



A GIS and Remote Sensing Approach in Assessing Impacts of Mining in Chegutu District, Zimbabwe

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How to cite this paper: Muromba, T.G. and Xu, L.H. (2024) A GIS and Remote Sensing Approach in Assessing Impacts of Mining in Chegutu District, Zimbabwe. *Open Access Library Journal*, **11**: e12635.
<https://doi.org/10.4236/oalib.1112635>

Received: November 15, 2024

Accepted: December 23, 2024

Published: December 26, 2024

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Abstract

Mining is one of the human activities that is an important economic activity sustaining livelihoods and hence infrastructural development. However, on the other hand, it is usually carried out at the expense of certain environmental aspects that include loss of vegetation and associated ecosystem services. This study aims to assess spatio-temporal variation of LULC in Chegutu and the extent to which mining has led to LULC change in the district. The study analysed the annual temporal variation of climatic variables namely temperature and rainfall for the period 2002-2022. To determine the spatio-temporal variation of LULC changes in Chegutu, the study applied geospatial techniques during the period 2002-2022 at five-year intervals using Landsat imagery. Trend analysis of temperature and rainfall in the study area was assessed through MannKendall test statistic. A supervised image classification was performed in QGIS for the years 2002, 2007, 2012, 2017 and 2022. Much of the land gained by constructional area landuse class was from vegetation possibly through land clearing to either construction or land degradation. A trend analysis of NDBI was performed to ascertain changes increase in constructional area since the onset of mining activities in Chegutu district with respect to infrastructural development inferred to be resulting from mining activities. Hence, the research acknowledges associated costs and benefits from the impacts of mining activities in the area. This study provides valuable insights for environmental conservation and policy makers on how to minimize the effects of mining on environmental degradation in Chegutu.

Subject Areas

Mineralogy

Keywords

Chegutu, Degradation, LULC, Mining, Zimbabwe

1. Introduction

Background of the study

For the past centuries, it has been observed that the earth's surface has significantly changed mainly due to climate variability or change or human activities [1]-[3]. However, the major change has been postulated to be mainly linked to human-driven through socioeconomic, ecological or political factors. These factors can be easily detected mainly through analysis of land use land cover (LULC) changes, to assess the influence such as local management and environmental crises that have led to changes on the earth's surface [4]. Globally, the major evident driver of LULC change is deforestation for various reasons, which is mainly associated with loss of vegetation cover [5] leading to negative effects on the environment that include biodiversity loss and climate change [6]. On the other hand, LULC changes are caused by various factors including urban expansion (urbanisation), climate change induced extreme weather conditions like droughts and floods, human activities like agriculture and mining [3] [7]-[9]. With respect to climate variables such as rainfall and temperature, they form the core of the variables used in determining environmental response to climate change or variability [10].

Mining is at the core of the basic and most important economic foundations for most countries in the world [11]. This is evident from the Mining Global Report of 2023 where the global mining market price was reported to have ballooned from approximately \$2022.6 billion in 2022 to \$2145.15 billion in 2023. However, this boom has been of course associated with major and extensive levels of pollution of environment, including topsoil (essential for agriculture) leading to sedimentation of both groundwater-surface water sources [12]. It is also quite evident from literature through chemical analysis and numerical risk assessments how mining impacts the environment [12]. However, besides the negative impacts on the environment from the mining activities that can cause vegetation loss, air pollution and water pollution, mining is also a catalyst for the development of new settlements through urbanisation and this can influence LULC. Most countries including Zimbabwe a developing country, have their economy heavily reliant on mining activities. However, mining activities can displace local communities and disrupt traditional livelihoods. It can also lead to social issues, including conflicts over land rights, water access, and compensation [13]. Cultural heritage sites may also be impacted by mining, raising concerns about the preservation of cultural and historical artifacts [14]-[17].

In Zimbabwe, mining is becoming a poverty alleviation scheme [18] where the mining sector contributes approximately 70% of the foreign exchange, infrastructure

development and revenue of the country [19]. Thus, the country has both large scale and small-scale miners [18]. However, just like the world over, including communities like Chegutu and Kwekwe in Zimbabwe, mining has been significant in improving the livelihoods of the people by reducing poverty, improving incomes and ensuring food security [20]. For example, Chegutu situated in Midlands Province is a region that is rich in mineral deposits and has witnessed significant mining activities over the years. Due to the rapid increase in mining activities (both formal and informal) and increase in the population, there have been positive and negative impacts on the socio-economic activities and the environment. These include an increase in crimes through the *machete gangs* as illegal syndicates fight for mining space [20]. However, despite the contribution of mining industry to economic growth, it also led to environmental degradation as well [18] [20].

It is thus important to understand the landscape changes that happen in areas around mineral rich environments considering that they have complex factors contributing to the LULC change dynamics. Mapping LULC is an effective way of capturing changes that occur in the environment. In the case of Chegutu where there are extensive mining activities, it is important to understand the historical patterns of LULC change in order to predict the future changes to foster environmental sustainability. This can be done for making informed decisions on protecting the biodiversity and sustainable development of the area. The main driver of LULC change is associated with deforestation, which has led to climate change and biodiversity loss [3] [7] [21]. This is evidence for the need and importance of analysing the effects of LULC changes on the environment and their driving factors. The spatio-temporal variation of LULC change in the mining sector is critical to understanding the environmental and social impacts of mining activities in an area. Many human interventions have consequences on LULC ending up affecting surface—groundwater quantity—quality [22] [23]. Ultimately these impact on changes in LULC, hydraulic works, artificial inflows, and outflows [24]. These often interact at different scales in time and space, which makes the understanding of LULC change detection a complex combination of multiple processes. Despite human activities influencing LULC change, natural forces like climate change or variability also have a bearing on LULC changes over time. However, it is worth noting that classes of the LULC are not affected equally, some may gain while others lose their areal extent.

The main environmental agent fostering environmental monitoring in Zimbabwe, is the Environmental Management Agency (EMA), while the management of land is under the custody of Ministry of Lands spearheaded by the respective Councils including Town and Rural District Councils. Of these councils in Zimbabwe, Chegutu District is undergoing land cover deterioration due to a population growth rate of approximately 2% per annum and due to environmental changes [25]. Zimbabwe's urban population is increasing, leading to both a high-water demand and the discharge of wastewater into various river systems. The

main problematic factors leading to urban growth include population growth and economic growth both of which exacerbates LULC change through various contributing factors. However, it is therefore important to balance economic growth, social welfare and environmental health with sustainable development [26]. Both illegal and legal small scale mining are inferred to be the most destructive form of mining worldwide. In Zimbabwe, generally, the mining sector increased in 2009 due to failure of microeconomic policies like the Empowerment Act leading to closure of many companies and leading the country to a shortage of basic commodities [20]. Hence, in Zimbabwe; illegal mining was observed to overshadow formal mining where over 35,000 registered artisanal miners however, illegal miners are assumed to be over one million [20]. The illegal miners mainly do opencast mining because of a lack of advanced machines and technology [27]. Opencast mining does not require sophisticated heavy machinery that is expensive to purchase where unmonitored removal of overburden, dumping and backfilling in excavated areas is unsustainably carried out. The increase in poverty for most of the districts of Zimbabwe, has driven people to practice mining. Mining has sustained the living conditions of people in various areas with mineral deposits, however on the other hand it has caused massive environmental loss and violated environmental rights of indigenous communities [20]. Artisanal miners violate fundamental rights to stay in a healthy environment for example the enjoyment of access to clean water, land and air is vital [20].

In Zimbabwe there have been reports of water contamination from heavy metals like lead and mercury, which can cause serious health problems for people and animals [20]. Soil erosion, air pollution, deforestation and water contamination have all been linked to mining activities in Zimbabwe. These have significant negative impact on the health of people living nearby, and end up contributing to climate change. Moreover, mining often requires a lot of energy, which can strain local power grids and contribute to blackouts. It can also put pressure on local communities, as they may have to compete for resources like water with the mining companies. Moreover, many communities in Zimbabwe are concerned about the loss of traditional lands and livelihoods due to mining. This is because mining can lead to the displacement of people, and the loss of access to natural resources like water and food [28]-[31]. In addition, mining can cause social and cultural disruption, and negatively impact local economies. Furthermore, there are worries about the long-term health impacts of mining, both from the exposure to harmful chemicals and the disruption of traditional ways of life. For instance a report of 2016 from EMA reports that in the city of Mutare (Bindura Nickel Mining Corporation), increased levels of heavy metals like lead in the blood of children living near a mining site, were observed. This is thought to be due to contaminated water and soil. In addition, in 2013 Centre for Research and Development reported that in the town of Shurugwi (Zimplats Mining Company), the expansion of a platinum mine has led to the displacement of more than 1000 families and the loss of traditional lands. In some cases, families have been forced to relocate

to temporary camps without adequate water or sanitation facilities.

