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Land Use Land Cover (LULC) Change Dynamics Associated with Mining Activities in Kitwe District and Adequacy of the Legal Framework on Mine Closure in Zambia

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Abstract: Land use land cover (LULC) changes resulting from copper exploration in Kitwe District, Copperbelt Province has adversely impacted the environment. To understand LULC change dynamics associated with mining activities, this study mapped LULC changes using the Google Earth Engine (GEE) from 1990 to 2020. In addition, the Zambian legal framework for mine closure was assessed in terms of adequacy and comprehensiveness. A remote sensing analysis using Landsat TM (1990, 2000, and 2010) and OLI (2020) images was performed and the GEE Random Forest classifier algorithm was employed to detect LULC changes. Then, transition matrices and overall changes were calculated for each LULC class. The LULC classification had an overall accuracy and kappa coefficient of 82.47% and 0.78, respectively. In total, 45.2% of the district area (360.92 km^2) experienced LULC changes from 1990 to 2020. The overall change indicates that the areas of built-up area, bare land, and grassland/pasture/agricultural land gained 35.84, 14.67, and 43.53 km^2, respectively, while forest lost 95.30 km^2, with the major driver being the privatization of mining companies. Several concerns regarding the mine closure process practiced in Zambia have principally been raised to the government. Although the legislation generally conformed to international best practices, a gap involving various pieces of legislation, overlapping requirements, and different interpretations of the laws by different governmental departments makes the system complex and unmanageable. An area of concern is the government's capability and competence to implement legislation. Ineffective law enforcement, that is, the inadequacy of the legislation, is to blame for LULC changes in mining areas, resulting in mining corporations not paying attention to the changes made, particularly regarding mine closures. This study provides decision-makers and land use planners with baseline knowledge on LULC changes that can be valuable for future mining legislation and how these legislations can be effectively executed to ensure sustainable mine closure.

Keywords: land use land cover (LULC); change detection; mine closure; rehabilitation; legislation; Copperbelt

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1. Introduction

The change of land use and land cover (LULC) has become a fundamental component of current strategies to manage natural resources and monitor environmental changes [1]. LULC resource uses have resulted in major anthropogenic changes [1,2]. Increasing human activities have caused large-scale changes in the terrestrial surface, disturbing the productivity of global systems [3]. Rapid LULC changes, especially in developing countries, have reduced essential resources, including vegetation, water, and soil [1]. Furthermore, factors contributing to LULC change have indigenous causes, one of which is economic activities by the local community.

One such major economic activity responsible for LULC change is mining. The exploitation of mining resources significantly impacts the ecological environment [4]. The study by [5] stated that mining results in urban growth, leading to LULC changes in many areas worldwide, especially in developing countries such as Zambia [6]. Open-pit, ore, and strip mining can lead to LULC change [7] which have already contributed to severe environmental landscape degradation in mine-adjacent areas of the USA [8].

Governments in many countries require the recovery of areas degraded by mining [9]. Both sustainable and eco-friendly mining necessitate continuous LULC change monitoring to identify their long-term environmental impacts [10]. Monitoring these changes provides fundamental security measures and data for planning ecological restoration and land reclamation strategies [7]. Furthermore, the spatiotemporal change quantification in an area resulting from open-pit mining becomes crucial in understanding the impacts of mining activities and evaluating their socioeconomic, environmental, and ecological impacts [11] through related legislation.

Copper mining plays an important role in Zambia's economic development. Commercial copper mines in Zambia have been in operation since 1928, when the first mine opened [12]. In Zambia, there are five major open-pit and eight underground mines that produce copper and other minerals, such as cobalt [12]. Copper mining takes place in the Copperbelt Province, located in the northern region of the country, which is the most densely populated and urbanized in the country [13]. Consequently, the development of urban centers around mines has posed spatial problems in reconciling the needs of a rapid population growth with the demands of the mining industry [13].

