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Original Article

Delineation of Land use Land cover Dynamics in Mining areas by Remote Sensing and GIS, the case of Buzwagi Gold mine, Kahama, Tanzania

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Land Use Land Cover, Mining Activity, Remote Sensing, Geographical Information System Buzwagi Gold Mine.

ABSTRACT

The present study aimed at studying dynamics of land use land cover (LULC) in Buzwagi gold mine project by using remote sensing and GIS. The project is in the North East of Tanzania in Shinyanga region. The dynamics of the LULC was studied by using satellite images which were downloaded from United States Geological Survey (USGS) website. The satellite images used were of the years 1993 (which represents the study area before mining commenced), 2013 (which represents the study area during the operation phase) and 2023 (which represents the study area after closure of the mining activity). The images were classified by using unsupervised classification. The results showed that the vegetation cover decreased from 5887 hectares (61% of the total area) in 1993 (before the mining commenced) to 1531 hectares (approximately 16% of the total area) in 2013 (during the operation phase). On the other hand the built up area increased from 429 hectares (4.45% of the total area) in 1993 to 2673 hectares (27.75% of the total area) during the operation phase and the barren land increased from 2663 hectares (approximately 28% of the total area) in 1993 (before the mining activity commenced) to 4760 hectares (approximately 49% of the total area) during the operation phase. The transition between the operation phase and the post operation phase showed a decrease in the barren land from 4760 hectares (approximately 49% of the total area) to 3016 hectares (approximately 31% of the total area). On the other hand the built up area decreased from 2673 hectares (approximately 28% of the total area) to 2056 hectares (approximately 21% of the total area) during the transition. During the transition from operation phase to post operation phase the vegetation cover increased from 1531 hectares (approximately 16% of the total area) to 3455 hectares (approximately 36% of the total area). Based on the results obtained it was concluded that all vegetation, built up area and barren land showed significant change while water body did not show a significant cover change.

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INTRODUCTION

Mining plays a crucial role in the economies of both developing and developed nations. For instance Ghana, the second-largest gold producer in Africa after South Africa (Tawiah & Baah, 2011), is also the continent's third-largest producer of aluminum and manganese (Boon & Ababio, 2009). The mining sector in Ghana contributes approximately 5.7% to the country's GDP and generates about 40% of its foreign exchange earnings (Aryee, 2001). Tawiah and Baah (2011) highlight key benefits of the sector, including foreign exchange earnings, employment opportunities, and tax revenues.

Similarly, in Tanzania, the mining sector's contribution to GDP increased from 1.94% in 1999 to 2.23% in 2012 (Magai & Márquez-Velázquez, 2011), reaching 3.3% in 2013 (Gupta, 2020). Despite Tanzania being classified as a low-income country, mining has significantly contributed to its economic development (Juma et al., 2016).

While mining is economically beneficial, it also has major environmental consequences, such as land degradation, loss of biodiversity, and displacement of communities (Simmons et al., 2008; Townsend et al., 2009; Gabarrón et al., 2018; Schueler et al., 2011). Mining-related accidents, including fatalities from collapsed mines, have been reported (Gupta, 2019). Furthermore, groundwater in gold mining areas has been found to contain elevated levels of cyanide and heavy metals, particularly during the dry season (Gomezulu et al., 2018). Open-pit mining, such as at Buzwagi, requires clearing vast land areas, making land cover change studies essential. Given these environmental impacts, mining projects in many countries, including Tanzania, are subject to mandatory Environmental Impact Assessments (EIAs) (EMA, 2004). These EIAs emphasize the need for re-vegetation or reforestation during post-mining restoration. The environmental management plans (EMPs) submitted with EIA reports outline measures for land rehabilitation after mining operations cease. Assessing land use and land cover (LULC) at different project stages is therefore necessary to evaluate EMP implementation.

Geographic Information Systems (GIS) and remote sensing technologies have been widely applied across various sectors. Magige et al. (2020) demonstrated the application of GIS in tourism, highlighting its capabilities in proximity analysis, network analysis, overlay analysis, temporal change detection, statistical analysis, and three-dimensional modeling. Remote sensing and GIS are effective tools for mapping vegetation and other surface features, as different land types reflect distinct wavelengths of light (Kumar et al., 2013). According to Bernhardsen (1999), GIS can integrate and store relationships between different types of spatial data, while Vairavamoorthy et al. (2007) emphasize its ability to transform large datasets into valuable information through modeling tools.

