A GEOSPATIAL APPROACH IN RESOLVING ILLEGAL MINING ACTIVITIES IN GHANA

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Key words: mining, remote sensing, environmental degradation, climate change, pollution

SUMMARY

The dynamics of the earth's surface are shaped by a number of key processes, including changes in land use and land cover (LULC) caused by anthropogenic factors. The environmental effects of this phenomena, which is happening at an astounding rate, has drawn the attention of geoscientist globally. Around the world, mining operations and related activities modify land use and land cover (LULC). This study's goal is to assess the spatiotemporal effects of illegal mining operations in the Western Region of Ghana. Deforestation, soil erosion, water and soil contamination have all been triggered by the mining enterprises, both large and small. From 2007 to 2022, historical LULC changes in the research area using the spectral bands of Landsat and Sentinel images were analyzed to determine the temporal and spatial extent of environmental degradation due to mining activities. Thermal emission rates, DEM analysis and analyzing climate data within the study area was also explored to quantify the extent at which illegal mining activities have altered the bio-physical nature of the environment. Following that, a CA-Markov model was applied to forecast future LULC changes based on recent changes. The study's findings indicate a loss in vegetative cover, increase in thermal emissions, pollution in water bodies and an exponential expansion in urban developments, particularly those near mining concessions. Additionally, the predictive time series analysis revealed that, in the absence of growth restrictions, urban expansion is expected to triple in 2049. This can be mostly ascribed to the expansion of mining operations in recent and upcoming years. Planning officials, decision-makers, and environmentalists in the community may find the debate and findings of this study interesting as they attempt to view the harm done to the environment and society as a whole.

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1. INTRODUCTION

The Earth's surface and ecosystems have changed during the past few decades as a direct result of human activity (Qian et al., 2017). In mining areas, severe environmental harm and ecological degradation, such as the eradication of native vegetation and soil erosion, are particularly prevalent (Gabarrón et al., 2018). Like most activities that support human life, mining has had the greatest impact on the ecosystem's structure and functioning in mining areas (Karaca et al., 2018). Ghana as a whole is a gold mining destination, as gold is one of the world's most valuable metals. This has attracted both legitimate and illicit gold prospectors from all over the world to the country. Ghana is dominated by two main mining sectors, including the Large-scale mining (LSM) and Artisanal and Small-scale mining (ASM). The operations involved in the ASM sector include: Legal or Licensed Small-scale mining, Illegal/ Unregulated Mining (Galamsey) and the newly established Community Mining. The only regions without ASM operations are Greater Accra and Volta regions. Unfortunately, all the three categories of ASM activities lead to uncontrolled land degradations and water pollutions. The Environmental Protection Agency (EPA) and the Minerals Commission are the regulatory bodies to ensure that only Ghanaian nationals can engage in small-scale mining. However, some people on the other hand, operate without these authorities' approval. As a result, their acts are considered illegal, a practice known as 'galamsey' in the area (Mantey et al., 2017).

Galamsey is primarily prevalent in alluvial mining, and it has severely damaged Ghana's forests and land (Owusu-Nimo et al., 2018; Schueler et al., 2011; Mensah et al., 2015). A study by NASA Analysts Barenblitt, Payton, and other colleagues in collaboration with the Ghana Space Science and Technology Institute and the Ghana Statistical Service recently discovered that from 2005 to 2019, there has been a 28% loss in vegetative cover due to artisanal and industrial gold mining. The destruction of the environment caused by galamsey in rural communities has a crippling effect on rural livelihood strategies (Obeng et al., 2019). Similarly, Hilson et al., (2019) discovered that increased gold mining activities in Ghana are claiming agricultural areas and depriving forest-dependent people of subsistence supplies. Even when mine sites are fully decommissioned, the deforestation caused by galamsey has long-term consequences due to significant damage to agriculture land (cocoa, rubber plantations, food crops, etc.) and forests, as well as watersheds contamination (Hilson et al., 2019). The illegal activity in mining communities has left many wastelands (pits, rubbish piles, deforested fields, etc.) neglected, inundated, and unreclaimed (Obodai et al., 2019) posing risks to nearby residents, particularly children, women, and livestock. To add to the latter, a recovered mining site could take ten to fifteen years to be ready for agricultural activity (Emmanuel et al., 2018).

Problems associated with artisanal and small-scale mining (ASM) in Ghana are becoming increasingly complex and difficult to address. Fourteen (14) of Ghana's sixteen (16) regions have seen severe damage to their land and water due to ASM activities. Surprisingly, the government's attention has not generated significant results since 2017, and this is likely due to a lack of understanding of the actual roots of the issue. Water sources have been polluted and tainted with harmful compounds like mercury, cyanide, lead, and arsenic, and many farmlands have been ruined due to illicit mining activities. These factors have contributed to the exponential growth in the price of purifying water for human consumption.

The artisanal and small-scale mining industry has developed outside the parameters of the governing law and now uses toxic chemicals, heavy equipment, and excavators to mine gold. Digging pits to remove ore results in the destruction of cocoa and other farms. In order to harvest gold, small-scale miners directly use rivers and streams. The impacted towns' rivers and other clean water sources are contaminated by the chemicals and mud used in the extraction process. The Ghana Water Company Limited (GWCL) has reported that because the river had turned brown and muddy, it was forced to ration water to inhabitants of several villages. For example, the turbidity of the water at the Daboase intake site has risen from 54NTU in 2007 to more than 3,000NTU at this time. An increase in the amount of sludge in the water used for processing had led to the problem, which required significantly more alum to produce water that was fit for human consumption. The Pra, Ankobra, and other smaller river bodies in the regions had all been impacted by the actions of illegal mining, according to GWCL officials.

Figure 1: Pictorial evidence of the effects of "Galamsey" on the environment
Source: JoyNews, 2020

According to Obodai et al., (2019) study on the health of gold miners, using mercury for gold amalgamation and panning has a number of negative effects on human health. High levels of mercury in the air, fish consumption, blood and other bodily fluids, as well as occupational health dangers for miners, are all mentioned in the report. Among the several implications of galamsey are mercury and hydrocarbon pollution of land and waterways (Hilson et al., 2019). Moreover, several virulent diseases spread by contact with water, including typhoid, hepatitis, trachoma, and liver damage are also prevalent in mining communties.

1.2 Research Problem

Ghana has a lengthy history of gold mining, producing a significant share of the world's gold for more than 1000 years (Benshaul-Tolonen et al., 2019). Gold, manganese, diamonds, and bauxite are just some of the precious minerals that can be extracted, and their extraction has been shown to benefit local economies and communities (Hilson & Osei, 2014; McQuilken & Hilson, 2016; Hilson, 2017; Bazillier & Girard, 2019; Pokorny et al., 2019; Yankson & Gough, 2019; Baddianaah et al., 2020). Yet, environmental damage is linked to the illicit and unsustainable mining of these resources. Land degradation, forests landscape and biodiversity loss, pollution, siltation, and diversion of dams, ponds, streams, and river system morphology are all major environmental impacts linked to mining (Ferring et al., 2019; Amproche et al., 2020; Forkuor et al., 2020; Machácek, 2020). As previously mentioned, the artisanal and small-scale mining (ASM) industry is commonly linked to the aforementioned negative environmental consequences (Owusu et al., 2019; Abaidoo et al., 2019; Obeng et al., 2019; Amproche et al., 2020; Forkuor et al., 2020).