LULC vary both in space and in time. Analysis both locally and globally shows various scales of analysis [22] [24] [32]. The variation is both in time (for example, years) and spatial resolution (as determined by the satellite spatial scales). There is no consistency in the use of a given satellite dataset due to the satellite's historical information and life span in service/product provisioning. As a result, in most cases where there is a need for long-term historical information—Landsat, is the most preferred one since it has information dating back to as early as 1970s [32] [33]. Therefore, some satellites are limited to applications in later years due to their lack of historical long-term data archives despite having better spectral, temporal and spatial resolutions. For example, Sentinel-2 (data available from the year 2016 to date) has a fine spatio-temporal resolution of 10 m and five days. Geospatial techniques offer an appropriate and timely method to evaluate LULC change over space and time through gathering multi-spectral bands of the exact location at two or more specific times. Hence, this provides a study focused on identifying any difference in a given class that might have occurred in the same selected area among the times under consideration [6]. Furthermore, conducting a change detection study of a given geographic area is essential to better understand and interpret remotely sensed data. To monitor a given land change with highly accurate results as well as low cost, it is advisable to use satellite remote sensing methods rather than traditional techniques [7].

There are various approaches in use for assessing the impact of mining activities on the environment including traditional and cutting-edge technological methods. However, most of the traditional approaches lack spatial representation of the effects of mining activities [32]. Hence, use of GIS and remote, one of the cutting-edge technological tool; is on the rise in modelling the spatio-temporal variations of environmental change. In Zimbabwe, mining industry is growing at an alarming rate. There are various mining activities in Zimbabwe including Chegutu, Kwekwe, Kadoma and Zvishavane [20] and these bring in various environmental changes including landuse change and water quality issues. Chegutu District located in Zimbabwe, is one of the areas dominated by various mineral exploration and extraction which has seen the area experience an increase in landuse change. Given the areal extent of Chegutu District, use of traditional approaches in monitoring environmental response to mining activities is less likely to give intuitive results. Therefore, a GIS and remote sensing approach was implemented to give a spatio-temporal variation response of the environment due to mining activities going on in Chegutu. This study used geospatial approaches in assessing the impact of mining activities on LULC change in Chegutu District for the period 2002-2022. This was done by determining temporal variation of rainfall, LULC trends in Chegutu district for the same period. At a global scale, the Sustainable Development Goals (SDGs) call for responsible production (SDG 12) and no poverty (SDG 1) by the year 2030 [34]. Therefore, the outcomes of this research are relevant to the policy makers in the relevant authorities within the

environmental sector as they will appreciate the spatio-temporal variation of the impacts of mining activities on the environment. Hence, resource allocation and site targeting can be easily achieved. Temporal analysis of LULC varies by authors where some authors in China considered decadal data where their three decades reveal a reduction of land uses like vegetation trend [21]. Analysis of LULC change has been employed on a continuous time series mapping using Landsat observations with various classification approaches [24] [35] [36]. In most cases, the results indicated rapid urbanization, with large LULC changes being triggered [7].

2. Materials and Methods

2.1. Description of Study Area

The study area, Chegutu District is located between the latitudes -18.200° and -17.700° , and between longitudes between 29.00° and 31.00° occupying an area of approximately 3869 km^2 , **Figure 1**. Chegutu has an annual temperature averaging 24°C , annual average rainfall of nearly 124 mm and has got an average elevation of 1190 m above sea level. Chegutu District, found in Midlands Province; is a host to massive mining activities, amongst other areas like Kadoma and Kwekwe. Zimplats mining company is the major mining operator in Chegutu, Zimbabwe. It started its underground mining in 2003. However, there was not much mining activity till 2008 which led to expansion and the formation of a city called Ngezi. Mining in Chegutu started in 1916, there was extraction of asbestos then later platinum, gold, beryl, chromite, iron ore and diamond [20].

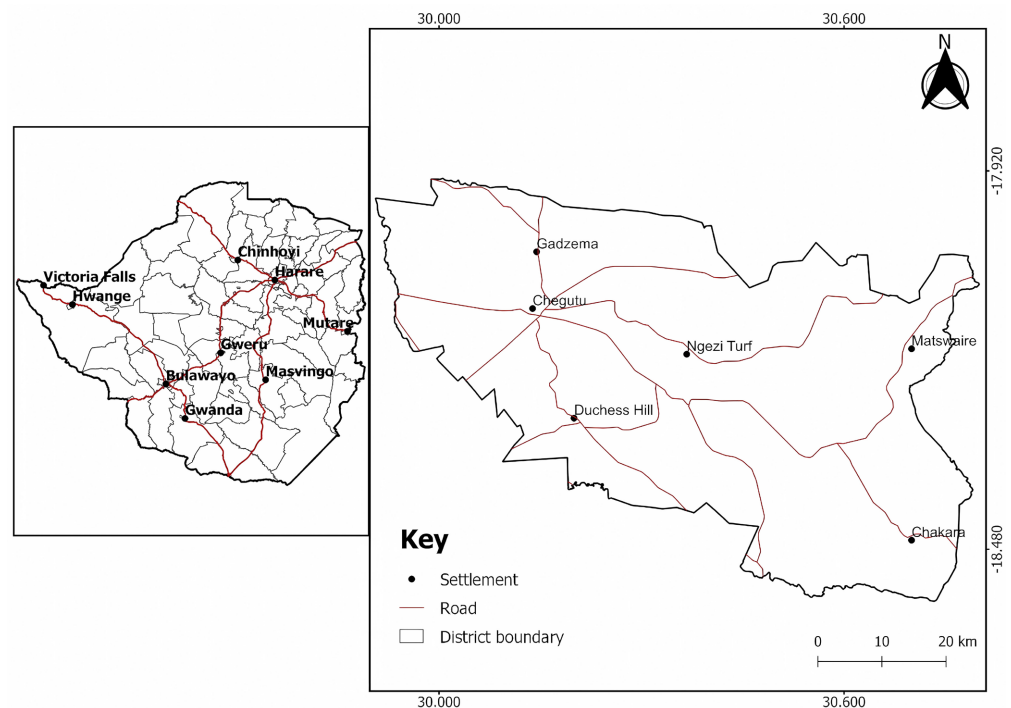


Figure 1. Study area, Chegutu District—Zimbabwe.

Topographical features

The vegetation in Chegutu consists of Mopane and acacia woodlands, grasslands and riparian vegetation. Mopane woodlands are trees that have butterfly shaped leaves and these adapt well to drier conditions. They form the dense parts of the forests in Chegutu. The open grasslands are found throughout Chegutu, they are often associated with Miombo woodlands [20]. The grasslands provide grazing land for the livestock and wildlife found in the area. Riparian vegetation is the vegetation that is found along the river sides. They are characterised by a mixture of trees, shrubs and grasses. There are however some open spaces in the area with no vegetation. There has been a decrease in the general coverage of vegetation in the area according to the satellite images [37].

Socio-economic activities

The population is mainly concentrated in the urban and mining areas of Chegutu district, mainly where mining activities are taking place. Chegutu district comprises various mining sites including Zimplats, ZIMASCO and Unki. Most of these legal mines belong to private mineral resource operator. All these mining activities take the form of various mining approaches that include underground mines (Unki and ZIMASCO, Zimplats) while ZIMASCO and Zimplats (practiced in the earlier years.) and local miners practice surface mining.

Generally, mining in Chegutu is done on both small scale and large scale. There are a variety of ways used during mining in the area. Illegal artisanal miners are very dominant in the area [20]. Open cast mining is the most common method of mining in Chegutu. For example, open cast was observed as the dominant method of extracting the minerals. It is the type of mining that involves opening of land to get the minerals through an open pit or quarry. It is used when minerals are close to the surface hence, involves the removal of overburden that is the soil, rocks and vegetation, commonly used in gold and chrome mining [38]. This is done both on large scale and on small scale. Small scale being the most common since it does not require expensive machinery.

2.2. Description of Data Collection and Analysis

The study aims to leverage geospatial technology to assess impacts of mining operations in Chegutu, Zimbabwe, on the environment (mainly urbanisation). This was done by gathering rainfall, temperature and satellite data. The study gathered satellite imagery from Landsat and secondary data (rainfall and temperature) to evaluate how mining activities in Chegutu affected the environment, especially urbanisation. **Figure 2** shows the methodological approach employed in this study.