For over seventy years, mineral resources have been mined near Kitwe, Copperbelt Province [14]. The long mining history and the existence of other pollution sources complicate the assessment of environmental impacts in Kitwe, thereby necessitating an indicator of environmental change [14]. Extensive quantities of mine residues, including broken rocks, fine particles, and slag, have been generated and deposited on the land [15]. These residues indicate the mining extent and are indicators of its environmental impact [14]. However, in Kitwe, the extent and dynamics of the changes have not been comprehensively studied, except for an old-time study before the privatization of mining companies in the 1990s [16]. There is limited information about the spatiotemporal extent of the LULC changes in this district, and no evaluation on the information has been done after privatization to enhance land use planning.

Although Zambia has made headway toward incorporating mine closure-related laws and policies, either directly or indirectly, into its constitution, implementing such legislation has achieved little success [17]. According to Clark and Clark (2005) [18], Zambia's current legal and policy frameworks for closure are too weak and fragmented to guarantee comprehensive mine closures because most governmental institutions involved in the management of closure are unable to fulfill their legal obligations owing to three factors: lack of political support, insufficient supply of human and financial resources, and hindrance by contractual agreements between mining companies and the government.

This study, therefore, aims to (1) understand the recent land use land cover (LULC) change dynamics resulting from mining activities in the Kitwe District of Copperbelt Province (1990–2020); (2) clarify the Zambian legal framework on mine closure; and (3) examine Zambia's mine closure legislation to determine if it complies with the sustainable development principle and most recent international best practices for mine closure. This study selected the period from 1990 to 2020 because the privatization of mines in Zambia began in the 1990s. Therefore, this study focused on understanding the changes in LULC that occurred immediately before and after the mines were privatized.

2. Data and Methods

2.1. Study Area

2.1.1. Kitwe District

This study was conducted in Kitwe District (799.42 km^2), Copperbelt Province, Zambia (Figure 1), located approximately 50 km northwest of Ndola City, the headquarters of the province. It is a mining district within the Neoproterozoic Katangan Supergroup basinal succession [19]. Kitwe City (12.8024302° S and 28.2132301° E) lies on the west bank of the Kafue River.

