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Mapping the spatio-temporal land use land cover trends in the Guinea Savannah artisanal and small-scale mining (galamsey) landscape of Ghana

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Abstract

Human activities like illegal mining (galamsey) have the proclivity to compromise natural resources such as forest landscapes and water bodies. This study used multi-sensorial Landsat images to analyse the LULC trend of the galamsey hotspots in the Guinea Savannah Landscape, Ghana from 2000 to 2020. Results showed that the bare land/mined class recorded the highest gain (30%) while the open savannah/cropland class decreased by 33.7%. In addition, the water body class decreased by 0.7%. The built-up frontier and closed savannah/forest classes gained by 3.8% and 0.6%, respectively. The normalized difference vegetation index (NDVI) maps showed that the inception of galamsey in the study area for two decades (2000-2020) has compromised the vegetation cover. The loss in vegetal cover and siltation of water bodies may have implications for the existing ecosystem's health and human well-being. The study recommends revegetation and reclamation of the galamsey degraded landscapes by the Government of Ghana and other stakeholders.

Keywords

Illegal mining; land use land cover change; environmental degradation; revegetation; guinea savannah landscape

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Contents

1. Introduction

The extraction of precious minerals such as gold, manganese, diamond and bauxite contributes to livelihoods and local community development (Hilson & Osei, 2014; McQuilken & Hilson, 2016; Hilson, 2017; Bazillier & Girard, 2019; Pokorny et al., 2019; Yankson and Gough, 2019; Baddianaah et al., 2021b). However, illegal and unsustainable extraction of these minerals is associated with environmental degradation. Prominent environmental impacts associated with mining activities include land degradation, destruction of forest landscapes and biodiversity, pollution, siltation and diversion of dams, ponds, streams, and the morphology of the river system (Ferring et al., 2019; Amproche et al., 2020; Forkuor et al., 2020; Macháˇcek, 2020). The artisanal and small-scale mining (ASM) sector is largely associated with the aforesaid adverse environmental implications (Owusu et al., 2019; Abaidoo et al., 2019; Obeng et al., 2019; Amproche et al., 2020; Forkuor et al., 2020).

In Ghana, artisanal and small-scale mining operations occur twofold–the registered small-scale mining and the unregistered small-scale mining (galamsey) operations. The registered miners are perceived to operate within designated concessions under defined environmental guidelines (Owusu et al., 2019; Obeng et al., 2019; Yankson and Gough, 2019). Therefore, the associated environmental ramifications of registered small-scale mining operations are construed to be less intensive compared to galamsey operations (Aggrey et al., 2021). Galamsey is a corrupt form of the term “gather them and sell” in the Ghanaian traditional language (Aryee et al., 2003:139; Ofosu-Mensah, 2011). Notably, the majority (about 85%) of the ASM operators in this country are found in the galamsey sector (Teschner, 2012). This same sector is responsible for a chunk of adverse environmental outcomes (Aggrey et al., 2021). Nevertheless, the early attempts to regularise illegal mining activities, which resulted in the promulgation of the Small-Scale Mining Law (PNDCL 218), 1989 and supporting legislative instruments, have failed to distinguish between the operational characteristics of illegal and legal small-scale miners (Debrah et al., 2014). This resulted in a free-for-all prospecting for gold in which foreigners (Chinese) dominate the ASM landscape (Botchwey & Crawford, 2018; Hausermann et al., 2020), although licensed ASM is meant for only Ghanaians (Hilson, 2002; Boafo et al., 2019).

Illegal mining operations have destroyed large hectares of arable lands and forest reserves (Boadi et al., 2016; Abaidoo et al., 2019; Baddianaah et al., 2021b). Thus, a significant measure to halt the continued destruction of these valuable ecological resources led Ghana’s Government to ban small-scale mining operations in March 2017 (Owusu et al., 2019). In addition, the agenda to restore the galamsey degraded areas was spearheaded by the government in the same year (Abaidoo et al., 2019; Baddianaah et al., 2021a). However, many galamsey degraded landscapes across Ghana’s mining zones are yet to be identified and quantified to inform policy on appropriate reclamation projects to be executed in these localities. Furthermore, the pursuit of monitoring illegal mining activities during and after the small-scale mining ban featured strongly in all policy discussions in the country (Forkuor et al., 2020). In so doing, some scholars (e.g. Ren et al., 2019) suggested the use of unmanned aerial vehicles (UAVs) in monitoring ASM areas for possible reclamation. Nevertheless, this can only be done sparingly as UAVs are costly to use and do not allow for direct quantification of the extent of degradation caused by illegal mining operations. Therefore, multi-temporal satellite imagery involving the application of Remote Sensing (RS) and Geographic Information System (GIS) in mapping and monitoring the illegal mining landscapes through land use land cover change (LULCC) analysis is encouraged (Abaidoo et al., 2019; Asamoah et al., 2017; Forkuor et al., 2020; Kumi-Boateng & Stemn, 2020).

On this premise, empirical studies conducted in southern Ghana involving the use of free access Landsat imagery have reported significant levels of LULC variations across forest landscapes, watersheds and croplands caused by illegal mining activities (Schueler et al., 2011; Amproche et al., 2020; Forkuor et al., 2020). For instance, Schueler et al. (2011) obtained a reduction in forest landscape from 58% to 45% in the Western Region of Ghana. Similarly, Amproche et al. (2020) reported a massive gain in bare lands of about 80% attributed to illegal mining activities in the Black Volta Basin of Ghana. Despite the nuanced results produced by the involvement of multi-sensorial imageries in LULC monitoring of illegal mining activities on forest landscapes in southern Ghana, the trends and extent of LULCC caused by illegal mining activities on the land cover of Guinea Savannah Landscape remain dearth in the literature. In addition, the majority of the studies involving satellite imagery analysis of the galamsey degraded landscapes pay limited attention to the perspectives of the local dwellers regarding the LULC variations. Against this background, this study aims to monitor, map and quantify the extent to which illegal mining activities induce spatio-temporal LULC variations in the Guinea Savannah. Intending to achieve the study objective, the following questions were raised:

1. how do the local dwellers perceive ASM operations in terms of LULC variations in the Guinea Savannah Landscape?
2. to what extent do ASM activities induce spatio-temporal land use land cover change in the Guinea Savannah Landscape?

