ASM sites identified from the study will far exceed the 221 sites when the individual sites are considered in contrast to the clusters of ASM sites. This number of ASM sites in the study area is similar to what has been reported in previous studies (Owusu-Nimo *et al.*, 2018), indicating that coarse to medium resolution satellite images provide an efficient and cost-effective means of mapping the location and distribution pattern of ASM. The presence and richness of alluvial gold deposits, large numbers of abandon underground and surface mines, long history of mining and low security and law enforcement regimes could contribute to making the Tarkwa-Nsuaem municipality an attractive destination for small-scale mining. This could accounts for the identification of high numbers of ASM sites within the municipality (Owusu-Nimo *et al.*, 2018). The identified 221 ASM sites covered an area of 26.79 km^2, representing 12.72% of the total land size of the study area. The 12.72% of the study area being affected by artisanal and small-scale mining is on the high side and requires the urgent attention of society. Particularly because ASM is characterised by the presence of large void left behind in the mined-out areas since most artisanal and small-scale miners have no or limited focus on land reclamation and rehabilitation. Due to this limited focus on land rehabilitation by artisanal and small-scale miners, there is the need to address the fast rate at which other land covers are being transformed into artisanal and small-scale mines.

Fig. 3 is a map showing the spatial distribution of the ASM sites in the study area relative to each of the six Area Councils in the study area. By mapping the locations and distribution pattern of ASM sites, the study identifies areas critically affected by ASM warranting reclamation and rehabilitation by authorities. From Fig. 3, it can be observed that artisanal small-scale mining activities are widespread in the entire study area, as the ASM sites are well distributed throughout the study area.

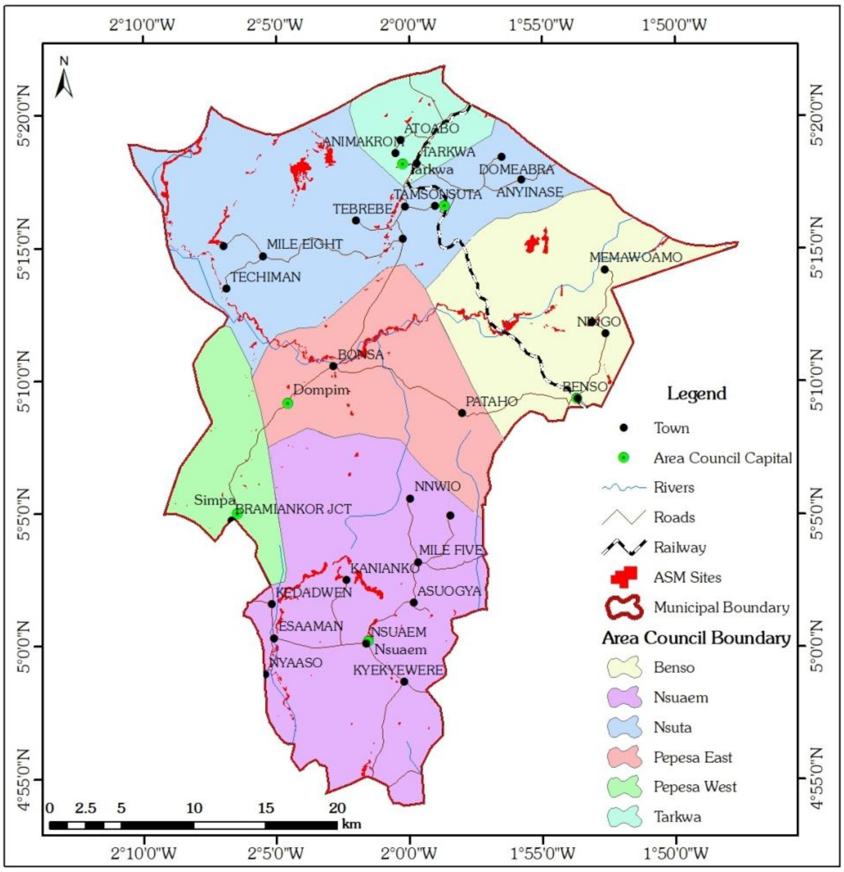

Fig. 3 Spatial Distribution of ASM Sites in the Study Area

Even though the ASM sites can be found across all sections (north, south, east and west) of the study area, the most ASM sites are located at the northern part, beginning from Dompim upwards (see Fig. 3). The middle portion (that is between Dompim and Simpa, see Fig. 3) of the study area has the least number of ASM sites. In terms of the land size the ASM sites were occupying, the smallest ASM site had an area of 0.000155 km^2, whereas the largest ASM site had a total area of 4.45 km^2. The average size of an ASM site was found to be 0.12 km^2.