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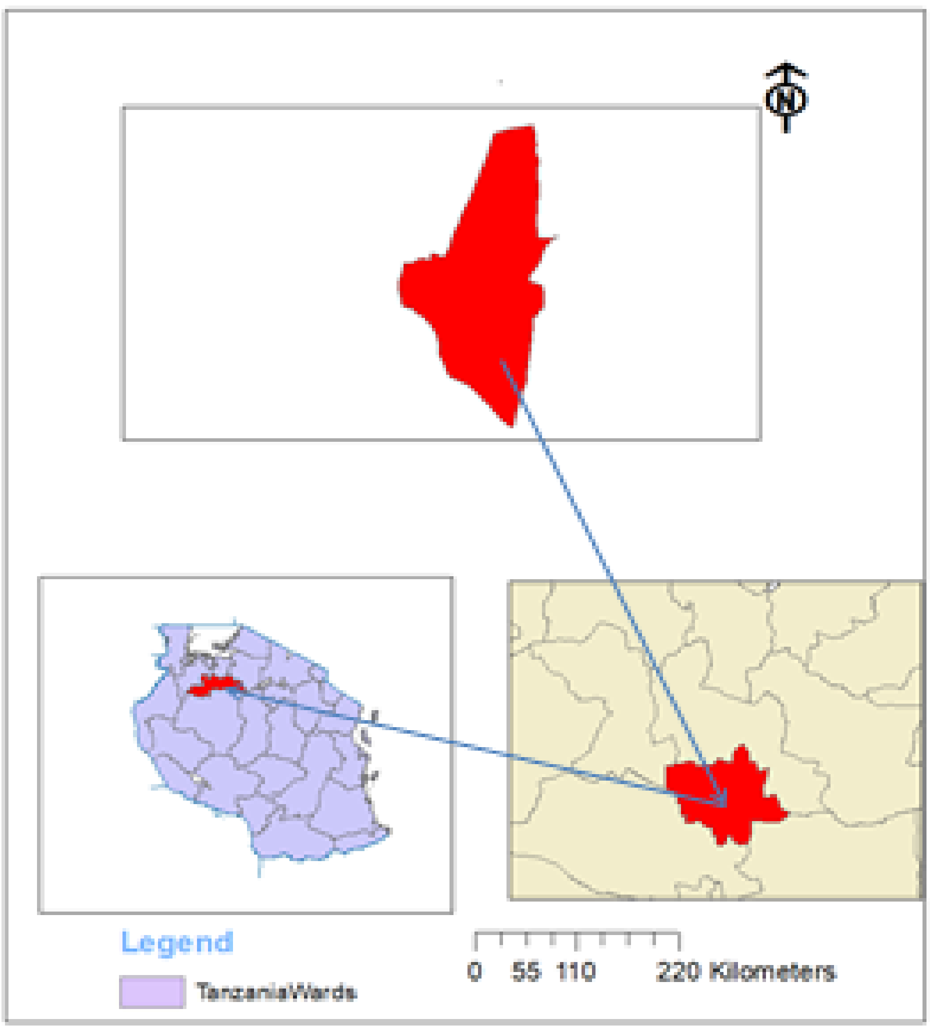
The application of remote sensing and GIS in analyzing land cover changes caused by mining activities has been widely acknowledged (Stefoul et al., 2010; Joshi et al., 2016). Beyond monitoring land cover dynamics, these technologies are also used in mineral exploration (Ghazi, 2023) and risk assessment (Sutton, 2012). The availability of multi-temporal and multi-spectral satellite imagery makes remote sensing and GIS highly effective for evaluating spatial and temporal land cover changes. Khan and Javed (2012) emphasize the importance of using satellite images captured during the same season to minimize seasonal variations and ensure uniform spectral and radiometric characteristics. This study aims to assess LULC changes using remote sensing and GIS, providing insights into the environmental impact of mining activities.