Temporal variation of rainfall and temperature in Chegutu District

Rainfall and temperature are vital meteorological variables that affect response of LULC in an area. It is worth considering rainfall and temperature analysis in LULC change detection since landcover like vegetation, water bodies and area under agriculture have a direct response to variations in these two factors [39]. These

variables can also be used to predict future trends of LULC. In addition, heavy rains can lead to soil erosion or transport of sediments into water bodies [9] hence water pollution and ecological harm [40]. Rainfall can pose a threat to roads [6] [8], mining tailings, dams and ponds by overflowing these containment structures [40]. However, in general, mining operations require a significant amount of water. Hence, rainfall patterns can affect water availability particularly in regions with seasonal variations in precipitation [41] [42]. For this study, both rainfall and temperature data for the period 2002 to 2022 were downloaded from climate change knowledge portal (<https://climateknowledgeportal.worldbank.org/>). A time series analysis was carried out in Excel using Mann-Kendall test. Mann-Kendall test is a non-parametric statistical method and was considered to help determine the consistency in variation of rainfall and temperature in Chegutu, Zimbabwe. Research applications of the method include hydrology, environmental science for time series data analysis [43]-[48]. Mann-Kendall statistic ranges from -1 (consistently decreasing and never increasing) to $+1$, indicating a trend that is consistently increasing and never decreasing. If there is no trend in the dataset, the statistic value is 0. In this study, Mann-Kendall statistic was computed to test whether the annual rainfall and temperature trends were monotonic or not for the period 2002 to 2022.

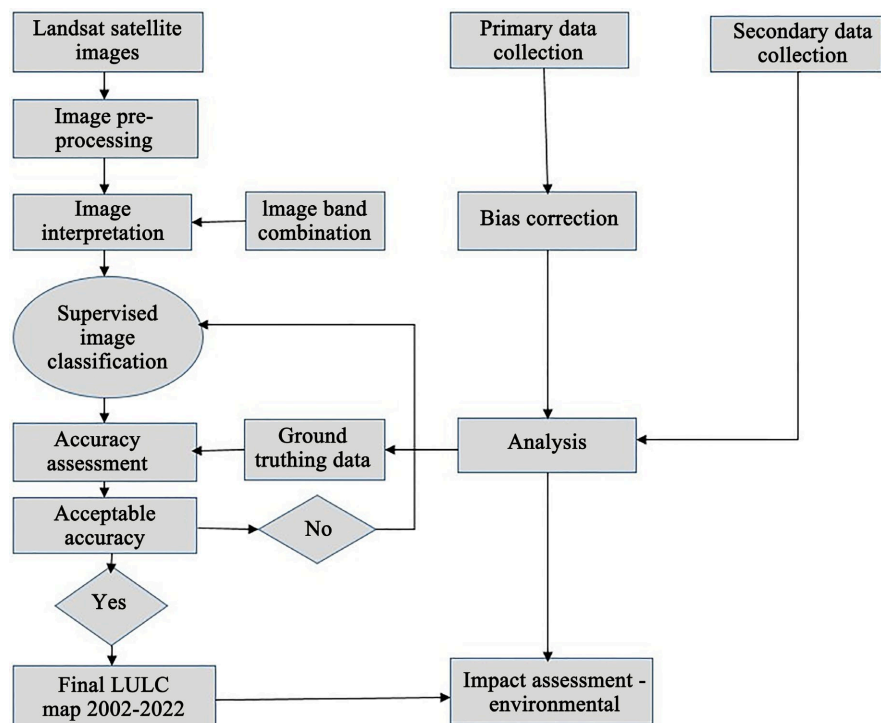


Figure 2. Methodological approach.

Spatio-temporal variation of LULC change in Chegutu District

By analyzing satellite imagery data from 2002 to 2022, this research provided insights into long-term trends and patterns in mining activities in Chegutu District.

LULC change detection is an important aspect of assessing any economic development in an area. The study gathered data for LULC change detection from Explorer website (<https://earthexplorer.usgs.gov>). The study then computed LULC change from 2002 to 2022, considering 2002, 2007, 2012, 2017 and 2022. Routine image pre-processing were employed such as cloud masking, atmospheric correction and image compositing to improve the quality of images [32] [49]. This study considered LULC classes namely water bodies, constructional area (including bare or degraded areas), agriculture (mainly area under irrigation) and vegetation (forest, grassland or bushland). The study carried out supervised image classification using maximum likelihood approach, in QGIS on previously pre-processed Landsat images. This research chose maximum likelihood approach because of its high accuracy and reliability in image classification [50]. Geospatial techniques are widely used to monitor land cover changes around mining sites [8] [14] [51].

Impact of mining activities on LULC in Chegutu District

The study emphasizes environmental monitoring and sustainability in mining operations, contributing to responsible resource management practices. An assessment of mining activities in Chegutu was considered to be based on the rate of increase in area under constructional areas since the onset of mining activities in the district. Normalized Difference Built-up index (NDBI) was observed to clearly display constructional areas [8]. As a result, NDBI was utilised in this study to detect constructional areas, so as to see if the residential areas were expanding since onset of the mining activities in Chegutu. In this study, this index used Near-Infrared and Mid-Near Infrared spectral responses from Landsat satellite imagery to indicate regions that are covered by constructional areas. Thus the NDBI generates values within the range of -1 to $+1$, where positive values indicate impervious surface and negative values signify non-impervious surface area [8] [52]. The constructional regions in this study are designated by impervious surfaces, used to measure the economic development as shown by the development of much of the impervious structures in the district. However, there might be mixels from vegetation and water [8], hence images from the dry season were downloaded.

2.3. Validation

The study used Mann-Kendall test to assess any significant patterns/trends in rainfall and temperature data [43]. 30% of the ground truthing datasets were used for training image classification while the remaining 70% of the dataset was used to validate the classified image results [41] [53] [54]. This study further used stratified random method, ground truth and visual interpretation to represent all the LULCC classes in the area. After the comparison of the reference data and the classified images, the statistical results were represented in error matrices that determine the user's and producer's accuracy [8]. Thus, guided by the Landsat images' eye observation, training points were marked for each class and crosschecked

for verification using a high-resolution image downloaded from Google Earth concerning the selected periods [7].

3. Description of Results

3.1. Temporal Variation of Rainfall and Temperature in Chegutu District

Figure 3 shows annual variation of precipitation and temperature in Chegutu District. The highest annual rainfall (approximately 1010 mm) was received in the year 2017 while the least annual rainfall (460 mm) was observed in the year 2015. Maximum annual temperature (23.56) was observed in the year 2005 and the minimum temperature (22.29) was recorded in the year 2013.

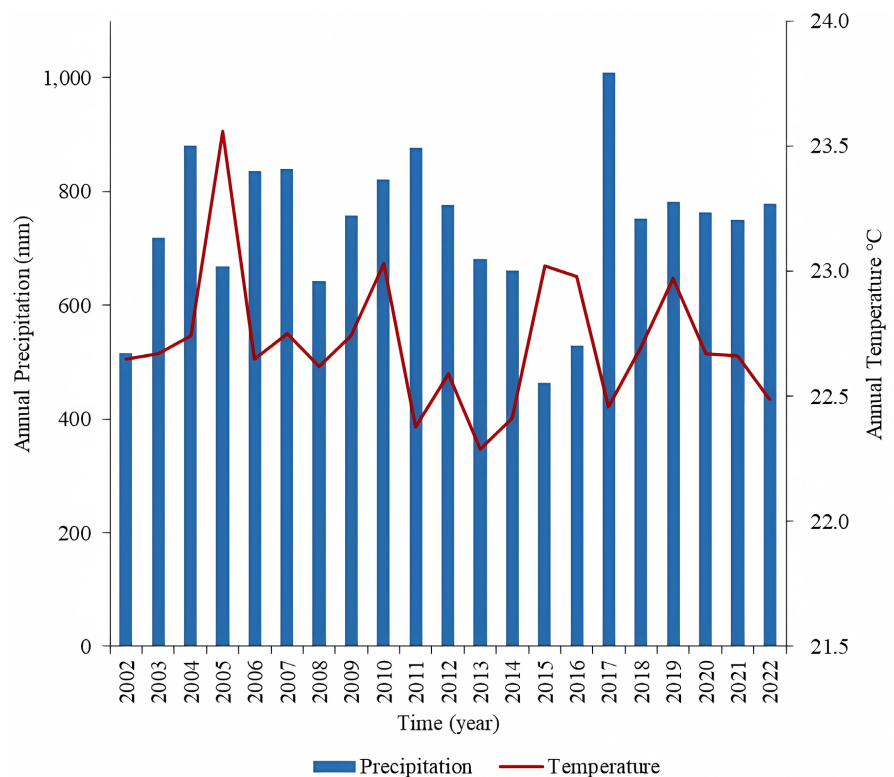


Figure 3. Temporal variation precipitation—temperature in Chegutu.

Table 1. Trend analysis of Chegutu rainfall and temperature, 2002-2022.

Mann-Kendall statistic	Precipitation	Temperature
Alpha	0.05	0.05
MK-stat	2.00	-25.00
S.E.	33.12	33.07
Z-stat	0.03	-0.73
P-value	0.98	0.47
Trend	no	no

Table 1 shows precipitation and temperature annual trends during the period 2002-2022 in Chegutu, at a significant level of $p < 0.05$. The Mann-Kendall analysis showed no trend for both the precipitation and temperature data over the study period.