Regarding the distribution pattern of ASM activities in the respective Area Councils, Fig. 3 depicts that there is not a single Area Council where there were no ASM sites, suggesting that all six Area Councils are affected by ASM activities. However, the extent of ASM activities differ from one Area Council to the other. For instance, the Nsuta, Nsuaem, Pepesa East and Benso Area Councils had the highest distribution of ASM sites, whereas Tarkwa and Pepesa West Area Councils recorded the lowest distribution of the ASM sites (see Fig. 3). The number of ASM sites located in each Area Council as well as the area extent have been presented in Table 2. From the table, it can be observed that Nsuaem, Nsuta and Pepesa West Area Councils had the highest number of ASM sites, recording 72, 64 and 39 sites respectively. Conversely, Tarkwa and Pepesa East had the lowest number of 12 and 16 ASM sites respectively. When considering the size of the ASM sites relative to the respective size of each of the area councils, it can be observed from Table 2 that, Nsuaem, Benso and Pepesa East are the Area Councils experiencing artisanal and small-scale mining the most. While only 0.21% and 0.57% of the total size of the Pepesa West and Tarkwa Area Councils were respectively identified as ASM sites, 3.83%, 3.58% and 3.12% of the Nsuaem, Benso and Pepesa East have been affected by ASM activities, respectively. Thus, the Nsuta and Benso Area Councils have been identified as the ASM hotspot Area Councils in the municipality.

3.2 Spatial Analysis of ASM Sites in Areas of Interest

Fig. 4 shows the locations and distributions of the ASM sites relative to urban areas, large-scale mines, forest reserves and rivers. Considering Fig. 4, it can be observed that the three AOI and surface water bodies have been affected by ASM activities. The fig. depicts that the Bonsa river and its tributaries have become a convenient location for artisanal and small-scale mining largely due to the abundance of alluvial gold deposit in the Bonsa river and along its banks. Specifically, ASM activities is ubiquitous along the river, as there was not a single location along the river without an ASM activity. This present a high risk to the quality of water obtain from the river as some communities along the Bonsa river use water from the river for domestic purposes, including washing, cooking and bathing. This is particularly important and a key threat to public health since ASM results in the deposition of high concentration of sediments in the river. Moreover, mercury and other poisonous chemicals are used in gold extraction among artisanal and small-scale miners, compromising the quality of water obtain from the river. Therefore, the abundance of ASM sites along the Bonsa river does not only present livelihood support to locals but also present a significant risk to their health. This is because the presence of small-scale mining activities along the river could be an indication of the high concentration of sediments, mercury and other heavy metals in the river, which makes water from the river unsuitable for human use. Since mercury magnifies along the food chain, presence of mercury in the river does not only present a threat to the aquatic life but also to human health and hence taking action on combating ASM on or close to water bodies in the study area and Ghana at large is a critical decision that authorities would have to consider. Regarding the sediment load of the river, it presents a huge threat to water treatment since water from the Bonsa river is the major source of water for the entire municipality.

Table 2 Number and Area of ASM Sites in the respective Area Councils

Area Council (AC)		ASM Sites		
Name	**Size (km^2)**	**Number**	**Size (km^2)**	**Percentage to AC Size**
Benso	183.96	18	6.59	3.58%
Nsuaem	303.11	72	4.27	1.41%
Nsuta	278.8	64	10.69	3.83%
Pepesa East	153.34	16	4.79	3.12%
Pepesa West	75.59	39	0.16	0.21%
Tarkwa	50.85	12	0.29	0.57%
Overall	**1045.65**	**221**	**26.79**	**12.72%**

Fig. 4 also shows the presence of ASM activities within the three forest reserves located in the study area, with Nueng South and Bonsa forest reserves being the most affected, recording a total of 15 and 8 clusters of ASM sites. These forest reserves have been nationally gazetted and all activities including ASM are completely forbidden in the reserves. However, there appears to be lack of oversight in ensuring that activities that threaten the survival of the forest reserves are prohibited from happening within the reserves. The occurrence of ASM within the reserve present a risk to the health of the reserve, particularly due to the rudimentary, uncoordinated, unplanned and artisanal nature of ASM, which result in the destruction of vegetative land cover without any consideration of rehabilitation. Therefore, it is recommended that purposeful, targeted and high coordinated consented efforts of authorities are required to protect the integrity of the forest reserve in the Tarkwa-Nsuaem municipality as they are being affected by ASM activities.