The study was conducted in the Wa East District, a hotspot of galamsey in the Guinea Savannah Landscape (Laari et al., 2015; Baddianaah et al., 2021b). Illegal mining activities in the Wa East District transcend decades of which the continuous degradation of croplands has generated land use conflicts between the illegal miners and the smallholder farmers (Agyemang & Okoto, 2014; Baddianaah et al., 2021b). In addition, the Wa East District is the food basket of the Upper West Region (Ghana Statistical Service [GSS], 2014). Thus, the rising environmental degradation by illegal miners in the district has implications for food security and livelihood in the Upper West Region and the country at large. The paper contributes to the scientific literature on the mapping and monitoring of illegal mining activities and could inform policymakers and Ghana’s government of the need to monitor the destructive effects of illegal mining activities on croplands, forests and water bodies in the Guinea Savannah Landscape. The study is timely in shedding light on the extent of illegal mining-induced environmental change to help trigger policy and local concern on land reclamation. It presents insight into the protection of yet-to-be-degraded forests and farmlands in mining communities. Thus, the study has a wider scope of shaping land use policy at the local, national and international levels

2. Literature review and conceptual framework

2.1 Effects of artisanal and small-scale mining on the physical environment

In this study, we posited that ASM activities have deleterious consequences on all aspects of the physical environment (Figure 1). The trickled-down effects of ASM on the natural environment may result in loss of biodiversity and a reduction in the quantity and quality of ecosystem services, thereby compromising the well-being of nearby households (Barenblitt et al., 2021; Nyamekye et al., 2021). Therefore, this study posited that the effects of ASM activities in the Guinea Savannah Landscape have the proclivity to compromise the quality of human well-being in terms of access to potable water, food security and health (Figure 1). As a result, regular monitoring and quantification of galamsey impact on the physical environment are sine qua non to inform policy on revegetation, reclamation and further policing of illegal mining activities in local communities.

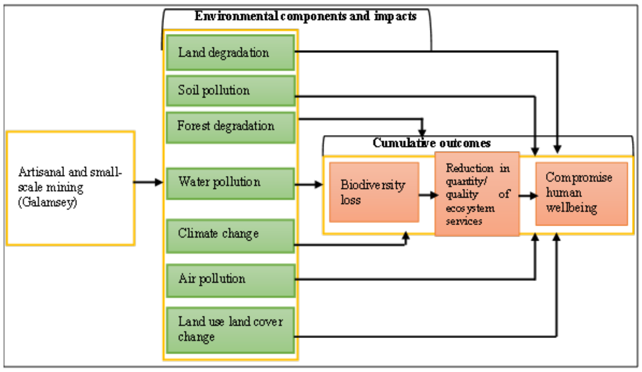


Figure 1. Framework on ASM's Environmental Impacts and Human Wellbeing

2.2 GIS and remote sensing analysis of galamsey effects on the physical environment

The literature on ASM's impact on land and its related aspects is now beginning to appreciate the importance of the application of GIS and RS technologies. These applications have aided scholars in producing nuanced findings to that effect (see Table 1). Abaidoo et al. (2019) used Artificial Neural Networks (ANN) to monitor the range of coverage and reclamation of small-scale mining of degraded lands. The study found peak periods of ASM activities to have increased land degradation (bare lands) of approximately 60.4% with an associated reduction in vegetation cover of 18.7%. An increase in the built-up area (87.3%) was likewise recorded. However, the study revealed that the introduction of revegetation activities in the area for about six years succeeded in reducing the area under bare lands from the erstwhile 60.4% to 51.7% leading to an increase in the vegetation class by 3.9%. A past study undertaken by Kumi-Boateng et al. (2012) revealed similar land cover variations in degraded lands and expansion of the built-up area caused by mining activities in the Tarkwa Mining Area (TMA).

In the work of Ferring et al. (2019), RS and GIS technologies were used to determine ASM's pits relationship with the spread of diseases (malaria) to a nearby household. This study revealed that abandoned mined pits serve as breeding grounds for mosquitoes, the carrier of Plasmodium responsible for causing malaria. As the adoption of GIS and satellite-based RS technologies proved to be useful in determining 'what has changed and by how much' (Telmer & Stapper, 2007), the challenge scholars face has to do with cost and access to high-resolution imagery to enable them to identify minute changes that occurred on the land surface over time (Ren et al., 2019). Isidro et al. (2017) pointed out the challenge of mapping small-scale mining areas using low-resolution satellite data. These scholars alluded to the inconsistencies of the shape of small-scale mining units and the relative pixel size of the Pleiades and SPOT-6 satellite imageries as a challenge to effectively map the mining areas. On this premise, some scholars (e.g. Ren et al., 2019) suggested the use of unmanned aerial vehicles (UAVs) in monitoring and tracking the illegal mining degraded areas for possible reclamation. However, the use of UAVs has come with several drawbacks including high cost of acquiring drones, heavy use of computer-aided tools and the risk of shooting down the drones by the illegal miners.

According to Werner et al. (2019), although the use of GIS and RS tools in mapping mining impacts has challenges, the associated benefits suggest a worthy embracement of these technologies. These scholars pointed out the useful application of GIS and RS techniques in mining studies at local, national, continental and global scales. At the local and national scale, "environmental and socio-economic risk assessments, disaster mitigation, and adjudication on mine-related conflicts can be performed while at a regional level, spatial analyses can support cumulative and strategic impact assessments and at a global level, spatial analyses can reveal industry-wide land use trends, and provide key land use data for comparative analyses of mining impacts between commodities, locations, and mine configurations" (Werner et al., 2019:1). This suggests that GIS and RS has a wide scope of application in monitoring and analysing mining impacts across a multitude of geographic space provided the needed resources and experts are available.

In the Rutsiro District, Rwanda, Macháček (2020) recently employed GIS and RS technologies to assess the impact of alluvial small-scale mining operations on river courses and consequential pollution of water bodies and found that the geomorphological structure and fluvial processes of the rivers were affected by artisanal and small-scale mining activities. Similarly, along the Black Volta Basin of Ghana, Amproche et al. (2020) found a significant increase in bare land and settlement areas due to illegal mining activities around the basin. Forkuor et al. (2020) presented a more nuanced finding by employing the Sentinel-1 Time series data to monitor illegal mining impacts in Southwestern Ghana from 2015 to 2019. The study found a decreasing trend in degraded areas as artisanal mining activities decreased. These scholars, however, attributed the decreasing trend of degraded lands to measures employed by the government to halt illegal mining activities in the country over the period, especially the small-scale mining ban that spans 2017-2018. Thus far, the application of RS and GIS techniques in monitoring and quantifying the LULC variations of illegal mining landscapes is pertinent.

3. Materials and methods

3.1 Study area

The Wa East District (Figure 2) is one of the leading illegal mining zones in the Guinea Savannah Landscape (Baddianaah et al., 2022; Laari et al., 2015). The district is geographically located in the Northwestern part of Ghana (Upper West Region) with Wa as the regional capital (Ghana Statistical Service, 2014).