Yet, many nations in the global south that are rich in mineral resources do not have even the most fundamental technological safeguards to ensure that their mining operations do not negatively impact the environment or local communities (Aznar-Sánchez et al., 2019). The current methods of monitoring exploration activities, mining operations, and environmental impacts in these nations require technological applications (Batterham, 2014). The contributions of a mine to the local achievement of specific SDGs are essentially dependent on a local context, which includes factors such as geography, environmental endowments including geology, land cover, land use, and social values.

Although several research have been done on the effects of illegal mining activities such as Boadi et al., (2016) who analysed the effects of illegal mining in the Offinso forest reserve; Schueler et al., (2011) who examined the effects of surface mining on land use/land cover changes in the Western Region; Gallwey et al., (2020) also used sentinel-2 images to analyse the effects of artisanal mining in Ghana; and Opoku-Ware (2014) determined the social impact of mining operations of Newmont Ghana in Kenyasi. A substantial amount of study, however, is still necessitated to ensure environmental sustainability in Ghana's mining communities.

The geospatial sector, which includes Earth Observation and Remote Sensing, Global Positioning Systems, Photogrammetry, Drones, and Geographic Information Systems, is an innovative technology with an important contribution to make in this discussion. Combinations with other technologies like the cloud, IoT sensors, AI, blockchain, and so on, are becoming increasingly common (Clark, 2020). Yet, in the context of sustainable mining in Ghana and the African continent as a whole, the utilization of these cutting-edge technology techniques to address issues associated to sustainable development is novel. Their potential and utility in this context are nascent and require further study. Additionally, despite the widespread adoption of such tools, there is still a lack of comprehension of sustainability challenges in mining sector operations and no well-established links between the triple-bottom-line concept and physical locations.

1.3 Research Questions

The unresolved concerns are: How can we use technology to better track the repercussions of mining, both good and bad? How can geospatial data and technologies help governments and people make more informed decisions for mineral resource development that will have a positive impact on future generations? This research, then, investigates the application of geospatial technology in an effort to resolve unlawful mining activities in Ghana, with the hopes of answering the aforementioned issues.

2. THE MINING INDUSTRY IN GHANA

Mining is the process of removing metals and minerals from the Earth, such as manganese, gold, copper, and tin (Worlanyo and Jiangfeng, 2021). For many years, the extraction and subsequent processing of gold has given thousands of native people jobs and stimulated economic growth in numerous countries (Hilson, 2009; Hilson et al., 2019). Mineral resources are crucial for economic growth on a global scale. Mining aids in the development of the national economy in a number of low- and middle-income nations that are rich in non-fuel mineral resources (Addison and Roe, 2018; Ericsson and Löf, 2019). According to studies, between 1996 and 2016, 10 of the 20 nations with the highest mining contributions rose one or two tiers on the World Bank's country categorization (Ericsson and Löf, 2019; Addison and Roe, 2018). African nations in particular have benefited. Indicators of socioeconomic growth so point to advancement in the mineral-rich nations of Africa. For instance, in Guinea, the Papua New Guinea Extractive Industries Transparency Initiative estimated that in 2020, the mining industries contributed 10.1 percent to corporate tax, salary and wage tax, dividends, and royalties while making up 89 percent of exports and 29 percent of the country's GDP (Yamarak and Parton, 2021).

Also, mining operations, whether on a large or small scale, have increased per capita income in Kenya, Tanzania, and other regions of developing economies by creating jobs, which has improved the standard of living for locals and communities (Apollo et al., 2017; Mwakesi et al., 2020). For example this can be said of farmers and other farm workers in Kenya and Cote d'Ivoire, where mining has been seen as an off-farm source of income (Mwakesi et al., 2020). To add to this, Forkuor et al., 2021 reported that mining provides 25 percent and 5.9 percent, respectively, of the gross domestic product in Guinea and South Africa (GDP).

The output of gold in Ghana, which averages 77 tons annually (Ahadjie, et al., 2021), is the second-largest in Africa after South Africa. The mineral sector in Ghana contributed roughly 14% of all tax revenues, 5.5% of the country's GDP, and 44% of its exports in 2011 (Ayee et al., 2011) and $6.6 billion dollars in revenue in 2022, making it the leading source in export revenue in the country (Samuel A. Jinapor, Minister of Lands and Natural Resources, 2023). Although gold reserves can be discovered throughout the country, the most of them are in the country's southern sectors, especially Ashanti, Western, Central, Eastern, and some areas of the Volta region. A portion of the northern region has lately been discovered to hold gold resources as well. This makes the gold mining sector one of the most significant sectors in the nation and a crucial sector to research. The industry is highly capital intensive, similar to the gold mining in other African nations, however there are not many direct jobs being created in relation to its economic importance. Despite making up 5.5 percent of GDP in 2010, it was predicted that only 20,000 Ghanaian nationals—or 0.08 percent of the population—were employed in large-scale mining (Ayee et al., 2011).

According to Mensah et al. (2015), large-scale mining contributed more than $300 million in salary to the national economy between 1986 and 1998. On the other hand, the growing shift from large-scale underground mining to large-scale surface mining may have lowered labor demand, causing laborers to move into artisanal and small-scale mining (Yankson & Gough, 2019). Beyond its direct and indirect effects on employment, the mining sector also contributes to the overall economy through taxes and royalties. Since a portion of the mining rents are given to the local populations, Ghana has been cited as an excellent example of how mineral-rich nations might disperse their mining income (Standing & Hilson, 2013). Also Gajigo et al. (2012) stated that, Ghana's mining royalty climbed from 3 percent to 5 percent in 2010, which was the average rate for the continent's gold production.

In Ghana, when the state ended its monopoly on gold mining in 1984, small-scale mining sector (ASM) operations became legal. Thus, the ASM industry is a significant employer in Ghana including many other African nations (Hunter, 2020). Around 1 million people in Ghana are thought to rely on income from ASM activities to sustain themselves. The artisanal small-scale mining (ASM) and large-scale mining industries coexist occasionally, but occasionally conflict results from divergent interests, as in the area of Prestea, where domestic galamsey miners have clashed with the international concession owner (Hilson & Yakoleva, 2007). Research shows that up to 52% of ASM sites, as shown by a geographical overlay of ASM sites using satellite imagery, are situated inside the borders of large-scale gold mines, demonstrating competition over resources and the possibility of conflicts (Patel et al., 2016). Even after oil was discovered in 2007 and production and exploration efforts were subsequently stepped up, mining has continued to be the top recipient of FDI and a significant part of the Ghanaian economy. The majority of sector revenues continue to be made from gold. The total amount of gold produced in 2016 was 4.1 million ounces, which brought in 5.15 billion US dollars in royalties, income tax, and permit fees (Dashwood et al., 2022).

Despite this, there are numerous environmental issues and difficulties related to mining, which are brought on by the contaminating of, as well as the rivalry for, surface and groundwater. One of the main factors contributing to worldwide land and environmental degradation is mining, particularly surface mining (Mert, 2019; Amponsah-Tawiah and Dartey-Baah, 2011; Gabarrón et al., 2019).