Finally, it can be observed from Fig. 4 that some of the ASM sites are located within the mining concessions of large-scale mines, presenting a security risk as this could be a potential source of conflict between owners and workers of the large-scale mines and the artisanal small-scale miners. Again, some of the ASM sites are located either within or in close proximity to urban settlement which present a public health and safety risk, as ASM sites are characterised by large abandon pits and high contaminated tailings. The effect of ASM on high conservational areas such as the forest reserves and river warrant the urgent attention of authorities, particularly due to the recent changes in the ASM operations. Several studies have reported that ASM has transitioned from the previously traditional, rudimentary and artisanal operations to capital intensive, mechanical and politically driven money generating operation involving the use of heavy earth moving equipment such as bulldozers and excavators (Mantey *et al.*, 2017; Bansah *et al.*, 2018; Owusu-Nimo *et al.*, 2018). This change in ASM operations means there could be the destruction of large tracks of land within a relatively shorter period, and therefore the risk ASM presents to the forest reverses and rivers could be exacerbated with the current mechanical operations.

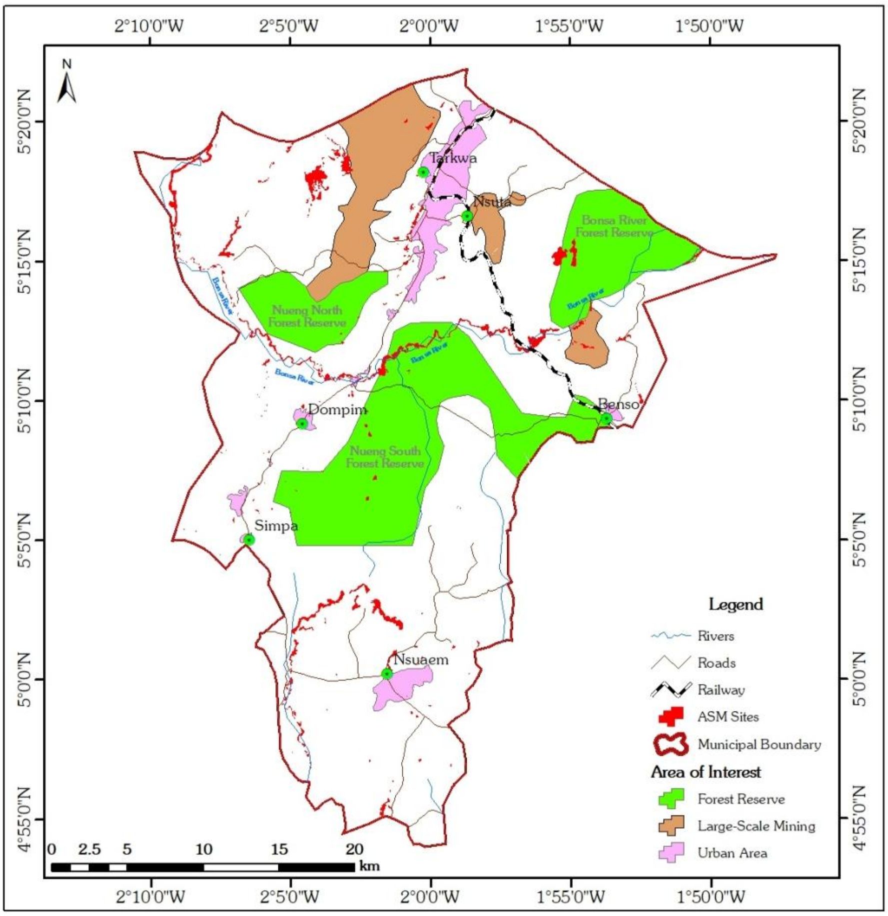

Fig. 4 Map of ASM Sites Relative to the Selected Areas of Interest

4 Conclusions

This study demonstrates the use of course to medium resolution satellite image to identify the locations and spatial distribution of artisanal and small-scale mining sites. The study used a 2020 Landsat OLI TIRS satellite image acquired from the US Geological Survey to map out ASM sites in the Tarkwa-Nsuaem municipality using several image processing techniques. Overall, a total of 221 clusters of ASM sites, representing 12.72% of the land size of the study area were identified. The study observed that ASM is ubiquitous in the entire study area, and proliferate in environmental sensitive areas such as rivers, forest reserve and urban settlement and the risks and hazards ASM presents in these areas have been discussed. The study was also effective in identifying environmental critical areas where the abundance of ASM activities present a significant threat to ecosystem services and require the urgent attention of authorities.

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