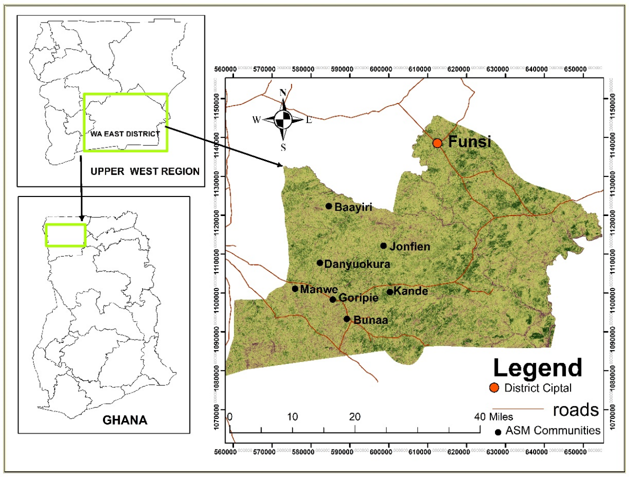


Figure 2. Map of Wa East District

Spatially, the district is located between longitude $1^o10'$ W and $2^o5'$ W and latitudes $9^o55'$ N and $10^o25'$ N, occupying a total land area of approximately 1,078 km^2 (GSS, 2014). Recent studies have shown that the activities of illegal miners have had adverse effects on the physical environment including land and forest degradation, pollution and siltation of water bodies (Laari et al., 2015; Baddianaah et al., 2021a). The economy of the district is agrarian, hosting about 94% sof mallholder farmers. However, the youth in particular are currently shifting from agriculture to the extraction of gold (Agyemang & Okoto, 2014; Laari et al., 2015; Baddianaah et al., 2021b). This is partly so because the district is endowed with gold-rich granitic and metamorphic rocks of the pre-Cambrian geologic sub-strata (GSS, 2014). Also, the erratic nature of rainfall coupled with other extreme weather conditions make agriculture unreliable in the region, hence the shift of the youth to alternative income sources of which mining is one of them.

3.2 Study design and data collection

Before the start of the research process, a literature review was carried out on key areas such as the effects of ASM on the physical environment, application of GIS and remote sensing in mapping mining areas, satellite imagery analysis of mining areas, and land use land cover classification of artisanal mining areas. The knowledge obtained from the extant literature guided the study in terms of the data types and sources, data collection instruments design, reliability, and attainability of the study objectives. Primary data for the study were sourced through in-depth interviews while secondary data (multi-temporal satellite imagery) were sourced from the United States Geological Survey (USGS) Department.

The study employed concurrent mixed methods design involving the collection of both qualitative and quantitative data simultaneously (Creswell, 2014). Because the study sought to combine local perspectives and satellite data analysis to assess the illegal mining (galamsey) induced land use land cover dynamics in the Guinea Savannah Landscape of Ghana, the triangulation mixed methods research approach was employed (Yiran et al., 2020). This method supports the combination or integration of qualitative and quantitative data during the interpretation of the results (Osumanu & Ayamdoo, 2022). Therefore, quantitative satellite data analysis and qualitative in-depth interviews with chiefs, landlords and lead miners were involved in assessing the LULC trends of the study area. We purposively selected the chiefs and landlords for the survey. In addition, the lead miners were selected through snowballing. From the extant literature, illegal mining activities are ubiquitous in three (3) administrative districts in the Upper West Region, namely Wa East District, Wa West District and Nadowli-Kaleo District (Laari et al., 2015; Baddianaah et al., 2021b; Baddianaah et al., 2022). However, this study was geographically focused on Wa East District because of the intensity of illegal mining operations in the district compared to the remaining districts (Baddianaah et al., 2022). In addition, historical narrative reports revealed that the Wa East District pioneered illegal mining activities in North-western Ghana (Agyemang and Okoto, 2014).

Furthermore, seven (7) galamsey communities were purposively selected in the Wa East District taking into

Table 1. Summary of Literature on the Use of GIS and RS in Monitoring Illegal Mining Landscapes

Article	Author	Year	Research Gap/Objective	Materials and Methods	Key findings
Monitoring the extent of reclamation of small-scale mining areas using artificial neural networks	Abaidoo et al.	2019	Monitoring illegal mining activities for reclamation of the mined degraded areas is pertinent in Ghana	Quantitative supervised and unsupervised classification involving artificial neural networks was used to classify Landsat imageries	• Mining areas together with the bare lands gained by 60.4% while the vegetation cover declined by 18.7% from 2007 to 2011 • The introduction of reforestation caused a decrease in the bare land area to 51.7% in 2016 • Mining contributes to an associated increase in the settlement frontier by 87.3%
Geospatial assessment of land use and land cover patterns in the Black Volta Basin, Ghana	Amproche et al.	2020	Illegal mining (galamsey) activities have caused significant environmental losses within Black Volta Basin in Ghana	Quantitative methods consisting of multispectral Landsat imageries with the Spectral Angle Mapper (SAM) supervised classification and feature extraction	• Except for the bare land class, all the land cover classes assessed from 2000 to 2018 recorded a decline • Barelands recorded the highest gain of 21% from 2000 to 2015 but declined to 18% from 2015 to 2018. • The study also employed the feature-based extraction to delineate potential mining sites within the Black Volta Basin
Examining the performances of true colour RGB bands from Landsat 8, Sentinel-2 and UAV as stand-alone data for mapping artisanal and small-scale mining (ASM)	Nyamekye et al.	2021	The study examined the accuracies of using the true colour RGB for mapping ASM activities in Ghana	Quantitative analysis involving the use of Landsat (L8) 8, Sentinel-2 (S2) and UAV in LULC mapping of ASM areas	• The stand-alone RGB accurately mapped ASM operations up to 90% and suggests they are the best for mapping ASM activities • The findings suggest more scientific grounds for the application of UAV in ASM mapping • All the images used showed massive destruction of forest cover because of ASM • Remote sensors are useful in providing reliable data for mapping ASM activities
Using participatory spatial tools to unravel community perceptions of land-use dynamics in a mine-expanding landscape in Ghana	Aggrey et al.	2021	There is a dearth of literature on the use of participatory GIS tools in assessing mining land use and consequential effects	Qualitative methods involving the use of GIS tools and activity-based actor perspectives	• The activity-based actor-produced maps help in the visualization of the transformation going on between croplands, large-scale and small-scale mining, and settlement expansion among all participants • This helps to project the future consequences of the transformation by 2035
The large footprint of small-scale artisanal gold mining in Ghana	Barenblitt et al.	2021	Limited scientific studies on the spatial footprint of illegal mining in Ghana	Quantitative machine learning and change detection algorithms were used to classify Landsat images obtained from Google Earth Engine	• About 47,000 ha (± 2218 ha) of the vegetal cover has been converted to artisanal mining sites at an average rate of 2600 ha yr-1 • High percentage (50%) of the mining activity occurred between 2014 and 2017 • About 700 ha of the mining activity occurred in forest (protected) areas

consideration the intensiveness of ASM and accessibility to the mining areas (Agyemang and Okoto, 2014; Baddianaah et al., 2022). This is because at the time of conducting the survey, some mining communities such as Worzukore and Salingnyagaa, among others, were not accessible due to heavy rains that had cut off footpaths linking to study sites. Access to illegal mining areas was a major hindrance to researchers (Owusu-Nimo et al., 2018). Consequently, the study communities were Goripie, Baayiri, Danyuokura, Kande, Bunaa, Jonfien and Manwe. These communities have been empirically validated as illegal mining hubs (see Laari et al., 2015; Baddianaah et al., 2021b). On this premise, the chief, landlord (tendaana in the local language) and a lead miner were interviewed in each of the seven (7) study communities. Thus, seven (7) chiefs, seven (7) landlords and seven (7) lead miners were interviewed to ascertain their perspectives regarding the land use land cover transitions taking place in their respective communities and whether they consider that the illegal mining activities in their communities have been contributing to the changes in the land cover spatially and over time.