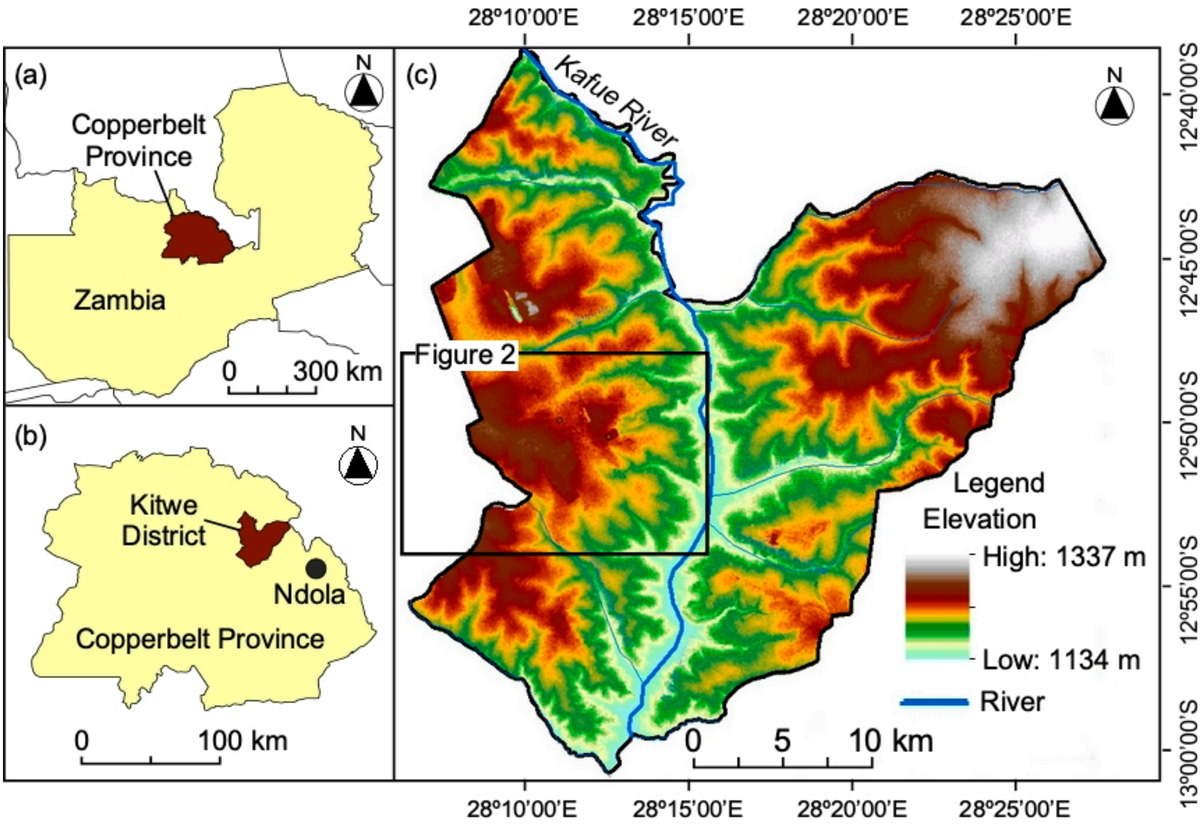

Figure 1. Study area of Kitwe District, Copperbelt Province, Zambia: (**a**) location of Copperbelt Province; (**b**) location of Kitwe District; and (**c**) map of Kitwe District.

Kitwe, which is the main commercial and industrial center of the province [20], is the second largest city in Zambia and the largest city in the Copperbelt Province. Kitwe rapidly developed a copper mining industry especially after 1936 along with the establishment of secondary industries [20]. It is famous for the Black Mountain, a copper slag dump located in the Wusakile Township. Kitwe has four mines, including the Mopani Copper Mine, a joint venture situated in Kitwe, where 95% of its operations take place. The ownership makeup includes Glencore International AG (73.1%), First Quantum Minerals Limited (16.9%), and Zambian Consolidated Copper Mines (ZCCM) Limited (10%), the national mining company [14]. Prior to privatization, the Nkana Slag Dump (Black Mountain) was owned by Nkana Mine of ZCCM Limited. This licensed dump received slag from the Nkana Smelter until the designed limit was reached in the 1990s [21]. The Konkola Copper Mine is the second mine in the study area. While the company is headquartered in Chingola, 15% of its operations, including the Nkana refinery, acid plants, and smelter, are situated in Kitwe [21] with the Nkana smelter being Zambia's largest main copper production plant. The third mine is Kagem Emerald Mine, owned by Kagem Mining Limited, the largest producer of emeralds, accounting for approximately 25% of the global emerald production. The fourth mine is the Mindola Underground Mine, once owned by Rokana Mine (now closed) and now owned by ZCCM. Extensive tailings are around this mine, and two small tailings dams are located in the city center.

2.1.2. Rokana Mine

The Rokana mine is one of the oldest copper–cobalt mines owned by ZCCM, located in the central part of Kitwe (12°49′59″ S, 28°12′6″ E) [15]. It has been in continuous operation since 1928, and during mine nationalization (1970–1991), underground and open-pit sources were operated [15]. Mining operations at Rokana were halted in the 1990s owing to unfavorable economic viability, resulting in ZCCM placing the mine under care and maintenance [22].

The Rokana mine generated large amounts of mine waste in the form of tailings (tailings dams a-l in Figure 2) and caused serious environmental problems [15]. All tailings dams in the district and around the abandoned Rokana Mine are currently closed, which means that all mine waste currently produced in Kitwe is transported to TD 15A (located in Kalulushi District), the only operating tailing dam near Kitwe (Figure 2).