2.1 The Illegal aspect of the mining industry in Ghana

According to Mantey et al., (2020), "galamsey" refers to the illegal mining and/or extraction of gold from Ghanaian soil and water that is either at or below the surface. It is an illegal or unregulated type of artisanal small-scale gold mining (ASM) and can either be done in a mining-only mode, a processing-only mode, or both simultaneously with gold extraction (Mantey et al., 2020). Galamsey is prohibited because those who engage in it lack the necessary regulatory approvals from the Ghana Minerals Commission, the Environmental Protection Agency, the Water Resources Commission, the Forestry Commission, or the host Municipal Assembly (Owusu-Nimo et al., 2019). Those we engage in galamsey also do not pay taxes or other required fees, operate in sensitive or forbidden areas like residential zones, forest reserves, bodies of water, and sacred and culturally significant areas, and pay little to no attention to human rights (Owusu-Nimo et al., 2019; Mantey et al., 2020).

Small-scale and artisanal mining operations are not novel approaches to mineral exploitation in Ghana. In actuality, Ghana was originally known as the Gold Coast, a label bestowed upon it by the British, the nation's colonial rulers, in recognition of the region's undeniable quantity of gold reserves at the time they first ventured in Ghana (Ofosu-Mensah, 2011). Ofosu-Mensah (2011) cites historical accounts that show that as early as the 4th century, local miners (citizens) enjoyed free explorations, harvesting, and selling of gold and other minerals including diamond, bauxite, and manganese across the Akan territories. Galamsey, which means "to gather and sell," was later used to describe the method of extracting, gathering, and selling gold that was predominantly carried out by citizens (Ofosu-Mensah, 2011).

Artisanal and small-scale mining employs crude mineral extraction processes. The majority of artisanal and small-scale mining operations are unregistered and generally operate on the black market (Hilson, 2010; 2019). From 2005-2008, small scale (artisanal) mining employed over 13 million people and provided a living for 80 to 100 million people worldwide (Telmer and Veiga, 2008). It also generates around 90% of job possibilities in Sub-Saharan Africa and provides approximately 38% of GDP in other developing nations (Weng, 2015). For instance, the International Labour Organization (Standing, 2010) reported that there were 80–100 million unemployed dependents of the ASM sector globally as of 1999, and 13 million active miners. Currently, there are 100 million associated beneficiaries and 20 million artisanal and small-scale miners in Sub-Saharan Africa (SSA) (Hilson et al., 2017).

However, the prospects of the ASM sector in the sub-region—and Ghana, in particular—continue to be negatively impacted by the miners' growing illegality and stealth manipulations (Forkuor et al., 2020; Osumanu, 2020; Dery Tuokuu et al., 2020; Ibrahim et al., 2019). Hilson and Potter (2003) inquired as to why "illegal gold mining activity is so pervasive in rural Ghana" in their repeated documentation of the dynamics of artisanal and small-scale mining activities in Ghana. Although Hilson and Potter's work has been ongoing for more than ten years (2003–2021), we still feel this question to be pertinent because, since 2003, illegal mining (galamsey) operations have significantly increased throughout Ghana, with a variety of ramifications. Even though artisanal mining has been practiced in Ghana since the 15th century (Hilson, 2009), the use of heavy machinery and an unexpected influx of foreigners, has drawn significant attention to small-scale mining and the environmental damage that these miners are responsible for (legal or illegal).

Ghana's indigenous mining operations are however governed by three main regulatory frameworks. These laws include the Mercury Law (Provisional National Defence Council Law [PNDCL] 217, 1989), the Precious Minerals Marketing Corporation Law (PNDCL 219, 1989), and the Small-Scale Gold Mining Law (Bebbington et al., 2018). According to the Minerals and Mining Act of 2006 (Act 703), which revised the Small-Scale Mining Law of 1989 (PNDCL 218), small-scale mining is an indigenous business that needs the approval of Ghanaians from the Minerals Commission to operate. It suggested that local residents are the only ones allowed to engage in small-scale mining. In addition, it has been noted that the high cost of obtaining the small-scale mining license, bureaucracy, corruption, collusion, and collaboration, as well as significant political influence, are obstacles that prevent the majority of the local miners from obtaining the license (Botchwey and Crawford, 2018; Adu-Baffour et al., 2021; Gbedzi et al., 2022).

Despite the environmental costs, artisanal and small-scale mining will continue to be a source of income for rural residents. This is a result of rural areas' lack of work options and poverty (Osei-Bagyina, 2012). Funoh (2014) claims that small-scale mining has allowed rural residents to switch between mining and agriculture year-round. According to Weng (2015), the small-scale mining industry is an unofficial economic activity that is not subject to government oversight or taxation, making it a simple and convenient way to help the rural poor and other vulnerable members of society support their way of life.

The majority of small-scale mining enterprises in Ghana remain unregistered. In 2009, Aubynn (2009) stated that, less than 30% of Ghana's estimated 250,000 small scale miners have secured a license and are officially registered with the Minerals Commission. This canker is attributed to the difficulty, bureaucracy, cost, and delay in obtaining a mining license in Ghana. This discovery is consistent with other academics' findings, such as (Hilson, 2010; Hilson et al., 2014; Crawford and Botchwey, 2016). According to Hilson et al. (2014), small scale mining registration and license processes in Ghana might take years, resulting in low production in the sector.

2.2 Remote Sensing Technology for Examining Spatio-temporal effects of Illegal Mining Activities

Remote sensing is the process of detecting and monitoring the physical characteristics of an area by measuring its reflected and emitted radiation at a distance (typically from satellite or aircraft). Special cameras collect remotely sensed images, which help researchers "sense" things about the Earth (USGS, 2022). Satellite remote sensing has the potential to be a significant tool for tracking land-use change with high temporal resolution and less expense than using conventional techniques (Joshi et al., 2016). The synoptic perspective, continuous coverage, and real-time data collection of remote sensing data make it extremely helpful. As a result, the digital data in the form of satellite images makes it possible to precisely calculate different land cover/land use categories and aids in maintaining the spatial data infrastructure, both of which are crucial for keeping track of urban development and conducting land use studies (Youseff et al., 2019).

Academics and civil society organizations outside the mining sector have also used GIS and RS to analyze the effects of mining for a variety of reasons. These include local assessments of environmental and socioeconomic risk (including those for disaster mitigation), regional assessments of cumulative and strategic impact, analyses of industry-wide land use trends, and global comparative analyses of impacts across commodities, locations, and mine configurations. However, in an effort to develop and execute a comprehensive regulatory framework to legalize small-scale mining across the country, the government of Ghana established the Inter-Ministerial Committee on Illegal Mining (IMCIM) to address the environmental effects of mining activities (Bansah, 2019). The committee in its findings suggested using geospatial technologies and tools to monitor small-scale mining operations and as part of the licensing process while creating the policy framework. They advised using Unmanned Aerial Vehicles (UAVs or drones) in particular to assess mining concessions before granting licenses and to keep an eye on unlawful mining activities (Bansah, 2019). Drones are helpful for mapping mining concessions in great detail, but they are not well suited for regularly and effectively monitoring mining activity across wide areas (Forkuor et al., 2020). To monitor events over a vast area, several drones would need to be deployed, which would increase the cost. Additionally, regular drone operation and image processing will involve a significant amount of human labor (Forkuor et al., 2020).