Table 2 shows nature of the rainfall-temperature trend in Chegutu for the period 2002-2022 at a significant level of 0.05. Although, there was no monotonic increase or decrease in the climate data considered in this study, precipitation showed to be slightly increasing over the study period years. This was deduced from a positive slope of 0.25 with data on the upper side by approximately 10.6 mm. However, temperature data showed an approximately negligible decrease with a negative slope of 0.01.

Table 2. Descriptive statistics of Chegutu rainfall and temperature, 2002-2022.

Descriptive statistics	Precipitation	Temperature
Alpha	0.05	0.05
Slope	0.25	-0.01
Lower	-8.46	-0.03
Upper	10.60	0.01
Mean	738.11	22.72
Standard deviation	130.05	0.28

Rainfall and temperature patterns in Zimbabwe generally follow that of tropical Savanna ecosystem. However, due to climate change; there have been erratic dry and wet spells in Zimbabwe as a whole. The study area showed some peaks and lows during the study period. In most cases, the peaks for rainfall were aligning to the periods when the country was also stricken by cyclones or tropical storms, for example Cyclone Japhet of 2003, Dineo of 2017 and tropical storms Chalane of 2020 and Eloise of 2021. The drought trends were as follows 2002-2003, 2015-2016, and 2018-2019 [55]; where the study area also received generally low rainfalls though with moderate temperatures. Similar studies in the Southern African region also observed similar variations in hydrometeorological variables e.g., a study in South Africa by Odiyo *et al.* [56]. Since rainfall and temperature showed no significant trends in the study area for the study period, their effect on landuse and land cover (LULC) change would be assumed to be minimal. This suggests that the LULC change should be greatly influenced by factors other than mainly due to dynamics in rainfall and temperature patterns.

3.2. Spatio-Temporal Variation of LULC Change in Chegutu District

Table 3 shows changes in area under each landuse for the period 2002-2022. Using 2002 as a base year and analysis year as 2022, the study observed increases in landuse covered by classes namely wetland, farmland and constructional area. Major increase was observed in area covered by farmland. Vegetation lost the

largest areal extent to other landuses. None of the landuse classes had a consistent increase or decrease over the study period.

Table 3. Variation of area (km²) under each LULC over time, 2002-2022.

Landuse class	2002	2007	2012	2017	2022	Overall change
Wetland	531	403	12	699	587	56
Farmland	1178	1339	49	558	1273	96
Vegetation	1618	1547	2594	1331	1423	-195
Constructional area	543	580	1215	1281	586	43
Total	3869	3869	3869	3869	3869	

Figures 4-6 show spatio-temporal variation of LULC in Chegutu. Constructional area is mainly concentrated in the southeast, central and northwestern sides of the study area. The central region is where the main town, Chegutu is housed. The south-eastern side is where the main mining activities are situated. With the increase in constructional area over the years, mining activities are suspected to be contributing significantly to landuse change in the study area.

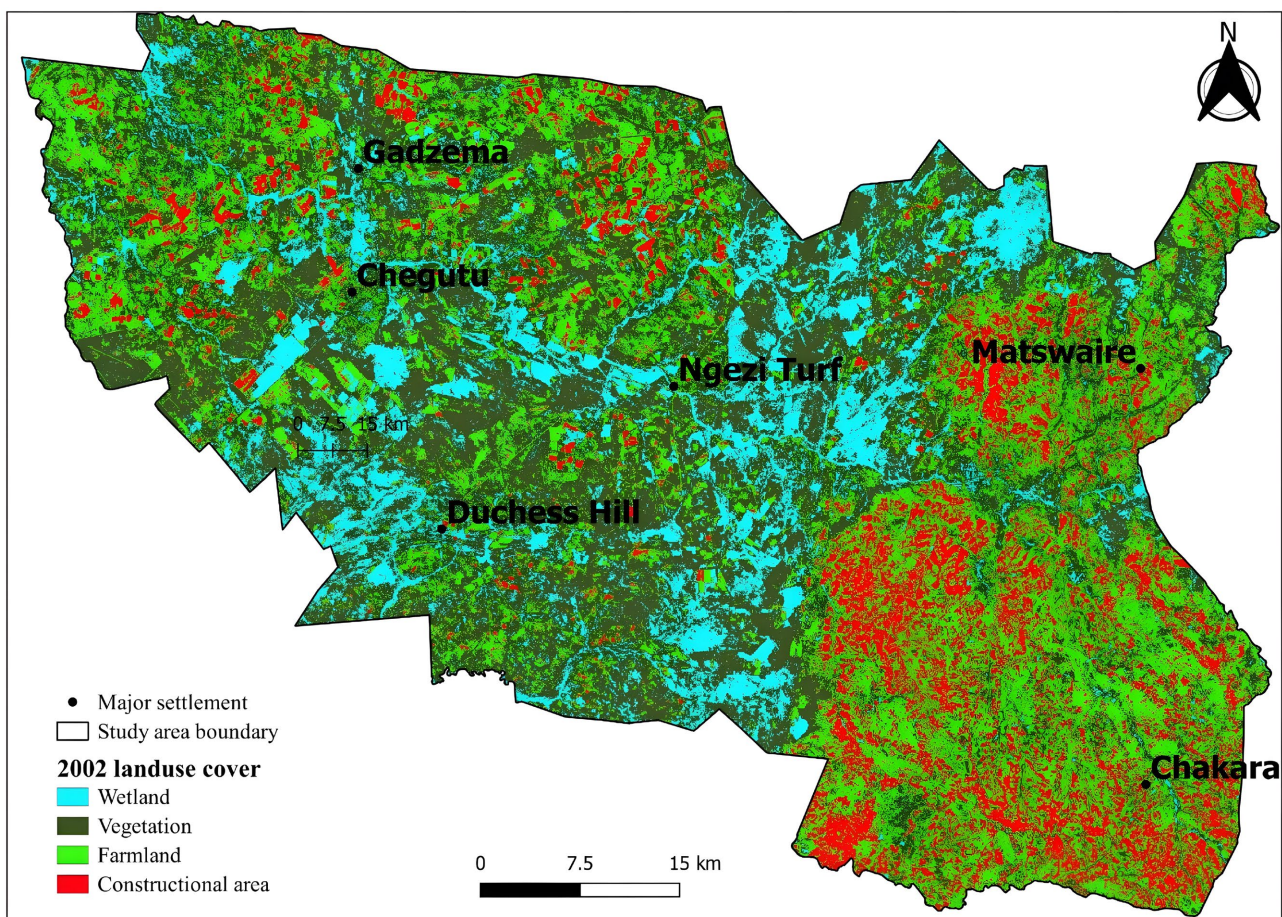


Figure 4. Spatial variation of LULC for 2002.