The interviews were conducted in the native language, tape-recorded and later transcribed into the English language. Each interview session lasted for about 45 mins. Furthermore, in the process of the transcription, rapt attention was given to identifying the dominant emerging themes, which were later harmonised for the analysis. The results were presented textually based on themes in the form of direct and indirect quotes. In addition, although the survey instruments were vetted and approved by the University for Development Studies Ethics Committee, informed consent of all the respondents was verbally sought before the data collection. The respondents were given the freedom to withdraw from the survey at any moment they deemed inappropriate in the course of the interview. The entire field data lasted for about two (2) months (From June 2021 to August 2021).

3.3 Satellite imagery acquisition and processing

Land use land cover trend analysis involving Landsat data and guided by the historical time scale of ASM operations in the study area was assessed. The inhabitants of the ASM communities in this study are predominantly smallholder farmers who combine mining with agriculture (Baddianaah et al., 2021b). Artisanal mining activities were first noticed in the study communities around the early 2000 and have stayed through decades. Therefore, based on the aforementioned time scale regarding the commencement of ASM activities in the region, three (3) multi-sensorial satellite images (spatial data) of Landsat 7 ETM+ (2000, 2010) and Landsat 8 OLI-TIRS (2020) covering two (2) decades were sourced from USGS Earth Explorer (http://glovis.usgs.gov) and analysed (Table 2).

Table 2. Characteristics of landsat images

Landsat Image	Acquisition Date	Reference System	Spatial Resolution	UTM Zone	Temporal Resolution	Path/Row	Bands Used
Landsat 7 ETM+ (2000)	3/21/2000	WGS84	30 m x 30 m	30 North	16	95/ 053	432
Landsat 7 ETM+(2010)	11/28/2010	WGS84	30 m x 30 m	30 North	16	95/ 053	432
Landsat 8 OLI-TIRS (2020).	12/17/2020	WGS84	30 m x 30 m	30 North	16	95/ 053	543

Source: USGS (2021)

The choice of Landsat data for the study was influenced by the relative availability and less cost compared to other satellite images such as Quickbird, GeoEye, Ikonos, and WorldView (Abaidoo et al., 2019). In addition, Landsat images are suitable for the analysis of the spatio-temporal dynamics of urban and peri-urban landscapes and the management of environmental resources on sustainable platforms (Osumanu & Ayamdoo, 2022). They are also used in assessing land use and land cover variations of mined and post-mined areas (see Laari et al., 2015; Abaidoo et al., 2019). The spatial resolution of Landsat (30 metres by 30 metres) allows for the identification of spectral signatures within the land cover. Therefore, Landsat images have been used by several scholars in land use and land covers investigations (Asamoah et al., 2017; Barenblitt et al., 2021; Kumi et al., 2021).

3.4 Data processing

The software used for the Landsat images classification was the Environment for Visualizing Images (ENVI 5.3 version). The pre-processing technique used in processing the images was the Quick Atmospheric Correction (QUAC). QUAC determines atmospheric correction parameters directly from the observed pixel spectra in a scene without ancillary information. In addition, QUAC performs a more approximate atmospheric correction than Fast Line-of-Sight Atmospheric Analysis of Hypercubes (FLAASH) or other physics-based first-principles methods, generally producing reflectance spectra within the range of approximately 10% of the ground truth (Bernstein et al., 2012). This helps in quick radiometric and atmospheric correction. Since the study aimed to determine the ASM-induced spatio-temporal variations in land use land cover of Wa East District, five (5) LULC classes were identified, defined and generated (see Table 2). The overall classification workflow is outlined in Figure 3.

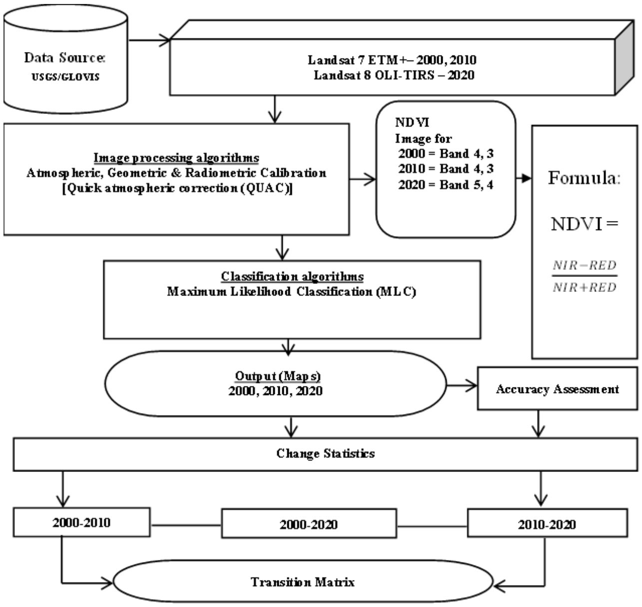


Figure 3. Methodological Framework for Image Classification. Source: Authors

Furthermore, the supervised Maximum Likelihood Classification (MLC) algorithm was adopted in classifying the images into the five LULC classes (see Table 3). The MLC is applicable in a situation where each identified class has a Gaussian distribution (Laari et al., 2015) and thus, is widely adopted by many researchers for image analysis (Laari et al., 2015; Osumanu & Ayamdoo, 2022). The Global Positioning System (GPS) together with Google Earth Pro assisted the researchers to collect coordinates (about 70 points each) within the designated land use land cover regions, which were used for ground-truthing. In all, 350 LULC coordinates were acquired and used in validating the satellite images as well as the accuracy assessment. The images classified in ENVI 5.3 were subsequently transferred to ArcGIS 10.5 in which overlay and sub-setting of the regions of interest (ROI) were done and projected to World Geodetic System (WGS84), Universal Transverse Mercator (UTM) Zone 30N. Further computations involving change statistics, normalized difference vegetation index (NDVI) (see Figure 3), and the confusion matrix were carried out. The classification outputs in the form of maps (figures) and tables–the confusion matrix–user's accuracy, producer's accuracy, overall accuracy, and the kappa coefficient were obtained and analysed. The estimation of NDVI follows the formula

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

The respective bands used in the computation of the NDVI are shown in Figure 3. NDVI value ranges between -1 and +1 for poor vegetation and good vegetation index respectively. NDVI value (e.g. 0.1 below) represents poor vegetation and indicates sand, snow, barren land, rock surface etc. while NDVI value (e.g. 02 to 0.3) is considered moderate and indicates grassland and shrub. In addition, NDVI value (e.g. 0.6 to 0.8) indicates high forest areas. NDVI analysis is important because they help in differentiating vegetation cover of an area from other types of land cover. It helps in determining the overall status of the vegetation cover of a defined area. This is important in determining the status of the vegetation cover of the Guinea Savannah Landscape which has been under the effect of artisanal and small-scale mining operations and other climatic variability including floods and bush fires for decades.