In this light, monitoring mining-induced degraded areas and other operations across wide areas is best accomplished using remotely sensed data from satellite sensors (both economically and in terms of human resources) (Werner et al., 2019). Satellite sensors have wider footprints (cover larger areas) than UAVs, are getting more affordable, and can capture photos almost instantly (Werner et al., 2019). Landsat images, which are freely available, have been used in earlier research conducted in southern Ghana and elsewhere to examine changes in land use and land cover. These studies deduced the presence of mining activities from the conversion of broad LULC classes, such as savanna areas to bare ground and settlement (Basommi et al., 2015; Osei-Bagyina, 2012). By employing multi-temporal optical remote sensing data from UK-DMC2 (United Kingdom—Disaster Monitoring Constellation 2), Snapir et al., 2017 improved on these earlier attempts by tracking the growth of illegal mining sites in a significant area of southern Ghana. They identified a significant obstacle to mapping and observing illegal mining activities in southern Ghana as the availability of cloud-free optical imagery.

Landsat data has frequently been used to track land area change in areas with underground mining, assess the amount of surface mining and reclamation, and detect the dynamics of land cover (Vorovencii, 2021; Yang et al., 2018; Mi et al., 2019). Obodai et al., 2019 also employed remote sensing technologies to evaluate the pattern of land use/cover change in the Ghanaian Ankobrah River Basin and came to the conclusion that between 2008 and 2016, the forest underwent significant change, with illegal mining serving as the main driver.

To add to this, in numerous mining-related studies (Mi et al., 2019, Coalfield et al., 2020, Pericak et al., 2018, Zhang et al., 2021) and other applications (vegetation mapping and monitoring, land cover mapping, agricultural application, disaster management, and earth science), Google Earth Engine (GEE) has also been used for land cover classification (Mutanga, 2019). GEE has grown to be a significant repository for earth observation data. It also hosts machine learning algorithms for categorizing vast areas, which would otherwise take a lot of time and money to do using desktop methods.

2.3 Study Area

The Western Region is located between longitude 0° 30" East and 1° 30" West and latitude 5° 30" North and 7 ° 22". It has a land area of 2, 391 kilometers square, which accounts for 10% of Ghana's total land area (Ghana Statistical Survey, 2013). It is at the south-western part of the country bordered by Cote d'Ivoire and the Western-North, Ashanti and Central regions in Ghana.

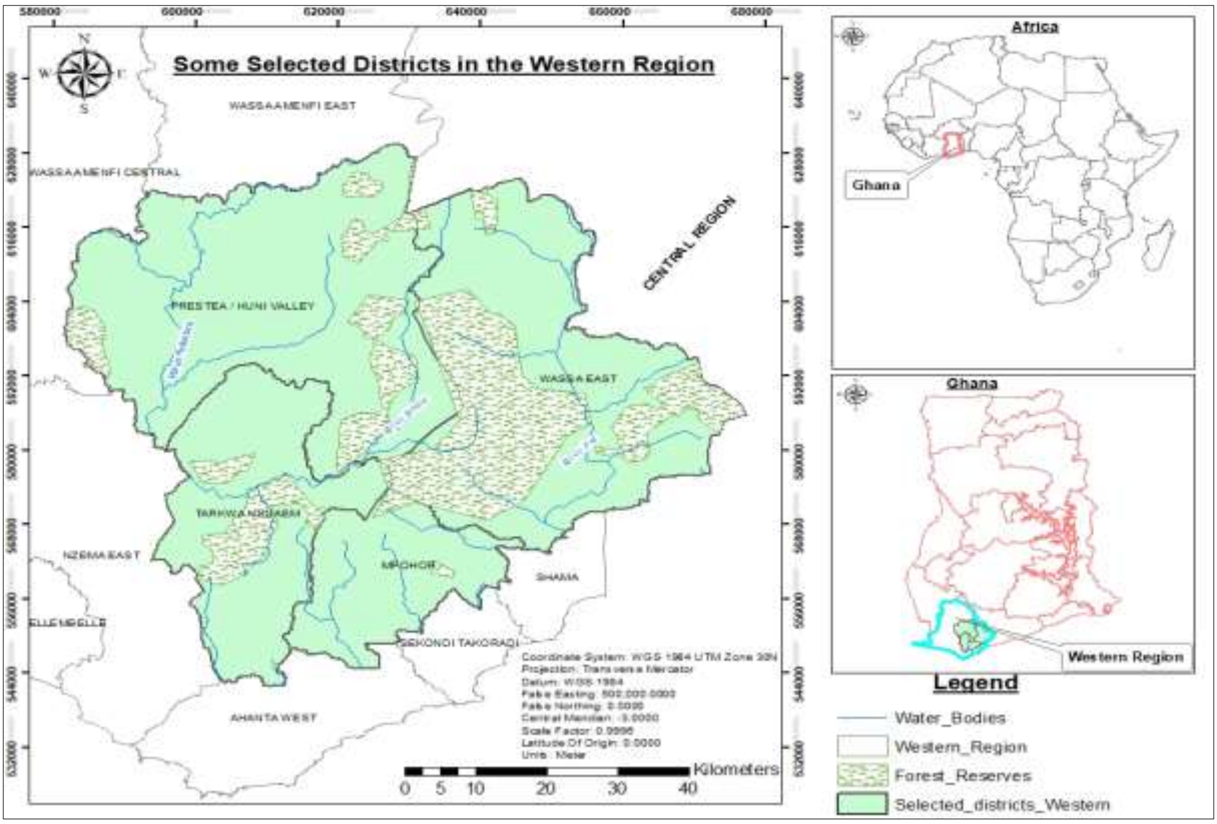

Figure 2: Map showing the study area

Source: Author's construct

The region's terrain is mostly vegetated, which has about 75% of its vegetation and lies in the equatorial climate zone characterized by moderate temperatures. The region is also well-drained, with the Pra, Bonso and Ankobra rivers covering extensive land areas. With an annual average rainfall of 1600 mm, beautiful green hills, and excellent soils characterize Ghana's Western Region. The Ankasa Conservation area is therefore the most biodiverse forest in Ghana since it is located in the region with the highest average annual rainfall.

The area's wealth of natural resources also gives it strategic relevance in the grand scheme of the country's economic development. It has been a leading supplier of cocoa, rubber, and coconut for decades, and it is also among the world's top oil palm suppliers. The Western Region's economy is dominated by offshore oil platforms and a plethora of gold miners, both small and large in gold, bauxite, iron, diamond and manganese.

After Greater Accra and Ashanti, this region ranks third in terms of infrastructure development. It has also profited from the supply of social amenities due to its relatively high urbanization rate. In 2021, the population of the region was recorded as 2,060,585 with an average population density of 861.8 per square kilometer (GSS, 2022).

3. RESEARCH METHODOLOGY

This paper explores the use of geospatial techniques to identify the effects of mining activities generating the landscape metrics and numerical data in the region of interest. The research methodology were categorized as sources of data, data processing and data analysis.