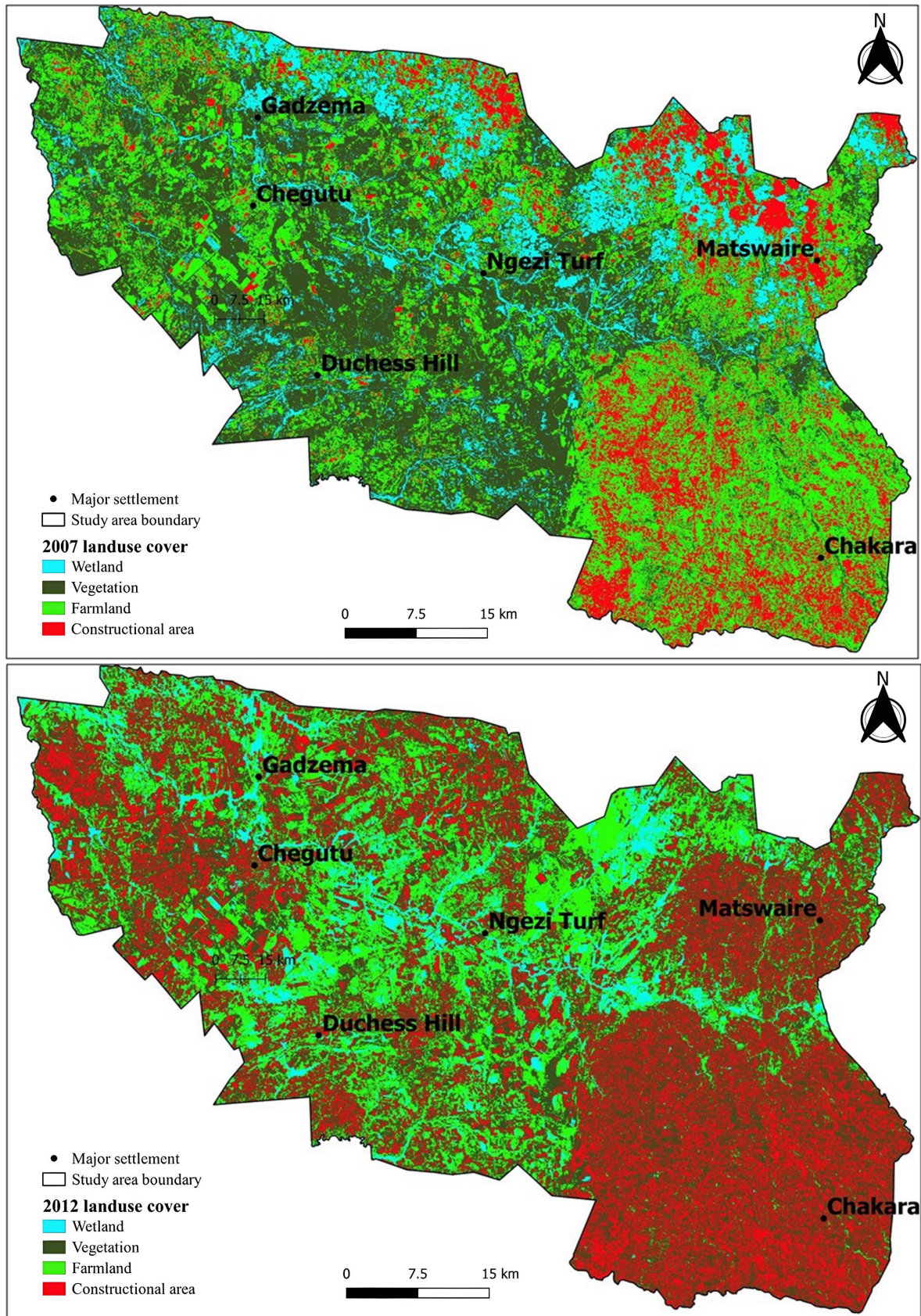


Figure 5. Spatial variation of LULC for 2012.

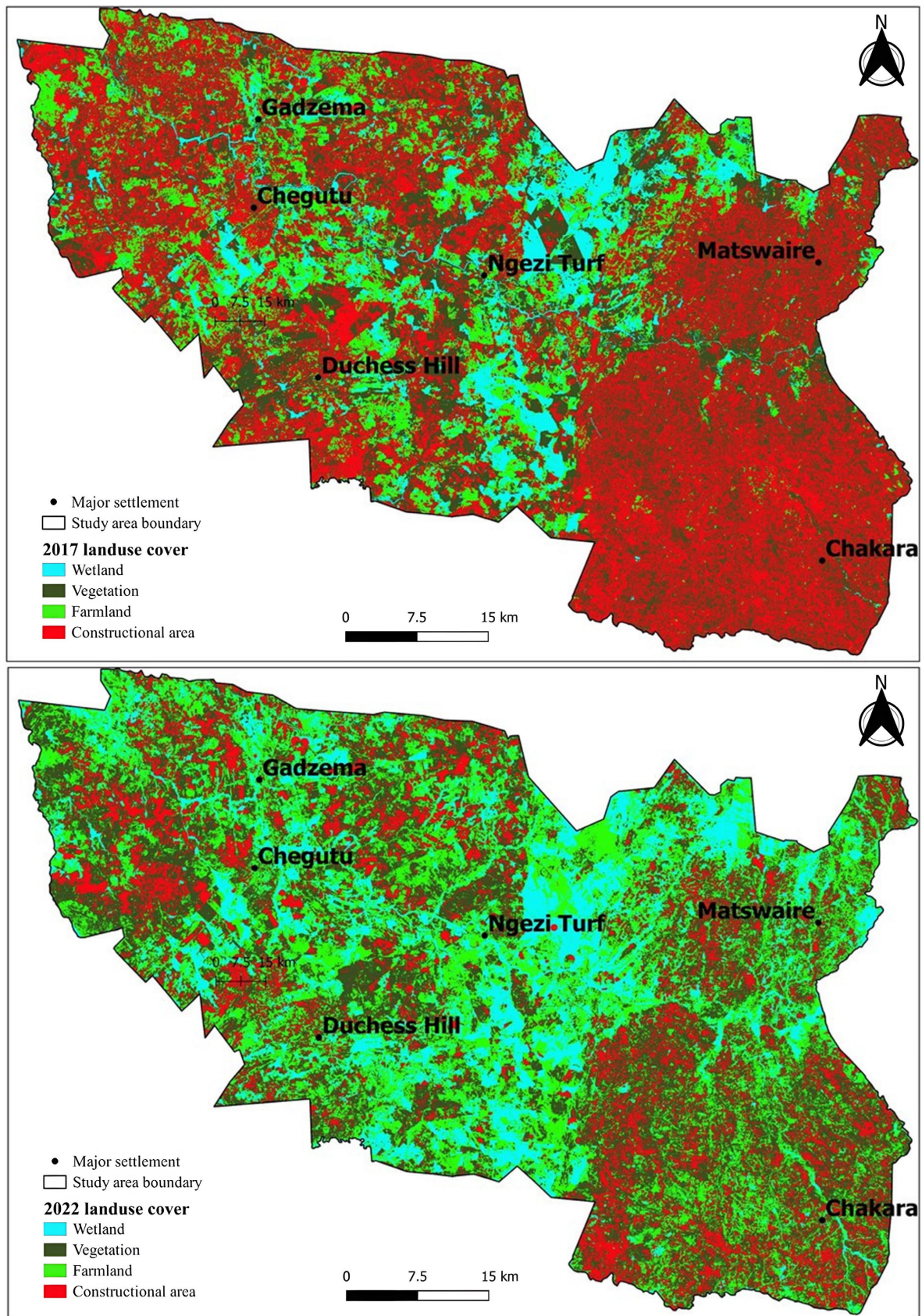


Figure 6. Spatial variation of LULC for 2022.

Wetland area is generally concentrated in the central region of the study area for all the years considered in this study. However, wetland area has the least spatial distribution during the year 2012. Farmland was poorly represented in the years 2012 and 2017 while for the other years it was evenly practiced across the study area. However, some of the areas classified as farmland may belong to mostly polluted water with aquatic growth or marshy lands. Vegetation represented forest, grassland and bushy land. Its distribution in the study area was almost consistent although with slight increases and decreases over the years. Vegetation strongly occupied the central region of the study in 2002, 2007 and 2012. Vegetation fragmentation was highly evident during the years 2017 and 2022, constituting scattered patches of various vegetation clusters across the study area.

Table 4 shows accuracy achieved in classifying LULC for the year 2022. All the classified maps for the period considered by this study achieved an overall accuracy of at least 71.5% where an acceptable accuracy level is usually considered at the benchmark of at least 70% [1]. Using the standard error observed in this study to assess the research's classification level of accuracy, it was observed that it is within the acceptable range. However, of all the classified classes, farmland and vegetation had the least levels of accuracy. This could be mainly due to that these two classes share spectral signatures hence the issues of mixels were unavoidable [57]. The mixed pixel effect might be a result of the Landsat images' medium spatial resolution hence could also be to blame for these misclassifications. However, given the small standard errors observed (values close to zero) hence the low accuracy observed for farmland and vegetation has no effect on the reliability of the LULC change analysis performed in this study.

Table 4. LULC accuracy assessment for 2022.

	Wetland	Farmland	Vegetation	Constructional area	Total
Wetland	623	119	19	2	763
Farmland	60	383	237	45	725
Vegetation	13	36	440	150	639
Constructional area	0	185	31	900	1116
Total	696	723	727	1097	3243
Producer's accuracy [%]	89.51	52.97	60.52	82.04	
User's accuracy [%]	81.65	52.83	68.858	80.65	
Standard error	0.004	0.007	0.006	0.006	
Overall accuracy [%]	72.34				

While other classes fluctuated somewhat over the course of the study, the basic LULC pattern generally showed a sharp increase in constructional areas and a steady increase in forest areas. Gudo *et al.* [7] found that population growth was directly correlated with the amount of constructional area, but they did not

account for the importance of other factors like natural resource availability, security, and economic development in the expansion of the site. Sobhani *et al.* [3] found that a variety of factors, including varying management objectives, use types, and the growth of human activity, contributed to the decline in ecological carrying capacity for the use of natural capital across the different zones.

Figure 7 shows the area that was gained or donated to another or overall retained by a landuse, 2002-2022. Farmland gained the most and this contribution was mainly from vegetation, wetland (marshy) and constructional area (bare land). Whilst farmland gained from vegetation, however, it overall lost much of its land to vegetation. Constructional area gained much of its land from vegetation. This comes in the form of land clearing resulting in bare land or construction resulting in more constructional area areas. Thus, the contribution of vegetation to bare land or constructional areas is worrisome especially if it is more of land degradation. However, it is beneficial if there is more economic development in the area.