METHODOLOGY

The study area

The study was conducted at Buzwagi Gold Mine, located in northern Tanzania within Mwendakulima Ward, which falls under the Kahama Town Council in the Shinyanga Region (Fig. 1). The mine is situated between latitudes 3°15' and 4°30' south of the Equator and longitudes 31°30' and 33°00' east of Greenwich. Buzwagi Gold Mine was one of the mining projects that have since been abandoned; having commenced operations in 2009 and its operations were ceased in September 2019.

Figure 1: The location of the study area



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Data collection

The study utilized satellite images obtained from the United States Geological Survey (USGS). Landsat images of 1993 (Landsat 4), 2013 (Landsat 7 ETM), and 2023 (Landsat 8) were analyzed (Table 1). The 1993 image was used to examine land use and land cover (LULC) before mining activities began, while the 2013 image provided insights into LULC changes during the mine's operational phase. The 2023 satellite image was used to assess LULC after the mine had been abandoned.

Satellite images processing and classification

To ensure high-quality satellite images, the cloud cover threshold was set to less than 30% during the download process. Additionally, all necessary preprocessing procedures were performed. Each downloaded image set contained seven spectral bands. From these, a composite image in BGR (Blue, Green, and Red) format was created by combining the bands. The composite bands were then clipped to fit the study area using the extraction by mask tool. Image classification was conducted using ArcMap version 10.5 through unsupervised classification, where different band combinations were applied to distinguish various land cover types. Table 1 shows the time, type and location of acquired satellite images.

Table 1: Type of satellite image, location and time acquired

Type of image	Date acquired	Path/Row
Landsat 4	04/02/1993	170/063
Landsat 7 ETM	24/07/2013	170/063
Landsat 8	01/01/2023	170/063

RESULTS AND DISCUSSION

Land Cover Changes before the Mining Operations began

The satellite image from 1993 reveals that the majority of the land **5,887 hectares,** accounting for **65.23%** of the total area was covered by vegetation (Fig. 1, Table 1). In contrast, built-up areas occupied only **429 hectares** (**4.45%** of the total area). This limited built-up space was likely due to the small population in the region at the time, as population size is generally **inversely related** to vegetation cover (Khan & Javed, 2012).

Tanzania has experienced **rapid population growth**, which significantly impacts land use patterns. For instance, in **1992**, the country's population was **less than 30 million**, but by **2013**, it had surpassed **45 million** (UN, 2003). As population increases, the demand for residential, commercial, and infrastructural development also rises, leading to **a reduction in vegetation cover**. Given the relatively low population in the study area in 1993, the demand for built-up land was correspondingly low.

In addition to vegetation and built-up areas, **barren land** accounted for **2,663 hectares (27.60%** of the total area) before mining operations began. Meanwhile, water bodies covered only **669 hectares (6.93%** of the total area) (Fig. 1, Table 1). The limited water coverage can be attributed to the absence of **large water bodies** such as rivers or lakes within the study area. At the time, local communities primarily relied on **groundwater sources**, such as **shallow wells, groundwater springs, and stagnant water pools.** The presence of some water in the satellite imagery is likely due to **seasonal factors**, as the image was captured during the **rainy season**, when surface water accumulation is more common.

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Figure 2. Classification of land use land cover in area surrounding Buzwagi gold mine in 1993