3.1 Source of Data

Secondary data comprising of satellite tiles with minimum cloud cover of 10% from the United States Geological Survey (USGS) were mainly used to achieve the objectives of the research. The details of the data used is seen in the table below.

Path/ Row ID	Date of Acquisition	Land sat Type
194/056	2007/01/13	7
	2023/01/02	9
193/056	2007/01/13	7
	2023/01/02	9

3.2 Data Processing

Image processing is critical to the study because it prepares the image for analysis by removing image defects to improve visibility. For the Landsat 7 tiles, cloud contamination, orbit, or sensing geometry issues were detected during image capture, hence the gap filling technique was used to correct the distortions on the images. A mosaic was done to combine the different satellite tiles in their respective years and a subset of the region of interest was extracted. Data analysis were done using the ArcGIS and Envi applications.

3.3 Data Analysis

Interactive Supervised classification analysis was done in ArcMap 10.8 to quantify the various land uses within the study area. To ensure accuracy in the analysis, Google Earth was used to select training samples in the classification process. Change detection analysis was also explored to quantify the various changes in land use/land cover from 2007-2023. Vegetative indices were also analyzed in the study area to determine both quantitative and qualitative measures of vegetation cover, vitality, and growth dynamics. In addition, temperature maps were developed to identify the resultant changes in land use/land cover on thermal emission rates. This involved the use of the ENVI software to undertake radiometric and thermal atmospheric correction on the Landsat images. Radiometric correction was necessary because it subtracts the background signal (bias) and divides by the instrument's strength to provide a radiance (in W/m2sr m). This provided the opportunity for the emissivisity normalization to be calculated and the resultant results in Kelvin was changed to Degree Celsius using the band math ratio [(b1) – (273.15)].

Furthermore, the CA Markov chain model was also explored because it is technique that can predict accurately and precisely the long-term LULC dynamics in both spatiotemporal patterns. This concept was initially used for land use modeling by Burnham (1973). However, numerous studies have attested to the Markov model's accuracy (Hamad et al., 2018; Karimi et al., 2018; Lu et al., 2019; Khawaldah et al., 2020). In summary, the CA Markov chain model merely explains the LULC change from one time to the next anticipating future change (Kumar et al., 2014). The method was used to predict changes in land use is explained by equation below.
S (t, t + 1) = Pij × S (t). Where S (t) denotes the state of the system at time t and S (t + 1) denotes the state of the system at time t + 1. The transition probability matrix in a state, Pij, is determined using the following formula.

$$P = \|p_{ij}\| = \left\| \begin{matrix} p_{1,1} & p_{1,2} & \dots & p_{1,N} \\ p_{2,1} & p_{2,2} & \cdots & p_{2,N} \\ \dots & \dots & \dots & \dots \\ p_{N,1} & p_{N,2} & \cdots & p_{N,N} \end{matrix} \right\|$$

$$(0 \leq P_{ij} \leq 1)$$

P is the probability of a transition; Pij is the likelihood that a state will change from one now held to another in the future; and PN is the likelihood that a state will exist at any given moment. The CA Markov model provided the framework to predict the changes in land cover over time.

4. RESULTS AND DISCUSSIONS

Surface mining, in particular, is one of the leading causes of global land degradation and environmental degradation. Therefore, this chapter explores this fact by analyzing spatial data over a 16-year period and determining the ramifications of mining from the historical data offered by spatial information.

4.1 Degree of Land Use/ Land Cover (LULC) Changes in Selected Districts in the Western Region

An initial investigation was carried out using hyperspectral images from Google Earth. To have a broader understanding of the changes on the surface due to illicit mining activities, historical images using the Time Slider option in Google earth was also used. Figure 3 gives a vivid visual description of how illegal mining activities are causing dire consequences to the land cover in Ghana especially to some selected districts in the Western Region.

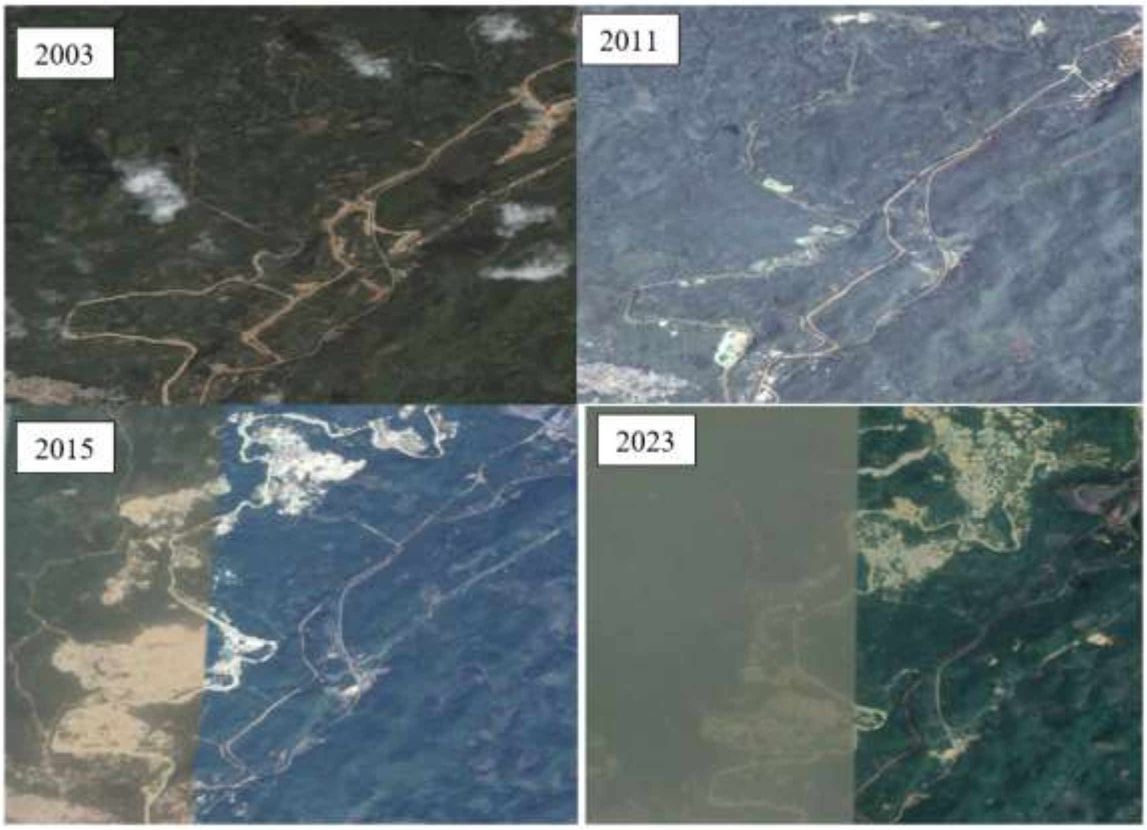

Figure 3: Hyperspectral imagery of identified illicit mining sites within the Western Region

Based on a review of hyperspectral images at an average height of 40m to the ground, Figure 3 reveals how mining has deteriorated a section of the Prestea Huni Valley District in the Western Region. This unfortunate phenomenon is not exclusive to Ghana's Western Region, but has also been observed in the country's Eastern, Ashanti, Western North, and Northern regions.