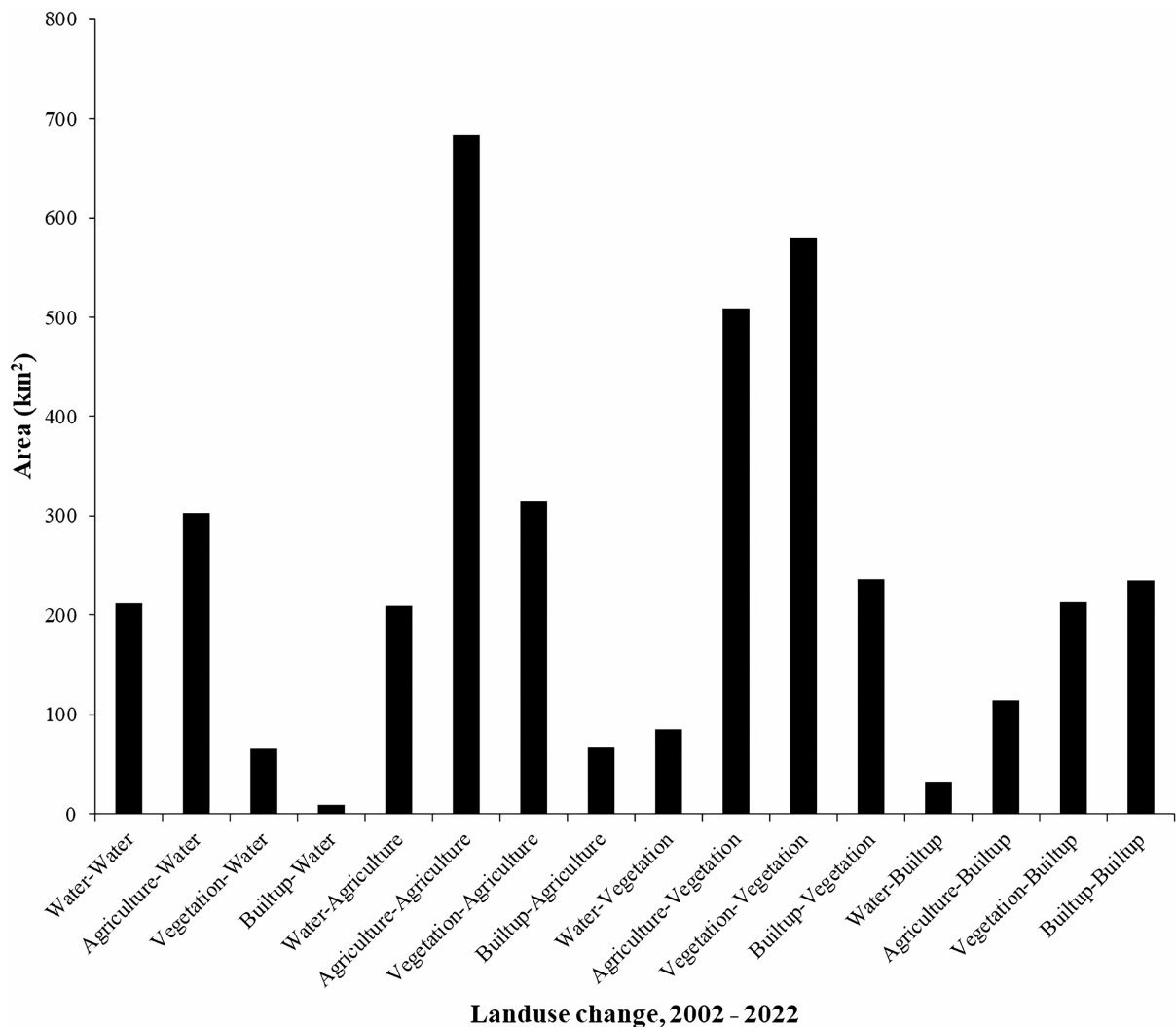


Figure 7. Area lost, gained or retained by a landuses class.

The findings demonstrate that between 2002 and 2022, the areas used for wetland increased steadily, with the overall increase of nearly 56 km². Vegetation category had an overall decrease in area of nearly 195 km². The study also observed overall increase in the areas covered by farmland and constructional areas, similar to results observed by Zhao *et al.* [58]. Additionally, the results of the quantitative and spatiotemporal analyses demonstrate a sharp increase in impervious areas including bare and constructional areas, particularly from 2002 to 2017. Constructional area growth is associated with socioeconomic factors like population increase, security, the availability of natural resources, and economic activity. For example, a study analysed the relationships between the constructional area expansion of Jubek State and population growth, security, the availability of natural resources, and economic development [7] whereas Sobhani *et al.* [3] observed that constructional area increased the most, while high-density pasture decreased the most in areas with growing economic activity. However, the transformation of LULC change varies depending on the main economic driver in a given area. For instance in this study, the results indicated that between 2002 and 2022, there was an increase in wetland, constructional area and farmland areas and a decrease in vegetation areas, **Table 3**; which can be attributed to mining economic activity going in the study region.

3.3. Impact of Mining Activities on LULC Change

Figure 8 shows spatio-temporal variation of NDBI in Chegutu from 2002 to 2022. The NDBI values are scattered throughout the study region.

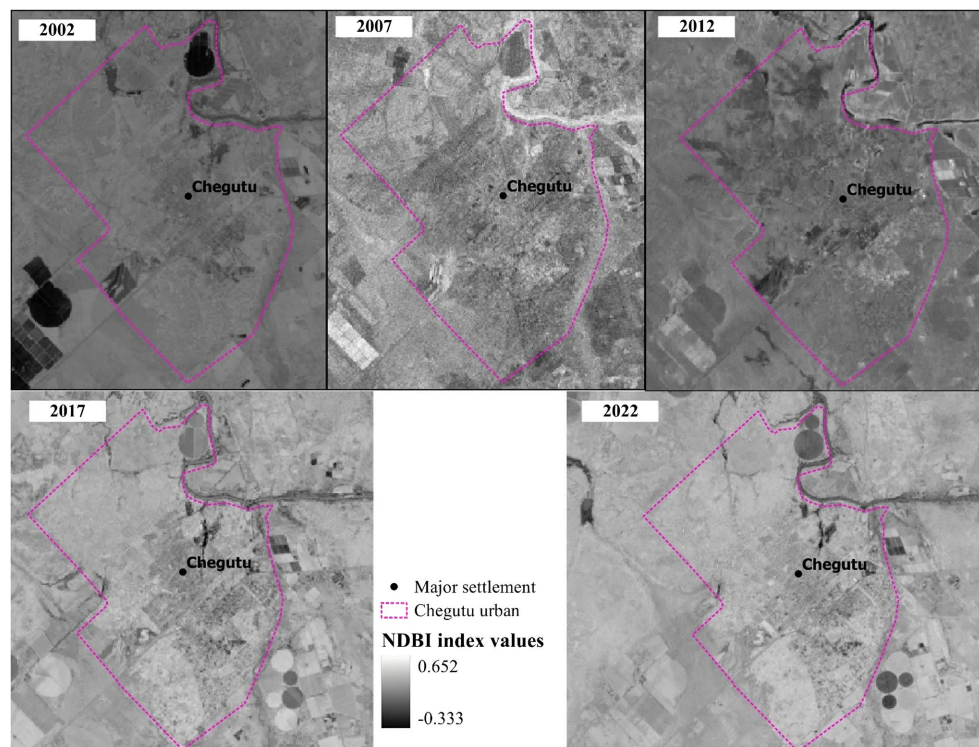


Figure 8. Spatio-temporal variation of NDBI in Chegutu.

However, the study observed an increase in the constructional area areas within Chegutu urban boundary. Nevertheless, the study observed that 2002 and 2012 had low NDBI values as compared to 2007, 2017 and 2022. This can be a result of other environmental variables other than the increase in number of infrastructural developments in the area. Fluctuations in rainfall and temperature patterns may lead to variations in areas that may reflect in a similar manner to surface impermeousness like buildings. This is so because in most cases, degraded areas share similar spectral reflectance with constructional area surfaces.

Figure 9 shows trend variations in NDBI in Chegutu for the period 2002 to 2022. The average NDBI values were low in 2002 and 2007 (below zero values) while the study region witnessed positive NDBI values from 2012 to 2022. There was a sharp increase in NDBI values from 2002 to 2017 and the study observed a slight increase in 2022 from 2017. The increase in NDBI values 2012-2022 can be due to cumulative effect of various constructional activities in the area where most individuals were attaining completion of their infrastructure. This is also supported by increase in human population occupying the area, given that the district's population rose from 50,590 inhabitants in 2012 while to 178,911 inhabitants in 2022 [19].