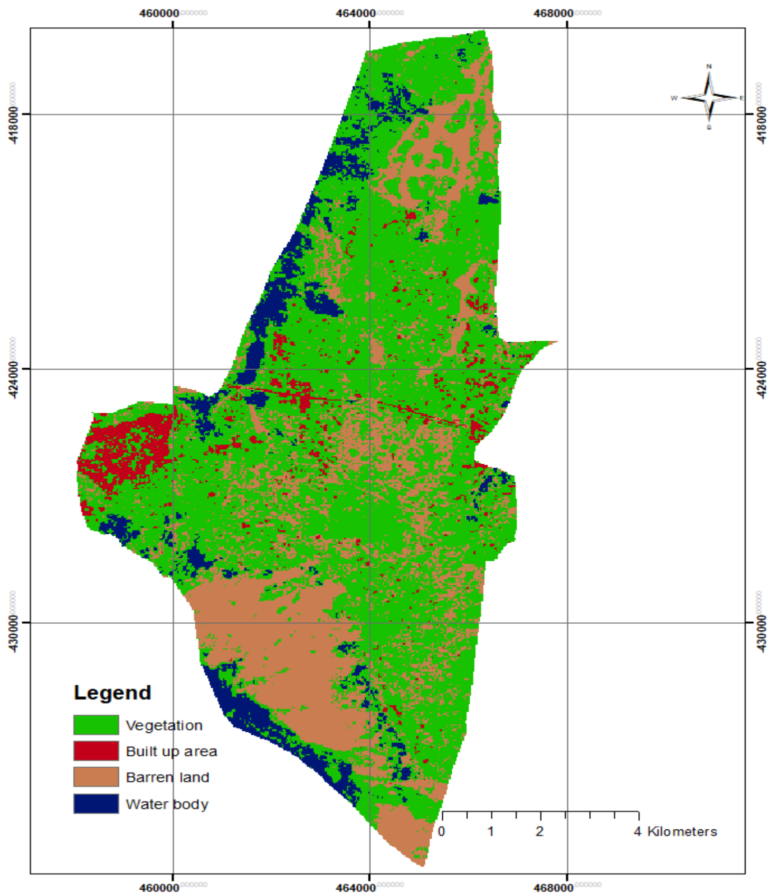

Table 2: Amount of LULC in area surrounding Buzwagi gold mining in 1993

Cover type	Area (Hectares)	Percentage area
Barren land	2663	27.60
Built up area	429	4.45
Vegetation	5887	61.02
Water body	669	6.93

Land Cover Changes during the Mining Operation Phase

During the operational phase of the mine, barren land became the dominant land cover, occupying 4,760 hectares (49.41% of the total area) (Fig. 3, Table 3). This significant increase in barren land was likely due to extensive land clearance to facilitate mining activities. The impact of mining is evident in the drastic decline in vegetation cover, which shrank from 5,887 hectares (approximately 61%) in 1993 (before mining began) to just 1,531 hectares (approximately 16%) during the mining phase (Fig. 3, Table 3).

The loss of vegetation highlights the environmental impact of large-scale mining operations, as forests and other natural vegetation were cleared to make way for excavation sites, infrastructure, and

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processing facilities. The shift from a predominantly vegetated landscape to one dominated by barren land underscores the extent of habitat destruction and ecological disturbance caused by mining.

Additionally, there was a slight increase in water coverage, from 669 hectares (6.93%) before mining commenced to 670 hectares (6.95%) during the operational phase. This small increase may be attributed to the construction of a water storage pond within the mining site, which was likely built to support mining activities, such as ore processing and dust suppression. Though minor, this increase indicates human intervention in water management within the mining zone.

Overall, the transition from a vegetation-rich landscape to a barren, mining-dominated environment during the operational phase demonstrates the significant land use changes driven by extractive activities.