Further, producer's accuracy is explained as the map maker accuracy and shows how the real features on the ground are rightly represented on the classified map. It shows the probability that a particular land cover recorded on the ground is truly represented on the map. It is cal-

Table 3. Land use land cover classes in the Wa East district

Land use land (LULC) cover type	Description
1. Built-Up Area	Rural and urban settlements, including roads, cemeteries, and football fields.
2. Bare Land/Mining Site	Areas without vegetation cover outside the built environment, including artisanal and small-scale mining operational sites.
3. Open Savannah/Croplands	Open grasslands with less dense vegetation cover designated as farmlands, fallow land or shrub.
4. Closed Savannah/ Forests	Dense vegetation cover of trees over a considerable area, including plantation farms.
5. Water body	Surface water resources such as rivers, streams, ponds, and dams.

culated by dividing the number of classified sites by the total number of reference points (sites) for that class. User's accuracy is how the map is understood from the user's point of view. It shows the user how often the class on the map will truly be depicted on the ground. It is calculated by dividing the total number of correctly classified pixels for a particular class by the total row. User's accuracy measures the reliability of the images classified. The Kappa value shows interreliability of the classification. It measures how well the classes are classified compared to a random classification. The Kappa value (coefficient) range from -1 to 1. Thus, a negative value shows that the classification is significantly worse off compared to a random classification whereas a value of 0 shows that the classification is no better than a random classification. However, a kappa value that is close to 1 suggests that the classification is significantly better than a random classification.

4. Results

The results from the survey were presented under two main sub-sections. First, the local communities' perspectives on ASM's ecological impact and the trends in LULC observed within their communities. The second section detailed the trends of the ASM–induced LULC involving the Landsat data analysis from 2000 to 2020.

4.1 Local perspectives on ASM's environmental impacts

Gold mining activities have spanned through centuries in Ghana and occurred under three major classifications: (i) large-scale (commercial) mining largely owned by expatriate corporations; (ii) small-scale mining (legal) solely for Ghanaians; and (iii) small-scale mining (illegal) undertaken by Ghanaians and a mix of foreign illegal miners (Botchwey & Crawford, 2018). Initially, ASM activities were done in southern Ghana, specifically the Akan land (Ofosu-Mensah, 2010, 2011). But in recent times, ASM activities have spread to cover a significant part of the Guinea Savannah Landscape including North-western Ghana (Hilson et al., 2013; Ntewusu, 2018) which have both positive livelihood implications as well negative environmental implications.

Discussions with the respondents revealed that galamsey has been a major catalyst of development in the local communities such as the provision of quick income, facilitating buying and selling in the local market including the acquisition of physical assets likes cars and houses. A landlord indicated that he gave out his land to his children to do galamsey because "that is what moves the community's development agenda forward". In addition, it was revealed from the survey respondents that the expansion of the built-up frontier of the communities was directly influenced by galamsey. A chief opined:

> *All the nice block houses you can see around are from galamsey. Galamsey can turn a village into a city within a month if the gold-bearing ore is rich. Consider places such as Banda Nkawnta, Tenga, Kui among others, these were typical villages a decade ago but with the inception of galamsey, you cannot call any of these palaces a village again. So you see! The activity is not bad at all but the problem is how it is done unregulated* (Source: Key informant interview June 2021).

This submission suggests that galamsey operations do not only affect the vegetal cover and water bodies but conditioned the expansion of the built-up frontier. The results indicate that the local dwellers appear to have understood development from the perspective of monetary gains resulting in the putting up of new buildings and purchasing of cars, among others, by the illegal miners in the host communities with no or little attention on environmental quality and consequential implications on their future wellbeing.

Despite the aforementioned benefits, it is without an iota of doubt that galamsey adverse impacts on the physical environment of Ghana including North-western Ghana is alarming. All the respondents interviewed shared a similar perspective that the inception of galamsey in their communities has caused significant levels of destruction and transformations in the physical environment. A lead miner reported:

> *That land (he points to a large parcel of degraded land to his extreme left) was more or less like a forest before we commenced our operations here in 2001 and you could see the entire vegetal cover is removed... indeed, our operations are transforming the land in the negative direction. But, as you know, one cannot eat her/his cake and have it. We want the money from gold mining; therefore, we must forgo our land to get the money* (Source: Key informant interview August 2021).

This finding suggests that the illegal miners are aware of their adverse impacts on the environment, yet they continue to degrade the land for monetary gains. A chief submitted that the variations in climate such as high daily temperatures, erratic rainfall accompanied by intermittent droughts experienced during the farming seasons are partly attributable to the environmental destruction by the illegal mining activities. A chief intimated:

> *As for the environmental impacts of galamsey, we are all suffering it. The youth are saying that agriculture output is low because of poor rains but they are causing it. They are cutting down trees to mine and think we can have regular rainfall as it used to be in the 1990s, that is impossible* (Source: Key informant interview July 2021).

The above submissions are mere ocular assessments and predictions of the galamsey impacts on the environment by the dwellers of local mining communities. Hence, quantitative analysis of the impacts of galamsey activities on the physical environment of the study was undertaken to proof the above assertions. In the next section, we determined the LULC trends for a more nuanced understanding of the LULC dynamics and whether the illegal mining activities have implications on the transfer in the LULC of the study area.

4.2 Galamsey induced LULC trends in the Wa East District (2000-2020)

For a better understanding of the LULC variations of the study area, the post-classification assessment involving the producer's and user's accuracy, overall accuracy and Kappa coefficient were computed (Table 4). From the results, the Kappa coefficient ranged from 0.85 to 0.98 for all classified images. The overall accuracy ranged from 89% to 99% with the 2020 image producing the highest overall accuracy (99%). This explains that the spectral signatures of the 2020 image were clearly identified and classified as compared to the others. Similarly, the producer's accuracy ranged from 90.65% to 97.70%, 82.76% to 97.56% and 95.93% to 100% for the years 2000, 2010 and 2020, respectively. Additionally, the user's accuracy ranged from 33.33% to 96.59%, 82.72% to 100% and 93.07% to 100% for the years 2000, 2010 and 2020, respectively. The accuracy reports imply that, the classification results are reliable and useful for further interpretations or analysis.