Therefore, using Landsat spatiotemporal data from 2007 to 2023, Google Earth reference data, and preexisting land cover data, this research employed supervised classification techniques to map and track unlawful mining activities. The methodology is based on the premise that changes in land cover caused by mining can be detected by comparing spatial-temporal images captured in the same month but across years as seen in Figure 4

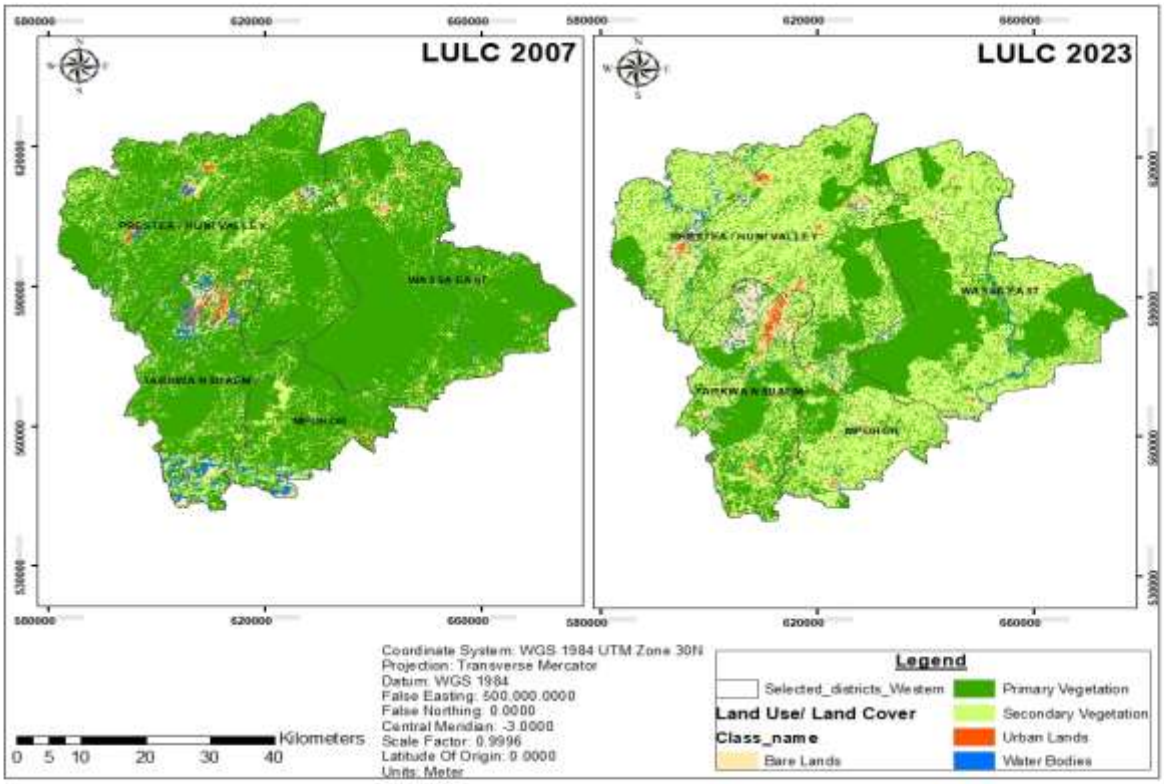

Figure 4: Land use/ Land cover map of Selected Districts in the Western Region
Source: Author's Own Construct

Figure 4 shows a comparison between the land use and land cover maps of four representative Western Region districts from 2007 to 2023. Five land cover classes' namely Urban Lands, Primary and Secondary Vegetation, Water Bodies and Bare Lands were identified in the study area. According to the classified images, the region is extremely green. This backs up claims made in other sources about the region's principal economic activity being agriculture. The few bare land areas are shown in cream, whereas urban lands are shown in orange. Primary and secondary vegetation are both represented by green shades.

In reference to this paper, LULC was categorised as follows in Figure 4;

- Urban Lands- This refers to parts of the landscape altered by human activity. This includes man-made structures, tarred surfaces, mining concessions, among others fall under this category.
- Primary Vegetation- This refers to dense forested lands.
- Secondary Vegetation- This refers to scattered trees, shrubs, farmlands and grasslands
- Bare Lands- This refers to exposed land surface, rocks and soil
- Water Bodies- This refers to all flowing water sources in the study area

Examining the LULC alterations from 2007 to 2023 in Figure 4 reveals a distinct decline in primary vegetated lands. This is cause for concern because, as of 2010, 75% of the region's land was located within Ghana's forest zone. Interviewing key stakeholders in issues related to "Galamsey," they attributed this rapid conversion of primary vegetation to mining activities in which individuals degrade forested lands in search of valuable minerals. Despite the best efforts of regulatory bodies, more needs to be done to maintain the long-term viability of Ghana's forested areas, particularly in the Western Region.

The change was also quantified using a statistical method called change detection analysis. This is accomplished by comparing and contrasting images of the same location taken at various periods of time. Significant shifts in land use patterns, such as the growth of urban areas or the reduction of agricultural land, can be readily identified using this method. The statistics of the LULC changes is depicted in the chart in Figure 5.

Figure 5: Change Detection Statistics in LULC of Selected Districts in the Western Region
Source: Author’s Own Construct

The change detection graph vividly illustrates the land cover categories that have changed over a 16-year period as seen in Figure 5 and 6. Secondary vegetation has supplanted primary vegetation, a decrease of 87%. This makes secondary vegetation consisting of a few trees, shrubs, and grassland the predominant type of land cover in the area of interest today. In addition, Figure 6 provides a simplified tabular representation of how land use has changes over the years.

Land Cover	2007 (sq. km)	2023 (sq. km)	Percentage Change
Bare Lands	74.3	320.2	**76.8%**
Primary Vegetation	3,872.3	2,070.4	**-87%**
Secondary Vegetation	774.4	2,364.1	**67.2%**
Urban Lands	74.9	58.8	**-27.4**
Water Bodies	94.1	76.5	**-23.1%**

Figure 6: Summarized Statistics of LULC of Selected Districts in the Western Region
Source: Author's Own Construct

It is worth noting that, the research indicates a substantial increase in bare lands in the study area, the majority of which are as a result of mining concessions replacing land cover types that used to be urban lands, water bodies and vegetated lands. These shifts in LULC represent substantial land surface conversions, and these are crucial drivers in the deterioration of the landscape's natural ecology.

NDVI analysis is another essential instrument for confirming land use and land cover changes. Using NDVI analysis, researchers can determine the vegetative status of a region. Since the literature suggests that the studied area is lush with vegetation, NDVI analysis was also performed to determine the current condition of the vegetative cover and to analyze the impact, if any, of mining on the area as seen in Figure 7.