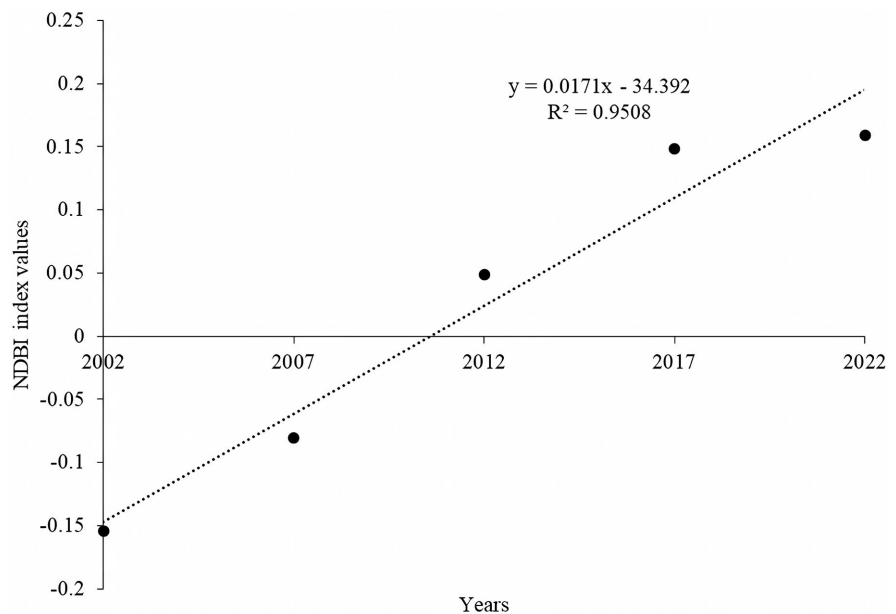


Figure 9. NDBI trend variation in Chegutu.

4. Discussion

4.1. Population

The 1982 population census recorded 19,621 inhabitants, rising to 30,122 by 1992. The population was estimated at 36,000 in 2002. By 2012 it had grown to 50,590 inhabitants while it rose to 178,911 inhabitants in 2022 [19]. The population growth indicates an increase in the number of people entering the mining industry. As the number of gold miners has increased, so too has desperation, which

has resulted in violent incidents involving illegal miners and the emergence of “Mashurugwi,” or gold thugs in the district. In addition to having little rainfall naturally, this region is also directly affected by the activities of gold miners, who are destroying potential agricultural land and thus exacerbating poverty in the area. For example, from literature, the past few decades have seen an acceleration of the landuse intensity trend in Xishuangbanna due to the growth of the population and economic development [21]. This saw settlement and arid land to have significantly increased while vegetative cover decreased. Another study observed that over the past few decades, extensive plantation operations on mine wastelands have increased the amount of forest cover by approximately 8.22% [59]. Thus, with the increase in mining and farmland at the expense of forests, some of the farmlands were given up to make way for the growth of constructional areas.

4.2. Socio-Economic

Chegutú was initially established as a mining settlement by gold prospectors where mining for gold and nickel remains important in the area. The rich National Great Dyke passes through the District thereby promoting various mining activities in the area. This is evidenced by the presence of various large-scale mining companies such as Zimplats, Afrochine and the list goes down to include small-scale miners [20]. Chegutú District has a vast of minerals such as platinum, gold, chrome and nickel besides other mining opportunities such as quarry. The abundance of raw materials resulted in the establishment of Sunny Yi Feng, the Country’s largest ceramic producer and one of the greatest tile manufacturer regionally besides the Norton brick molding company which is housed within the jurisdiction of Chegutú District.

Therefore, increased land damage will have an impact on local food production. Small-scale gold miners due to their open-pit mining methods cause the biggest deforestation in the area. For instance, the people of Mapanzure, a village in Chegutú, are upset about how small-scale miners have destroyed the ecosystem by clearing land and excavating pits. Minerals eventually move to another profitable land after they run out of resources, devastating the ecosystem in the process [20]. Small-scale gold and chrome miners in Chegutú are incredibly careless in that they dump solid and liquid wastes from their mining operations into waterways like the Ngezi River, in addition to destroying the surrounding vegetation. Residents in the vicinity are impacted because they will be unable to determine whether the water is safe for residential and agricultural use. The Zimbabwean constitution is working to strengthen all of the current laws governing the operation of our mining sector, granting the environmental and socioeconomic rights that those impacted are demanding. Additionally, people’s rights to a safe and clean environment are safeguarded by the constitution (section 73), to lessen the effect. As a result mining activities are envisaged to operate within the conservative measures boundary whereby any deviation from this punitive measure is applied to the culprit. This is where the role of EMA and polluter pays principle

comes in. In addition, land degradation resulting from mining activities should be reclaimed to restore the land in some usable form.

4.3. Landuse

In Zimbabwe, the town of Chegutu is known for its gold, chromium, copper, nickel, and platinum group elements mining. The three primary mining techniques used there are alluvial, underground, and open-pit mining. The main factor causing the area's vegetation to disappear is open cast mining. Both large-scale and small-scale mining are conducted in open-pit mines. The ecosystem and the amount of vegetation cover are destroyed when land is cleared for the purpose of extracting minerals. Our research indicates that vegetation has generally decreased over time, as evidenced by the data, which show that it was 1600 km² in 2002 and 1400 km² in 2022. This could be linked to an increase in small- and large-scale, legal and illicit mining activities that have occurred in the district over time. Vegetation clearance is necessary for mining operations, particularly open cast mining, and this causes deforestation, which lowers the amount of vegetation cover, similar to observations by other scholars on environmental degradation through mining activities [41] [60].

To a lesser extent, a changing climate may also be to blame for the decline in vegetation cover. Chegutu, like most of Zimbabwe, has been experiencing higher temperatures, less rainfall, and longer drought periods, all of which add up to less vegetation cover. However, the primary cause of the decline in vegetation in Chegutu may be attributed to open-pit mining, which is causing the landscape to be destroyed and leaving open pits [20]. Small-scale illegal miners cause the most environmental degradation because they do not use conservative mining methods. When the minerals in that area are exhausted, they clear the land and move on to the next. Because mining operations are clearing larger areas of forested land to extract minerals, deforestation is common in areas of illegal open cast mining communities in Chegutu among other pressures from human activities [61]. A new analysis of global climate datasets published in the August 14 issue of *Science Advances* suggests that a long-term deficit in atmospheric water content is the reason behind the halt in global vegetation growth over the past 20 years.

In addition, one of Zimbabwe's largest textile mills, David Whitehead was established in Chegutu. Wheat is grown with the aid of irrigation from the nearby Mupfure River, and cattle rearing is also a significant activity. The Cotton and Grain Marketing Boards established depots in Chegutu for cotton and grain respectively which serves as evidence of intensive agricultural activities within the Chegutu Rural District as it is blessed with rich and fertile soils. Due to opencast mining and related development activities a study observed similar results in the mining coalfields area where it has been observed to have a complex scenario of land use and land cover degradation [62]. Numerous mining tools, such as the dozer, dragline, and dump truck, significantly degraded the land. In fact, over time, the degraded land covers are converted to different uses. Understanding and

calculating the land use conversion and transformation in a dynamic mining area and its environment is therefore critically important. For example, open cast coal mining causes land use change, which is measured by evaluating the change detection analysis [8] [46].

Because of the activities associated with their operations, mining areas in LULC change undergo a variety of changes, **Figure 10**. Regular monitoring of LULC change in mining areas is necessary for a number of reasons, one of which is the pollution of the mine environment. The results of this study showed that the environment had undergone substantial changes, with residential areas encroaching on the area surrounding the mines and waterbodies slightly growing during the study period. Meaning use of wetland has increased generally for both mining and agricultural activities following dry spells that have been experienced in the country, hence farmers would want to augment low rainfalls through irrigation. This was presumably because of return water ponds. Due to the significant impact that these changes have on other land use activities that surround mining areas, it is imperative that these changes be analysed continuously and properly in order to effectively monitor them and assess their impacts on the environment [8].