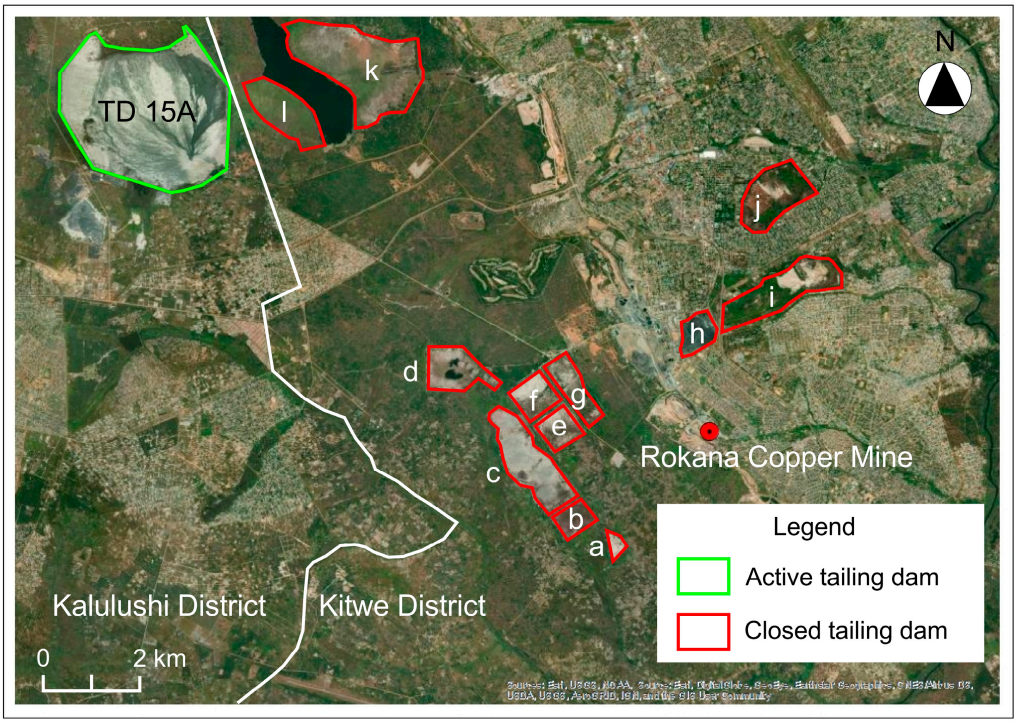

Figure 2. Locations of the Rokana mine and tailings dams (a–l) in Kitwe District and a tailing dam (TD 15A) in Kalulushi District. See Figure 1c for location. Base imagery: Esri, USGS, NOAA, Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community.

2.1.3. Kitwe District Population

The 2010 population census shows that the Kitwe District population increased from 347,024 in 1990 to 517,543 (27% of the Copperbelt Province's population) in 2010 (Table 1) [23]. The population reached 661,901 in 2022 [24], with a population density of 814.7 people per km^2. Approximately 276,000 people in Kitwe District are older than 18 years [25]. The average annual population growth rate of Kitwe is 2.1% [24].

Table 1. Population in Kitwe District, 1990–2020 (source: [20,24].

Year of Census	Population	Male	Female
1990	347,024	175,812	171,212
2000	376,124	189,650	186,474
2010	517,543	256,740	260,803
2022	661,901	321,654	340,247

2.2. Remote Sensing Analysis (Landsat Imagery and Processing)

Open-access Landsat 5 top of atmosphere (TOA) and Landsat 8 TOA reflectance data available on the Google Earth Engine (GEE) were used to create the satellite images (Table 2). Many Landsat images in this platform are processed with a relatively high level [26]. The Landsat 8 and 5 TOA reflectance data from Collection 1 Tier 1 are the highest possible quality imagery available [27]. In the Tier 1 collection, scenes were georegistered consistently, indicating that all images underwent correction for displacement using ground control points and digital elevation model data. Within this collection, a root-mean-square error $\leq$ 12 m was used to register all images [27]. The geometric registration guarantees that pixel-to-pixel correspondence is essential for the multitemporal image integration [28].

Table 2. Satellite data used for land use land cover (LULC) change analysis in this study.