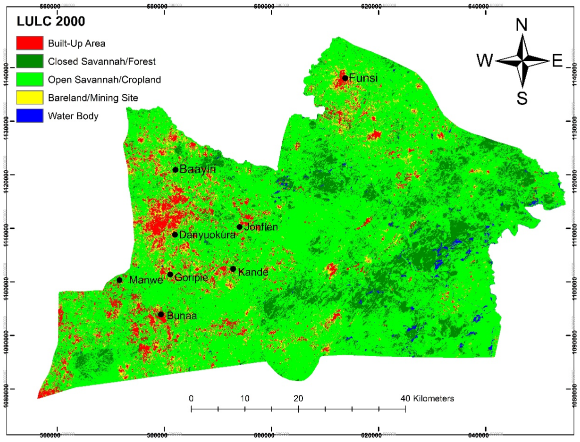


Figure 4. LULC map for Wa East district in 2000

Furthermore, the LULC maps (Figure 4, 5 and 7) showed five classes (built-up area, closed savannah/forest, open savannah/cropland, bareland/mining areas and water body) for 2000, 2010 and 2020, respectively. The accompanying area statistics (in hectares and percentages) are also presented in Figure 6.

Source: Authors The results (Figure 6) showed an interesting trend of variation within the five LULC classes for 2000, 2010 and 2020 images classified (see Figure 4, 5 and 7). From the results, the built-up area showed an increasing trend for the study period (2000-2020) occupying 20,789.6 hectares (5.7%) in 2000, 21,420.72 hectares (5.8%) and 34,827.9 hectares (9.5%) of the total land area in 2020. The closed savannah/forest cover occupied 56,187.5 hectares (15.3%) in 2000 but subsequently reduced to 35,538.03 hectares (9.7%) in 2010. Interestingly, the closed savannah/forest cover recorded a gain of 58,475.07 hectares (15.9%) in 2020. This may be induced by the government of Ghana effort in protecting and preventing forest zones from illegal mining operations which culminated in the use of the military in monitoring forest

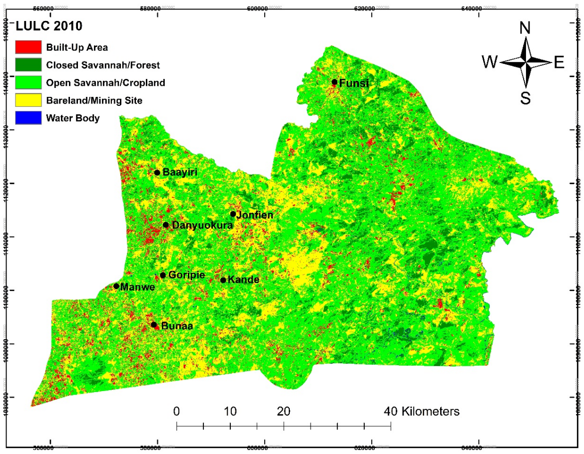
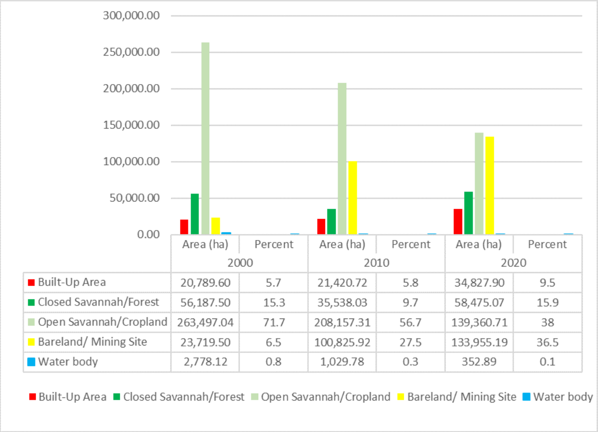


Figure 5. LULC map for Wa East district in 2010



	2000		2010		2020	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
🟥 Built-Up Area	20,789.60	5.7	21,420.72	5.8	34,827.90	9.5
🟩 Closed Savannah/Forest	56,187.50	15.3	35,538.03	9.7	58,475.07	15.9
🟩 Open Savannah/Cropland	263,497.04	71.7	208,157.31	56.7	139,360.71	38
🟨 Bareland/ Mining Site	23,719.50	6.5	100,825.92	27.5	133,955.19	36.5
🟦 Water body	2,778.12	0.8	1,029.78	0.3	352.89	0.1

Figure 6. LULC statistics for 2000, 2010 and 2020

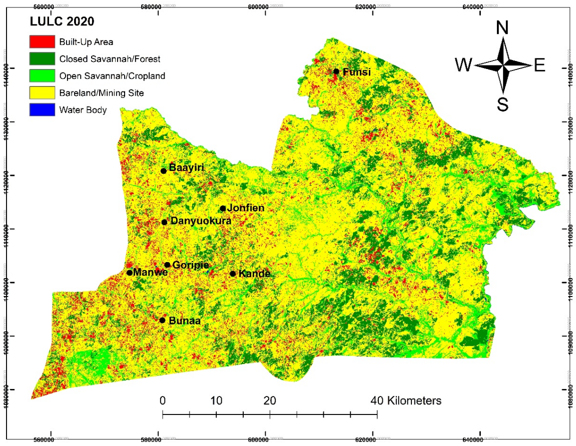


Figure 7. LULC Map for Wa East district in 2020

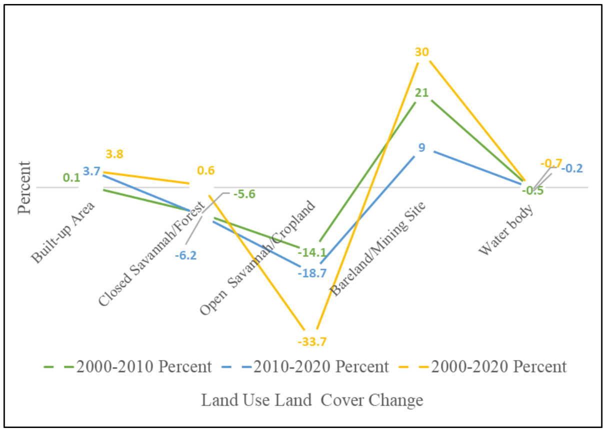


Figure 8. Percentage in LULC change 2000 to 2020

landscapes.