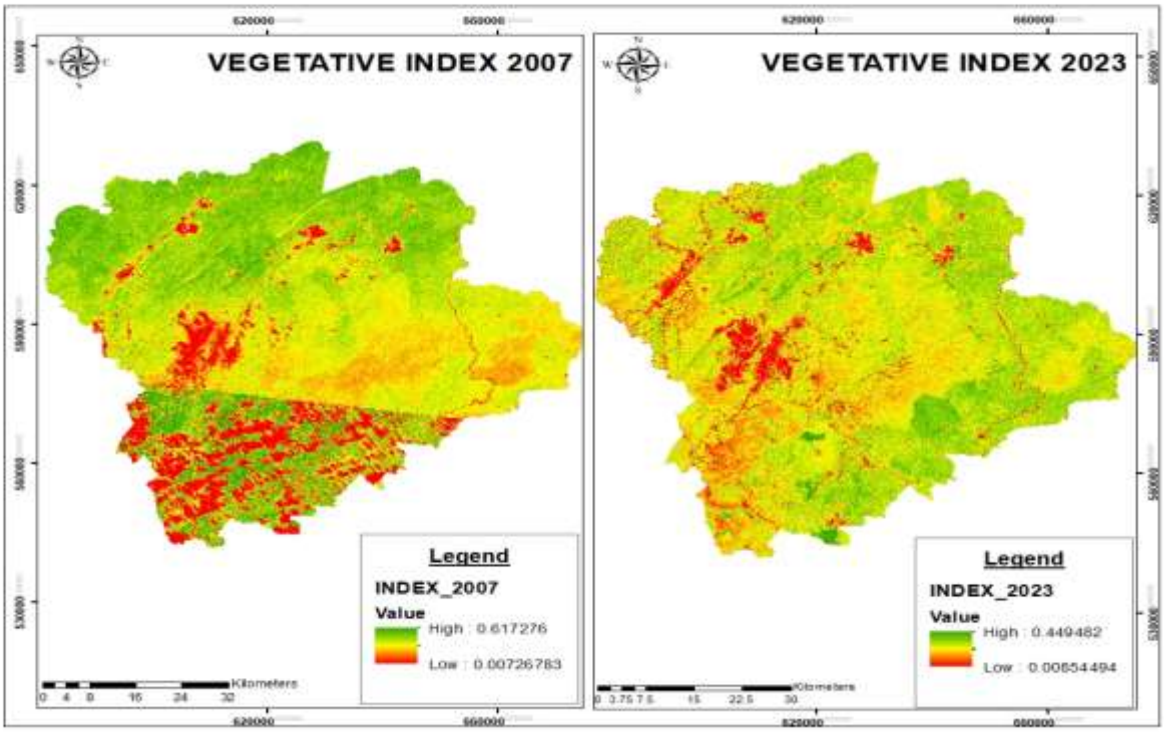

Figure 7: Normalized Difference Vegetative Index (NDVI) of Selected Districts in the Western Region
Source: Author's Own Construct

NDVI measurements of vegetation's spectral reflectance indicate the presence of vegetation and its general health (EOS, 2022). NDVI values ranges between -1 and +1. If the NDVI value is close to zero, there are likely no green foliage present and the area may be urban (USGS, 2018). Negative values or values less than 0.1 indicate a lack of vegetation. This includes water, bare ground, and exposed granite areas. NDVI values between 0.2 and 0.5 may be induced by sparse vegetation, such as shrubs and grasslands, or dormant crops. According to the analysis of NDVI data, the highest vegetative index registered in 2023 was 0.45 indicating the presence of moderately healthy plants. This is more prevalent in the region's, as shown in Figure 7. High NDVI values (between 0.6 and 0.9) indicate dense vegetation, such as that found in temperate and tropical forests or at the peak of crop growth (USGS, 2018).

4.2 Degree of Land Surface Temperature

Land surface temperature is affected by the change in land use and land cover over time.

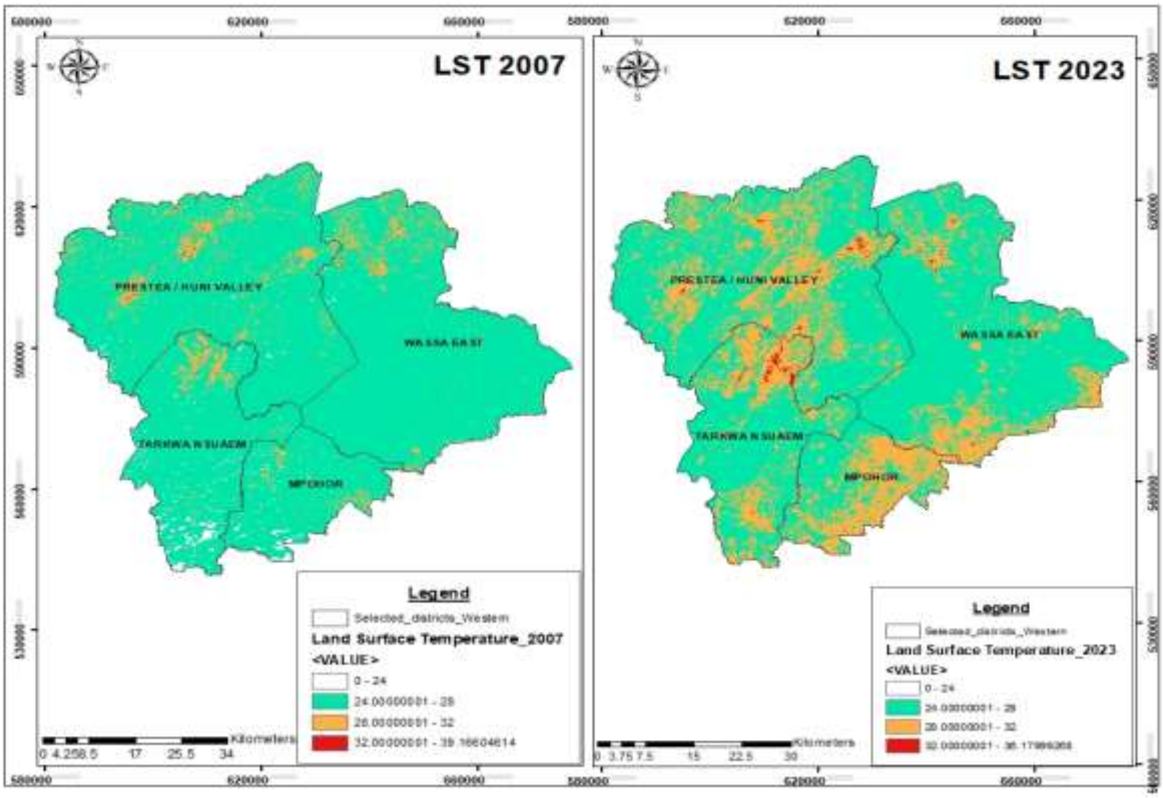

Figure 8: Land Surface Temperatures (LST) of Selected Districts in the Western Region
Source: Author's Own Construct

The amount of heat radiated by Earth as a result of sunlight striking the ground or the tops of plants can be measured by taking their land surface temperature (LST). This makes LST a useful indicator of how much energy is being transferred from the land surface to the atmosphere, as well as a sensitive indicator of changing surface conditions. Figure 8 shows the results of an LST analysis performed to investigate the impact of LULC shifts on annual mean surface temperatures. A rise in average temperatures across the Western Region's selected districts is visible on the map. Increases in LST are easily observable in regions where illegal mining is prominent, such as the Prestea Huni Valley District, the northern portion of the Tarkwa Nsuaem District, and the Mpohor Districts as a whole. An average increase of 4^{0C} in LST from 2007 to 2023 is cause for alarm in the context of global warming and climate change.