Figure 3. Classification of land use land cover in area surrounding BGM in 2013

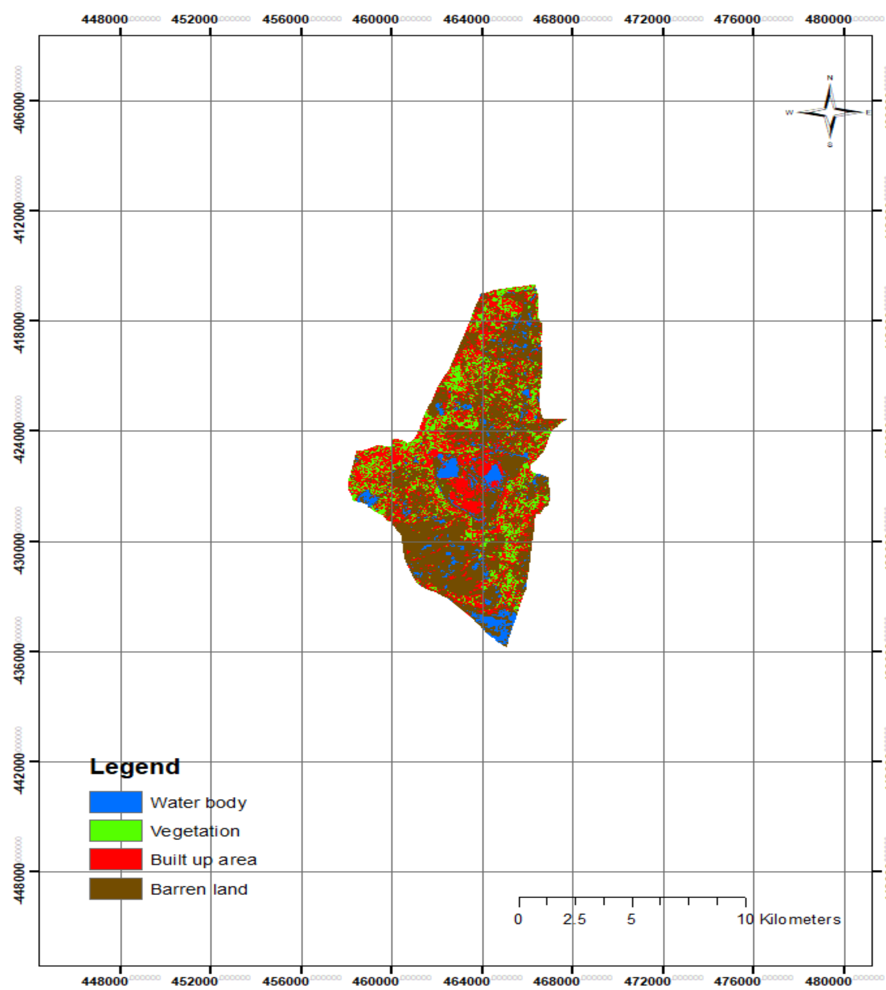

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Table 3: Amount of LULC in area surrounding BGM in 2013

Cover type	Area (hectares)	Percentage area
Barren land	4760	49.41
Built up area	2673	27.75
Vegetation	1531	15.89
Water body	670	6.95

Land Cover Changes after Mine Abandonment

Following the closure of Buzwagi Gold Mine, there was a remarkable increase in vegetation cover, rising from 1,531 hectares (16% of the total area) in 2013 (during the mining operation phase) to 3,455 hectares (36% of the total area) in 2023 more than a 100% increase in vegetation cover (Fig. 4, Table 4). This significant growth in vegetation is likely a result of re-vegetation efforts undertaken as part of the mine's Environmental Management Plan (EMP), which, like most mining EMPs, mandates land reclamation and ecological restoration after mining activities cease.

Simultaneously, barren land declined from 4,760 hectares (49% of the total area) during the mining phase to 3,016 hectares (31% of the total area) in the post-mining phase (Fig. 4, Table 4). This reduction in barren land is closely linked to the increase in vegetation, suggesting that reforestation or natural regrowth took place to fulfill environmental regulations and rehabilitation commitments.

Interestingly, there was also a small decrease in built-up areas, with a 23% reduction from the operational to post-operational phase. This contrasts with findings by Areendran et al. (2013), who studied LULC changes in an Indian mining district and observed no decrease in built-up areas. The decline in built-up areas in the present study suggests that some or all of the buildings previously used for offices and storage facilities were either removed or repurposed into green spaces after mining activities ended.

Another key observation is that vegetation cover experienced both negative and positive changes at different phases of the mining cycle. While there was a sharp decline in vegetation from the pre-mining to mining phase, there was a significant recovery after mining ceased. This pattern differs from Areendran et al. (2013), who observed only a negative change in vegetation cover, indicating that in some mining areas, land restoration efforts may be minimal or ineffective.

Overall, these findings highlight the positive impact of land rehabilitation measures after mining and emphasize the importance of enforcing environmental restoration policies to ensure sustainable land recovery following extractive activities.

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Figure 4. Land use land cover in area surrounding BGM in 2023