Source: Authors

In addition, the open savannah/cropland class, which represents the largest land cover of the study area, received the greatest disturbance between 2000 and 2020. As of 2000, open savannah/cropland occupies an area of 263,497.04 hectares (71.7%) but reduced to 208,157.31 (56.6%) in 2010. Consequently, the open savannah/cropland cover reduced to 139,360.71 hectares (38%) in 2020. Furthermore, the bareland/mining area showed a constantly increasing trend from 2000 to 2020. That is, as of 2000, the bareland/mining areas occupied 23,719.5 hectares (approximately, 6.5%) but increased to 100,825.92 hectares (27.5%) in 2010 and subsequently increased to 133,955.19 hectares (36.5%) in 2020. More so, the water body class showed a constant decreasing trend from 2000 to 2020. That is, the water body class was occupied by 2,778.12 hectares (0.8%) in 2000 but decreased to 1,029.78 hectares (0.3%) in 2010 and further decreased to 352.89 hectares (0.1%) in 2020 (Figure 5).

Source: Authors Figure 8 presents the percentage change in LULC trends of the study landscape from 2000 to 2020. The results showed that the open savannah/cropland class recorded the highest reduction (33.7%) while the bareland/mining site class recorded the greatest gain (30%). In addition, the water body class was reduced by 0.7%. Correspondingly, the closed savannah/forest and the built-up area gained by 0.6 and 3.8, respectively. Furthermore, ocular analysis of the LULC maps showed limited degradation for the 2000 image (Figure 4) and a noticeable level of degradation for the 2010 image (Figure 5). Undoubtedly, the 2020 image showed massive degradation across the entire study area (Figure 7). Thus, it can be argued that the continued engagement in galamsey activities by the local people has a negative impact on the vegetal cover including surface water resources. It was observed that the grinding and washing of the mineral-bearing ore on river banks and the dumping of earth waste materials in river channels resulted in turbidity and siltation of the water bodies.

Source: Authors

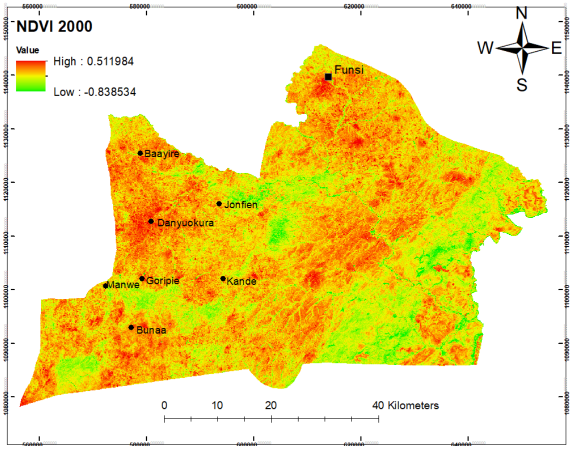


Figure 9. NVDI Map for 2000

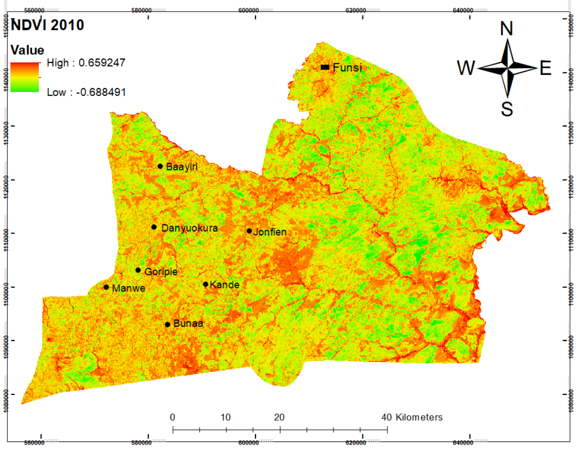


Figure 10. NVDI Map for 2010

The study sought to determine the impact of illegal mining on the health of vegetation in the study landscape through the normalized difference vegetation index (NDVI) analysis. The results from the 2000 image (Figure 9) revealed an NDVI value of -0.84 to 0.5 while the 2010 image (Figure 10) produced an NDVI value of -0.69 to 0.66; and the 2020 image (Figure 11) produced an NDVI value of – 1 to 0.36. The results showed that increased and prolonged illegal mining activities have dire consequences on vegetation cover as indicated by the low NDVI value obtained in the 2020 image (Figure 11) for the study area.

Source: Authors

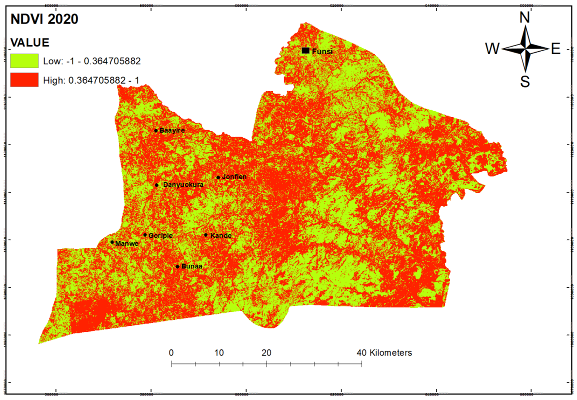


Figure 11. NVDI Map for 2020

5. Discussion

In this study, we establish the land use land cover dynamics of the Guinea Savannah Landscape with a specific focus on one of the most prevalent illegal mining zones (Wa East District) in North-western Ghana (Laari et al., 2015; Baddianaah et al., 2021b). The study results showed that ASM activities, although earlier on concentrated within the Akan land (Ofosu-Mensah, 2010), have expanded drastically across the country and the Guinea Savannah Landscape is no exception. This showcased that Ghana's mineral wealth in terms of gold deposit has a wider coverage–across the entire country. However, as the illegal gold mining operations continue to flourish, the adverse environmental impacts are on the ascendency. The local dwellers perceived illegal mining as a catalyst of local development because of its contribution to improving their financial statuses (Hilson, 2017). Nevertheless, the adverse environmental impacts of the illegal mining operations are suffered by the local communities and the world at large. Land degradation, destruction of forest cover and climate variability with dire consequences on agriculture productivity are common occurrences in the study area. These are common galamsey induced effects reported by the extant literature (Abaidoo et al., 2019; Amproche et al., 2020; Barenblitt et al., 2021; Nyamekye et al., 2021).

The accuracy assessment results on the LULC trends of the study area (Table 4) showed an overwhelming high accuracy value. The overall accuracy ranged from 89% to 99% while the Kappa coefficient ranged from 85% to 98%. The results indicate that the error level in terms of the image classification was limited suggesting a very minimal deviation between the reference points used for that accuracy assessment and the classified images (Laari et al., 2015; Forkuor et al., 2020), hence, reliable for further analysis or interpretation .