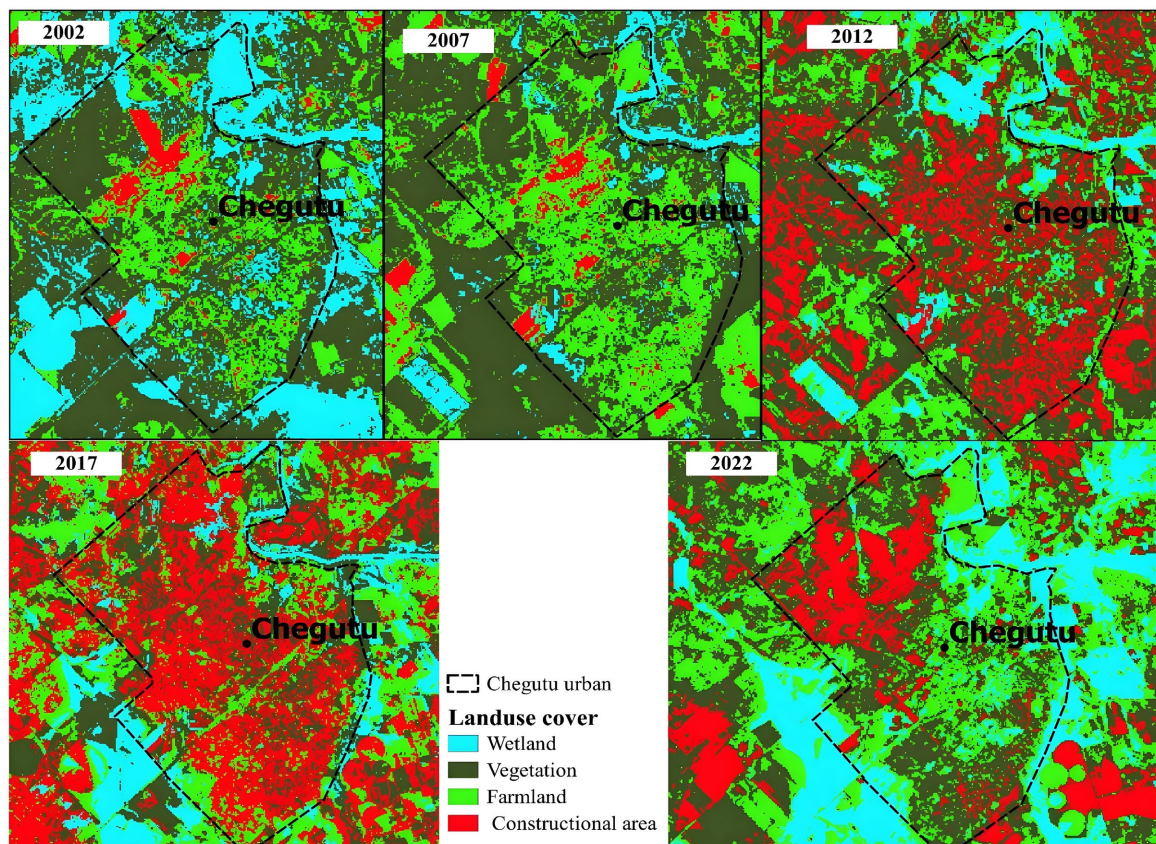


Figure 10. Urbanisation in Chegutu from LULC analysis.

According to the classified maps, Chegutu had a lot of vegetation in the form of vegetation in 2002. Since these various types of vegetation cover the least area,

they indicate that Chegutu does not have many large bodies of water. The most vegetation was destroyed between 2017 and 2022. The areas that were most affected were generally the northern, central and lower parts of Chegutu. According to the study, artisanal small-scale miners are mostly to blame for deforestation, land degradation, and water source contamination, putting Chegutu residents at risk for diseases like cirrhosis, asthma, cholera, and bilharzia [20]. Unquestionably, one environmental effect that is closely linked to the various stages of mining operations in Chegutu is land degradation.

4.4. Urbanisation

Constructional areas and bare land areas have positive values based on the results of the NDBI, which detects constructional regions and indicates the presence of bare land, including predicting the density of impermeable surfaces and urban heat islands. In this study, LULCC analysis was considered the first step toward a manageable and sustainable environment. Using the geospatial indices analysis approach which is timely, accurate, and has fewer significant errors when mapping large entities like vegetation cover, water bodies, and urban areas this study attempted to monitor LULCC caused by mining and other human activities in Chegutu. The utilization of geospatial techniques in this research has demonstrated their appropriateness in identifying alterations within a mining setting [8].

Beyond the boundaries of the mine site, mining can be the source and target of opportunities and threats of various kinds, influencing the socio-ecological system and raising the possibility of social unrest and business risks for mining companies. Therefore, a mining project is not just an industrial object; it is a matter of land planning. However, the current mandatory risk and impact assessment methods are frequently applied to a single project at a time, ignoring the socio-ecological vulnerability of the area where mining occurs as well as the coexistence of various mining activities [60]. In order to facilitate land-planning strategies in mining territories, this study advocates for LULC change monitoring that may be linked to urbanisation while at the same time fostering mining activities that are environmentally friendly.

The scientific community has extensively aimed for socio-ecological standards, which are usually supposed to be completed with traditional mining performances related to the internal operational sphere of the mine (e.g., financial viability, workforce requirements, extraction efficiency, resource supply). In order to meet the Sustainable Development Goals (SDGs) [31] and environmental, social, and governance performances, such standards are promoted by international initiatives and recognized by international and national policies [63]. For example, in Xishuangbanna, the expansion of rubber plantations, the implementation of the land-contracted responsibility system policy, and the economic incentives policy have resulted in the conversion of a significant amount of forests and cropland into tea and rubber plantations [21]. In order to preserve the sustainability of tropical forest ecosystems, Xishuangbanna created national, sizable integrated nature

reserves in 1958 [21], developed a pilot program to restore rubber plantations to their original locations in rainforests, and carried out the ecological protection and restoration project. As a result, public awareness of the need to protect rainforests and promote ecologically sustainable development needs to be looked into. The study further noted that from 1990 to 2019, Xishuangbanna's LULC changes were greater in shrubs and cropland and decreased in forests. The spread of impermeable surfaces brought about by urbanization has resulted in deforestation and degradation in the urban periphery, which may also raise the risk to the landscape ecology. Since LULC classification errors are unavoidable, increasing the high precision of LULC data is a significant step toward reducing ecological services' degradation [21] [60].

The constructional area had an acceleration tendency. However, a study in China observed no significant correlation between urban construction land and coal mining based on the reasoning that the construction of urban construction land is generally based on the planning of the government, instead of the layout of a coal mine [59]. In addition, urban land use change is a result of multiple factors such as urbanization and government behavior, rather than the single effect of the coal mining industry. In some instances, mining like in the case of coal mining also increases the content of heavy metal pollutants in water sources, which leads to the reduction of crop yield. The destruction of high-quality cultivated land caused by coal mining threatens regional, national, and even global, food security. As a result, reasonable city planning can improve land use efficiency. For example, given that, China is still in the stage of rapid urbanization and hence the conflicts between development, coal mining, ecological optimization, and cultivated land protection were necessary for city planning [26]. It is of crucial importance to predict the land use type after any mining activity to accurately, and grasp the rules of land use to formulate city planning in mineral resource-based cities.

It is significant to develop coordinated planning of land reclamation and village moving in mining areas, and optimize the regional land use efficiency. In addition, wetland areas should be used rationally, and the ecological environment optimized. In the case of mining subsidence, where single terrestrial landscapes transform into terrestrial-wetland landscapes this enhances the diversity of land use type, and enhances the anti-jamming capacity of the ecosystem [59]. Thus, formulating reasonable planning and utilizing subsidence water land contributes to the city's ecological environment protection. In addition, the government should integrate ecological management concepts into all parts of land planning, including design, formulation, implementation, and feedback.

5. Conclusion

The study area is experiencing an increase in temperature and a decrease in rainfall. Most of the LULC changes point to much of the land being lost from vegetation landuse to other classes, mainly constructional areas or bare. Since the study

region is within a mining region, loss of vegetation needs further investigation so as to aid in proper land managerial approaches in the study area. The study's conclusions demonstrate that the area's vegetation has been declining over time, mostly because of mining operations and the consequences of climate change. According to classified satellite images, there was a lot of vegetation cover in 2002 (1600 km²), but as time went on, it became less by 2022 (1400 km²). The findings indicate that the average NDBI values increased over the course of that year from -0.16 (2002) to nearly 0.25 (2022), indicating an increase in area under constructional area class. The constructional area class included even bare areas hence if precautionary measures are not taken, this decline in vegetation cover might be problematic over time. Although mining has helped to alleviate poverty in Chegutu, it has also resulted in environmental degradation and a sharp decline in the area's vegetation. The observed increased vegetation loss also demonstrates how land degradation may be able to destroy soil fertility, impacted domestic animal grazing areas, and negatively impacted vegetation in addition to food production. According to the results of this study, people have not been engaging in sustainable mining, which has resulted in the destruction of local vegetation. This is due to the Ministry of Mines and the Environmental Management Agency's inadequate enforcement of mining laws. The study suggests that there is a need for continuous monitoring of environmental degradation in the area despite the necessary economic growth that might be brought about by mining and other socio-economic activities. This paper has achieved certain progress in exploring LULC change in and around mining area of Chegutu town, while failing to establish or separate classification standards of land use type for mining activities and other uses, which might help to accurately measure the influence of mining on land use. In addition, the present study does not probe the influence of land use change on ecosystem service in a mining area. Further research is necessary to ascertain the coupling relationship between land use change and social economy in a mining area, especially the influence of mining on residents' livelihood transitions.

Acknowledgements

The authors would like to express their gratitude to the Urban and Rural Planning Department, Zhejiang Agriculture and Forestry University for an enabling environment that led to publication of this MSc project.

Conflicts of Interest

Authors have no competing/conflicting interests.

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