To add to this, the study tried to identify if there was a correlation between the variations in climate with the prevalence of mining activities from the Ghana Meteological Agency in Figure 9. Unfortuantely, up-to-date rainfall information was not made available. The available data showed a weak relationship between LULC shifts and the related surface temperature shifts. This may, however, be because too little is known at this time to make any firm conclusions.

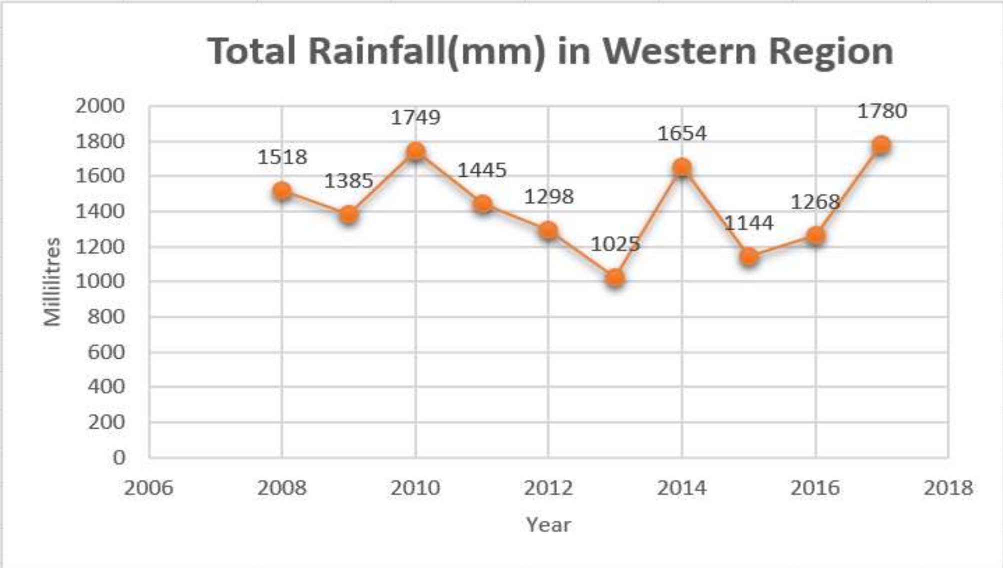

Figure 9: Rainfall data in the Western Region from 2006-2017
Source: Ghana Meteological Agency

Figure 9 shows that mining concessions have little effect on the fluctuating yearly rainfall measurement. An accurate picture of how illicit mining activities contribute to regional climate variability can be mended by including additional variables, such as humidity, elevation, and recent rainfall data collected at the district level.

4.3 Predicting LULC changes using CA Markov Model

The CA-Markov chain model is a powerful tool for predicting spatial LULCC because it combines the Markov Chain Model (MCM) and the Cellular Automata (CA) model. To effectively forecast spatiotemporal changes in LULCC, the integrated CA-Markov chain model is employed (Halmy et al., 2015). The CA model's central tenet is that the state of a cell at any given time may be defined in terms of both its immediate environment and the state of neighboring cells with respect to its immediate past (Liping et al., 2018).

To determine how well the CA Markov model can foretell future changes in LULC, it was applied to the classified land use/land cover images (Figure 4). Kappa index accuracy also indicated very excellent agreement of the selected periods, and the overall accuracy for each period was above 80%, indicating extremely good precision of the analysis. Using the CA Markov Model, it predicts that every 16 years without the proper safeguards in place, primary vegetated areas is anticipated to decrease by 31.5%.

5. CONCLUSION

Soil disturbance and associated vegetation disturbance are hallmarks of mineral resource extraction, especially opencast mining (Kuzevic et al., 2022). This research utilizes remote sensing technologies to examine land cover changes over time using multispectral images in order to determine the effects of mining operations in selected districts in the Western Region. Analysis of land cover change from 2007 to 2023 was performed using Landsat 7 Enhanced Thematic Mapper (ETM) and Landsat 8 images. The spatial distribution of land cover was detected, and their temporal changes was provided for analysis, using training data based on five classes (urban developments, primary and secondary vegetation, bare lands and water body).

There is a significant decrease in the amount of primary vegetation, urban lands and water bodies in the research region, as measured by change detection data. This can be attributed to the pervasive mining activities in the study area. Time-varying patterns of vegetative cover and surface temperatures were also visualized using the Normalized Difference Vegetation Index and Land Surface Temperature showing a decline in vegetative cover resulting in an increase in average land surface temperatures. After examining the results of mining activity in the area over a 16-year period, the analysis of these changes revealed that 87% of primary vegetated areas had been altered. Predictive analysis also revealed that every 16 years without the proper safeguards in place, vegetation is anticipated to decrease by 31.5%. Finally, the results confirmed the feasibility of using remote sensing data to document changes and assess the condition of landscapes affected by mining activities.

The primary purpose of this research was to provide information through geospatial data on how illegal mining activities in Ghana can be resolved. This goal was accomplished by analyzing the spatial and temporal shifts in selected district in the Western Region's land use/cover, vegetation, and projected shifts in land cover. This method employs GIS and remote sensing in combination with Markov model approaches. The study's findings corroborate those of previous works on the topic of mining's environmental impacts, including those by Vasuki et al., (2019) and Awotwi et al., (2018).

5.1 Recommendation

Through evaluating and examining the results of the study, the following recommendations to help ensure sustainability in mining regions are;

- Identify areas most vulnerable to illegal mining through spatial data and protect them by increasing the security in such regions. By doing this, the community can ensure that those in search of valuable minerals do not infringe on farms and protected areas.

- Invest in the acquisition of cloud-free multispectral images in order to frequently monitor the changes on the land caused by mining. When these mining concessions are closely monitored, any problems that arise on the ground can be found and dealt with as soon as possible. This will contribute to a nationwide decrease in illegal mining.
- Although local mining cooperatives have been promoted and a formal registration process for artisanal miners should made available, intense education is needed to the general public. By doing this, necessary skill training can given to small-scale miners on the effects of irresponsible mining on health, safety, and the environment. Also, the government will be able to supervise mining practices and activities more carefully by granting permits to local mining cooperatives.
- Initiatives by the local government needs to be intentional in creating attractive opportunities for alternate jobs in the community. By doing this, the locals are less inclined to engage in illicit mining activities; this is a long-lasting solution that involves giving rural populations access to economic prospects.
- The environment can be severely impacted by traditional mining processes, and some common practices, such as open pit and underground mining, pose some of the greatest environmental concerns. Mining corporations can lessen their influence on the environment by switching to innovative and low-impact mining methods
- In mining locations, rehabilitation of former mining sites can aid in promoting environmental sustainability. Although measures have been put in place for corporations to apply a variety of land rehabilitation strategies to restore the productivity of mined land or expedite the land's natural recovery, these measures do not apply to small scale or mining activities. To ensure environmental sustainability, restoration procedures should cover both small and large scale mining to preserve our lands.

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