Data Used	Sensor	Path/Row	Spatial Resolution (m)	Source
Landsat TM	TM	172/69	30	USGS
Landsat TM	TM	172/69	30	USGS
Landsat TM	TM	172/69	30	USGS
Landsat OLI	OLI	172/69	30	USGS
PlanetScope	OrthoTile	2792051_3533219	3	Planet

In addition to geometric registration, radiometric normalization is necessary for multitemporal imagery [29]. This normalization ensures consistent spectral-radiometric properties throughout observations from different days or sensors [30]. During the radiometric calibration, the unprocessed and raw digital numbers for each spectral band in a Landsat scene is converted into at-sensor radiance values that account for the specificities of the sensor acquiring the imagery, including mechanical failures, or deterioration in sensor quality and measurement changes [30,31]. For consistency with other scenes, the Tier 1 collection was elected in this study because all images in the collection have already been radiometrically calibrated with well-established methods [28].

Following radiometric normalization, the at-sensor reflectance was converted into a planetary reflectance value [32]. Images can be converted into either surface reflectance or TOA values [33]. The TOA collection was selected instead of the surface reflectance data because initial tests indicated that a Kauth–Thomas linear transformation significantly enhanced classification accuracy [34]. Presently, the Kauth–Thomas coefficients for Landsat 8 data are best established for TOA data [33,35]. TOA data have consistently been utilized to generate multitemporal image mosaics, resulting in high-accuracy land cover classifications. This is particularly notable when spectral indices or transformations are applied to enhance spectral signal [11,36–40]. Well-established calibration coefficients were used to compute the TOA reflectance values for the Tier 1 collection [30].

Between 1990 and 2020, a cloud-screening algorithm was used to eliminate cloud-contaminated pixels from each Landsat image, utilizing quality assessment bands. Six-month composites were then generated by calculating the median value from the images of the target months (July to December) [41]. For instance, for 1990, pixel values were calculated by taking the median of all cloud-free pixels from images between 1 July 1990, and 31 December 1990. A six-month window was used to ensure the availability of at least one cloud-free pixel for each composite and seasonality was considered. In this study, the dry season (July to December) was considered to clearly differentiate the spectral signatures of LULC types.

2.3. LULC Classification

Based on existing classifications of land cover (National Remote Sensing Centre) and field observations, the LULC for each year (1990, 2000, 2010, and 2020) was classified into five categories (Table 3): bare land (including mining areas), built-up area, forest, grassland/pasture/agricultural land, and water. The Random Forest (RF) decision tree classification algorithm in the GEE was used to extract the five LULC classes.

Table 3. Description of the five LULC classes used in this study.

LULC Class	Description
Bare land (including mining area) *	Areas devoid of vegetation cover, e.g., mining area, sediments, exposed rocks, and unpaved roads
Built-up area	Settlements and tarred roads
Forest	Land with tree canopy density more than 40%
Grassland/pasture/agricultural land	Areas where vegetation is dominated by grasses, pasture, and agricultural use
Water	Water bodies

* Only for the 2020 map produced by PlanetScope, mining area and bare land were distinguished from the class of bare land.

Before selecting the training samples, empirical analyses of satellite imagery, Google Earth images, and topographic sheets of the district were carefully performed. For most of the classes, a minimum of 50 training samples were collected across the study area.

This study used RF, a tree-based classifier with K-decision trees, to perform supervised pixel-based classification [42,43]. The RF addresses the overfitting problem through building an ensemble of decision trees [43,44]. To classify the composite Landsat images into five LULC classes (Table 3), this study trained the RF classifier on the GEE platform using 250 training samples.

2.4. Determination of the Mining Areas

LULC maps prepared by Landsat can identify bare land, including mining areas. However, the mining area must be distinguished from other bare lands; therefore, PlanetScope satellite images were used. The 2020 PlanetScope image was acquired from https://www.planet.com/products/planet-imagery/ (accessed on 19 November 2020). The satellite image is a 4-band multispectral image (blue, green, red, near-infrared) with a 3 m spatial resolution (image ID planet/item_id:"2792051_3533219_2020-10-29) (accessed on 19 November 2020).