The LULC maps produced for 2000, 2010 and 2020 (Figure 4, 5 and 7) showed variations in the land use land cover of the study area for the period (2000 to 2020). From the LULC statistics obtained (see Figures 5.6 and 5.8), the built-up class showed an increasing trend from the inception of the illegal mining activity (2000) to the peak periods (2010 to 2020). This expansion in the built-up space from 2000 to 2020 is expected and confirmed the findings of related studies (Abaidoo et al., 2019; Amproche et al., 2020; Kumi-Boateng & Stemn, 2020). For instance, Abaidoo et al.'s work in Tarkwa (2007-2016) obtained an increase in the built-up class by 87.3%. However, our study obtained an increase in the built-up class by 3.8% for the entire study period, explaining that the galamsey impact on the built-up front in this study is less intensive. The fact that galamsey operations are still at the rudimentary stage in the study area also come to explain its less impact on the built-up area. In addition, the area covered by this study may also explain the variation in the results obtained. Illegal mining activities are associated with cash and as people get rich, some may invest the money into building houses (Bazillier & Girard, 2019; Pokorny et al., 2019). Thus, galamsey is largely claimed as having more impact on the local community development than large scale mining activities (Yankson & Gough, 2019). Besides, the discovery and commencement of illegal mining attracts a large population and may increase the demand for housing units.

The open savannah/cropland is the dominant vegetal cover in the Guinea Savannah Landscape and occupied about 71.7% of the entire land area of the study district during the inception of the illegal mining activity in 2000 (Figure 6 and Figure 8). However, by 2020, the open savannah class recorded the greatest decline (33.7%). Interestingly, there is an improvement in closed savannah/forest cover from 9.7% (2010) to 15.9% (an increase of 0.6%) in 2020. The impact of mining on croplands, including the open savannah class, has been reported by many authors (Laari et al., 2015; Amproche et al., 2020). The gain in forest cover may be attributed to the government ban on illegal mining activities in the country from March 2017 to December 2018. It as well suggests that fewer illegal mining activities are carried out in the forested areas of the guinea savannah unlike in the southern Ghana, where the majority of the illegal mining activities are done on forest reserves (Boadi et al., 2016; Barenblitt et al., 2021; Nyamekye et al., 2021). Nevertheless, Abaidoo et al. (2019) obtained an increased in vegetal cover by 3.9% in southern Ghana, which was explained by some revegetation activities that took place within the Tarkwa Mining Area. This suggests that the policy on revegetation is eminent in restoring the lost vegetation caused by illegal mining activities and consequential impact on human health. The deterioration of the open savannah/cropland cover in this study implies that much of the illegal mining activities are done on farmlands and confirmed the findings of Nyamekye et al. (2021) that indicated illegal mining activities have degraded vast areas of farmlands. In addition, the individual ownership of farmlands may have implications on control and protection of these lands from artisanal and small-scale mining operations compared to forest areas which are largely communal or state owned. This may have adverse implications on food security. Therefore, constant monitoring and mapping of the illegal mining impacts on the local environment is pertinent.

Furthermore, the bareland/mining site class showed an increasing trend from the inception of the illegal activity (2000) to the peak periods (2010-2020) and recorded the highest gain (30%) for the entire study period (2000-2020) (see Figure 6 and 8). The low NDVI values obtained (see Figure 11) revealed that the illegal mining activity has a trickle-down effect on the entire vegetal cover. Thus, peak periods of galamsey caused a decline in vegetation cover with implications on ecosystem services and human wellbeing (Abaidoo et al., 2019). This is in tandem with the findings of related studies (Isidro et al., 2017; Barenblitt et al., 2021; Nyamekye et al., 2021) stating that illegal mining activities induced degradation and compromise the vegetal quality of the entire landscape. For instance, Amproche et al. (2020) obtained an increased in bareland/mined area of 80% while Abaidoo et al. (2019) got about 60.4% of the degraded/mined lands for their study period. Studies have posited that illegal mining activities have been the major cause of land degradation in mining areas (Isidro et al., 2017; Kumi-Boateng & Stemn, 2020; Barenblitt et al., 2021).

The extent of degradation caused by mining activities calls for further attention towards land reclamation in local mining communities. In addition, findings from the survey showed that the water body class has declined by 0.7%. The impact of mining on water resources is well-known and constituted a major factor that triggered the galamsey ban in Ghana (Boadi et al., 2016; Owusu et al., 2019). Illegal mining activities affect water bodies by increasing the turbidity, siltation and diversion of river channels including chemical pollution (Owusu-Nimo et al., 2018; Amproche et al., 2020; Macháˇcek, 2020). In the light of these findings, constant monitoring and quantification of the illegal mining activities on the physical environment for redress using various methods are key and well documented (Asamoah et al., 2017; Abaidoo et al., 2019; Kumi-Boateng & Stemn, 2020; Kumi et al., 2021 Owusu-Nimo et al., 2018) of which this study is an add-on to the body of literature.

6. Conclusion

The study investigates the land use land cover status of artisanal and small-scale mining areas in the Guinea Savannah Landscape of Ghana with a focus on its impact on the vegetal cover loses. This is pertinent following scholarship's call for the use of satellite imagery in monitoring and quantifying the impact of illegal mining activities on the landscape and its resources. In addition to the local stakeholders' perspectives on ASM impact on the LULC of the study area, five land cover classes consisting of built-up, closed savannah/forest, open savannah/croplands, bareland/mining site and water body were identified and classified for the periods of 2000, 2010 and 2020. The findings reveal that Illegal mining activities have adversely contributed to land use land cover conversion of the Guinea Savannah Landscape. The bareland/mining site class increased by 30% while the open savannah/cropland class decreased by 33.7% within two decades. In addition, the water body class decreased by 0.7%; and the built-up frontier savannah/forest class increased by 3.8% and 0.6%, respectively within the same period. The normalized difference vegetation index (NDVI) maps generated show that the inception of galamsey in the study area for the two decades has compromised the vegetation cover. The loss in vegetal cover and siltation of water bodies may have implications on the existing ecosystem health and human wellbeing. The study concludes that illegal mining activities are responsible for the major land cover conversion including degradation of croplands and water bodies in illegal mining landscapes. This work only explored the land use/land cover conversions of the galamsey landscapes in Ghana. We, therefore, suggest that future work in this field could quantify the impact of galamsey on the soil pollution within croplands and the implication for food security. Furthermore, annual quantification of ASM impacts using high-resolution satellite data like Sentinel series, Google Earth Engine and Machine Learning algorithms is imperative to help map spatial patterns in illegal mining activities, predict vulnerability and inform policy. In addition, the study recommends collaboration between local communities and state institutions towards revegetation and reclamation of the galamsey degraded landscapes. Furthermore, strengthening the capacity of the responsible institutions for consistent monitoring and educating local communities on the future consequences of illegal mining activities are forward looking steps to addressing the illegal mining menace in Ghana.

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