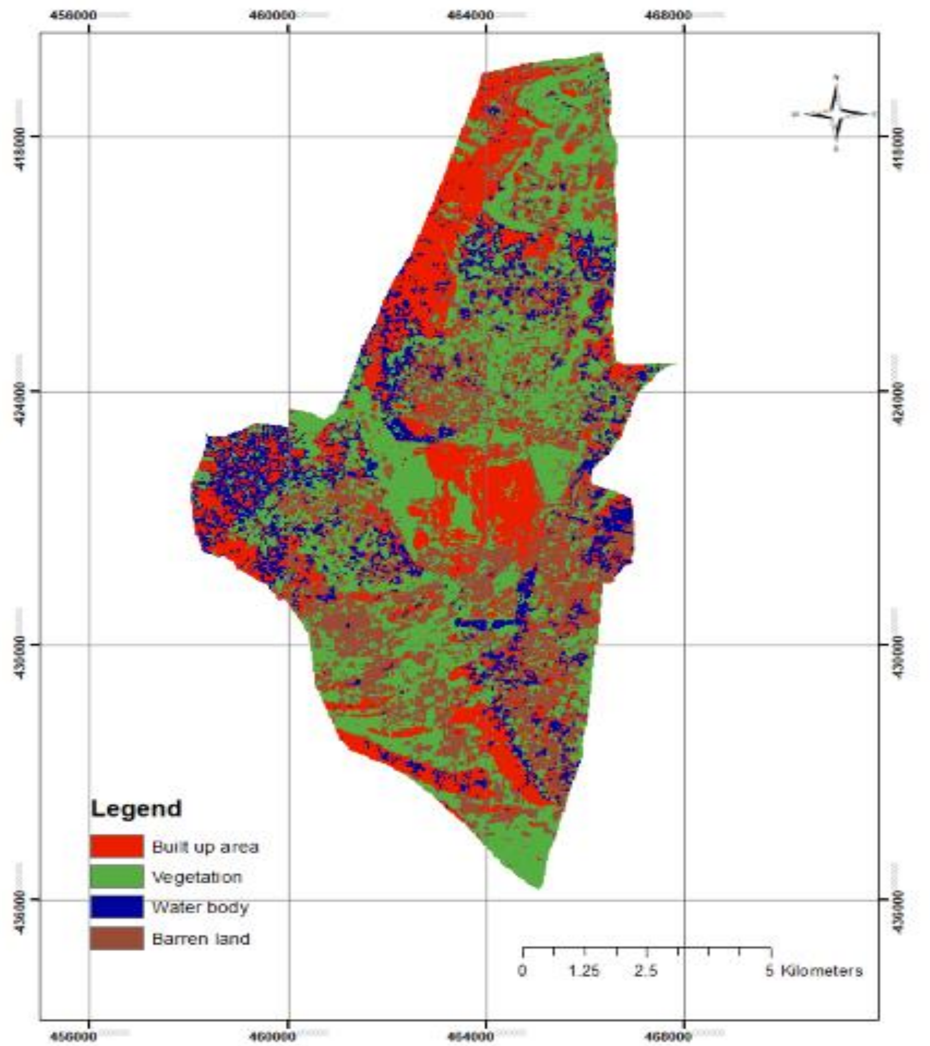

Table 4: Amount of LULC in area surrounding Buzwagi gold mining in 2023

Cover type	Area (hectares)	Percentage area
Barren land	3016	31.25
Built up area	2056	21.31
Vegetation	3455	35.80
Water body	1123	11.64

CONCLUSION

This study analyzed **Land Use and Land Cover (LULC) dynamics** using **Remote Sensing and GIS**, utilizing **multispectral Landsat images** from **1993, 2013, and 2023**. The findings revealed **significant LULC changes** due to mining activities across three key phases: **before mining (1993), during mining operations (2013), and after mine closure (2023).**

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During the transition from the **pre-operation to operation phase**, **vegetation cover declined significantly** as large areas were cleared to make way for mining activities. However, in the **operation to post-operation phase**, **vegetation cover increased**, likely due to **reforestation and land reclamation efforts** mandated by environmental laws. Similarly, **barren land expanded** during the pre-operation to operation phase as vegetation was removed for mining activities. Conversely, barren land **declined** in the post-operation phase, coinciding with the **increase in vegetation cover**, suggesting successful rehabilitation efforts.

The **built-up area experienced a significant increase** during the **pre-operation to operation phase**, likely due to **population growth and increased demand for settlements and infrastructure.** However, during the **operation to post-operation phase,** built-up areas slightly decreased, likely due to the **conversion of mining-related infrastructure back into green spaces.**

Water bodies remained relatively **unchanged** throughout the study period, as the **area lacks major surface water sources** such as lakes or rivers. Instead, the **local population relied primarily on groundwater** for their water needs. Overall, the study highlights the **major environmental impacts of mining** on land cover and the **importance of post-mining land reclamation efforts** to restore ecological balance. Effective implementation of **Environmental Management Plans (EMP)** and adherence to **environmental regulations** play a crucial role in mitigating the negative effects of mining activities on LULC.

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