This study did not use a maximum likelihood classifier; instead, a Support Vector Machine was used to analyze the satellite images using ArcGIS Pro software 2.8.2 (ESRI, Redland, CA, USA). This is because statistical methods, such as the maximum likelihood classification method, possess certain limitations, particularly concerning distributional assumptions and constraints on data input [45]. Many studies claim that machine learning algorithms, including Support Vector Machine, may frequently achieve higher accuracy in classifying a dataset than conventional classifiers [46–48].

Before classification, training samples were created by the region of interest tool for the five classes (mining areas independently classified). Signature sets involve selecting a set of pixels with similar spectral values, specifically for one class. As a result, for each identified class in the image, a signature was assigned and a signature set was integrated. Finally, the PlanetScope image was classified, and the classified image of the mining area was merged with the Landsat image.

2.5. Validation

The composites from different years were separately trained and validated in the classification process. The classifier was trained using approximately 70% of the sample points, with the remaining 30% utilized to assess the accuracy and validate the RF classifier. The error matrix was used to calculate the RF classifier accuracy and kappa statistics. The final maps were compared with the high-resolution imagery on the Google Earth.

2.6. Class Smoothing Process

Class smoothing was performed during image processing to remove noisy pixels using ArcGIS Pro. This was done because the process of classification typically results in a tiny percentage of unclassified, poorly classified, or solitary pixels, which are frequently seen around the boundaries of two areas that are unambiguously assigned [49]. This can create a "pointillist" or blurry appearance that may pose challenges for map production [50,51]. It is desirable to homogenize the classification by reassigning pixels to one or the other class [52,53]. To minimize unnecessary details and improve the classification accuracy, post-classification smoothing using a majority filter is fundamental [54]. This was performed by eliminating pixels < 900 m^2 (less than the size of one pixel of the Landsat images). Filtering entails reassigning isolated pixels to the predominant class in which they are located [55]. Classified images usually manifest a salt-and-pepper appearance, because of the inherent spectral inconsistency faced by a classifier when applied on a pixel-by-pixel basis [56]. In the bare land class, for instance, scattered pixels throughout the mining area boundary may be labeled as built-up areas, or vice versa. To address such instances, it is desirable to smooth the classified output, highlighting only the main classification [50,57,58].

2.7. Field Survey and Accuracy Assessment

The classified images from the GEE were exported to ArcGIS Pro for post-classification, where an accuracy assessment was performed.

A widely employed tool for evaluating map accuracy is an error matrix [59], which aligns and compares pixels in classified images with ground data [60,61]. The producer's accuracy assesses errors of omission, measuring the effectiveness of classifying real-world land cover types [62]. The user's accuracy assesses commission errors, representing the likelihood of a classified pixel matching the land cover type of its corresponding real-world location [49].

The Kappa statistic is a separate multivariate technique to assess accuracy [49]. The reference data for the 2020 map were a combination of data collected during fieldwork and Google Earth Pro image archives. However, clear and updated Google Earth Pro images were lacking for 2010, 2000, and 1990. In this study, stratified random sampling was employed to collect a minimum of 40 reference points. The sampling was based on the sizes of the land use and land cover (LULC) classes for the classified image in 2020. The Kappa coefficient was calculated computed based on reference [49]. A value > 0.80 shows excellent agreement, and that between 0.4 and 0.80 suggests moderate agreement between classification categories.

2.8. Collecting Legal Documents on Mine Closure

Legal documents on mine closures in Zambia were retrieved from Blackhall's Laws of Zambia (https://zambialaws.com (accessed on 20 July 2022)), which provides free access to Zambian laws containing primary and secondary legislation. All acts and subsidiary legislations were enacted in terms of principal legislation. This website was chosen because all acts are presented in fully revised and annotated forms, and their online database is amended in line with the publication of new and amended legislation. Blackhall's Laws of Zambia are intended as tools for both the legal community and public. It is arranged such that any enactment can be easily searched for on the Internet in chronological and alphabetical order with annotated amendments.

The laws and policies regulating corporate environmental practices in Zambia, with an emphasis on mining, were examined. The analysis of the legal and regulatory framework involved an examination of the extent to which it met international best practices and standards of corporate conduct and to which self-regulatory mechanisms were accommodated under the framework. This was accomplished by reviewing the four mining-related acts, laws, and relevant statutes regarding corporate environmental practices in Zambia. These statutes include the Mines and Minerals (Environmental) Regulations of 1997, the Environmental Protection Fund Regulations of 1998, the Environmental Management Act of 2011, and the Mines and Minerals Development Act of 2015.

3. Results

3.1. LULC Classification

Figure 3 shows the multitemporal LULC maps with five major classes, bare land (in the 2020 map produced by PlanetScope, mining area and bare ground are distinguished), built-up area, forest, grassland/pasture/agricultural land, and water, from 1990, 2000, 2010, and 2020. Table 4 summarizes the LULC temporal changes from 1990 to 2020. The percentage of each class area in 1990, 2000, 2010, and 2020 showed that grassland/pasture/agricultural land had the largest proportion in 1990, representing 46.2% (369.43 km^2) of the total LULC categories assigned. This class considerably increased by 51.7% (241.62 km^2) in 2020 (Table 4). The other class, which showed a large change from 1990 to 2020, was forest. This class decreased during the study period (Table 4). An increase was also observed in the built-up areas and bare land (Table 4). Although there was an increase in the water class during the study period, the change was not significant.

The PlanetScope image shows that the mining area was 22.95 km^2 in 2020 (Table 5). To determine the area of bare ground, the mining area was subtracted from the total area under bare land (35.58 km^2) (Landsat 8 image); hence, bare ground occupied 12.63 km^2 in 2020. Figure 3 shows that the mining area is concentrated in the western part of the study area.

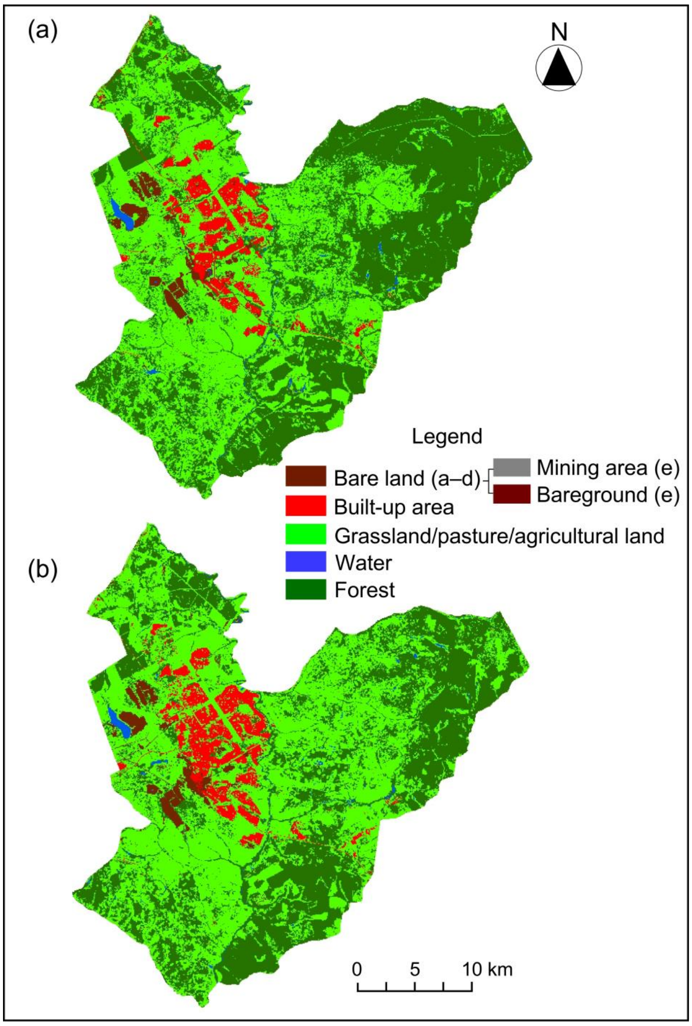

Figure 3. *Cont.*

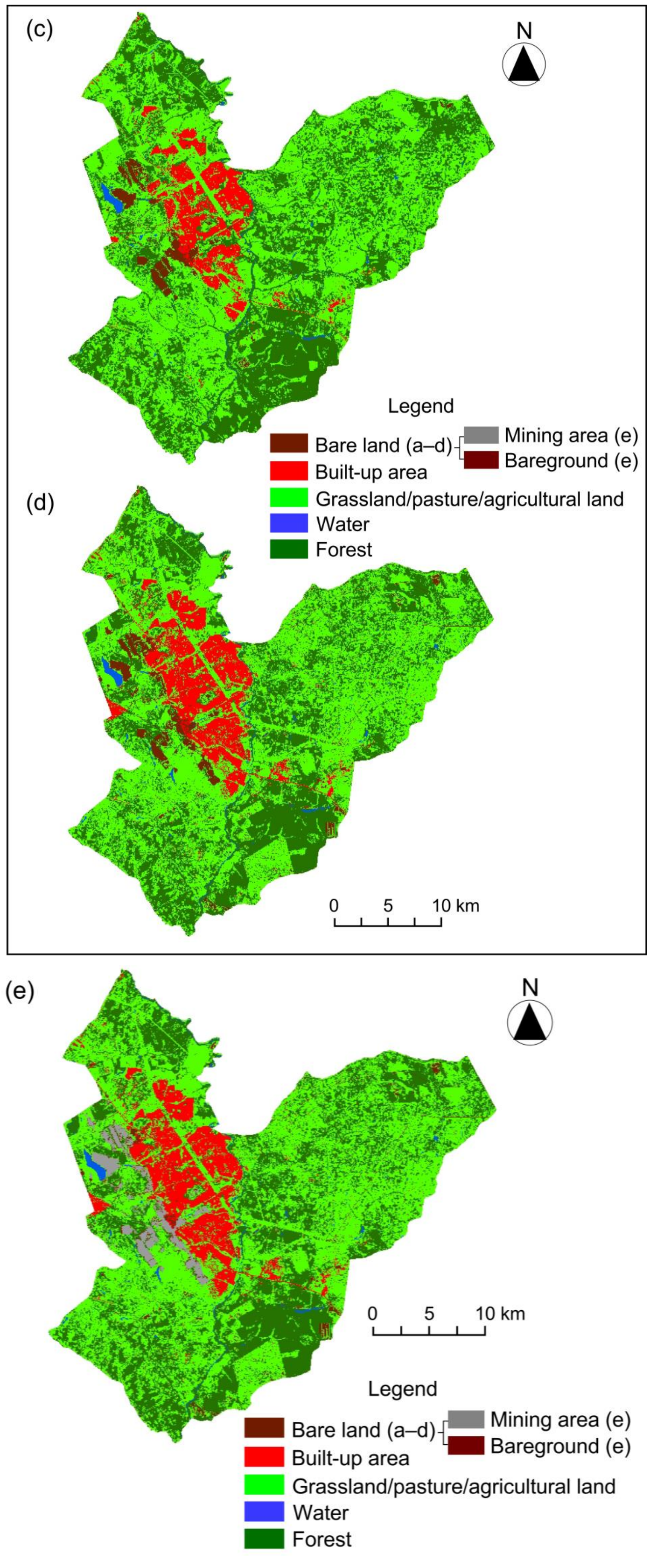

Figure 3. LULC maps in Kitwe District in (**a**) 1990, (**b**) 2000 (mining area included in bare land), (**c**) 2010, (**d**) 2020 (mining area included in bare land), and (**e**) 2020 (mining area and bare ground distinguished).

Table 4. LULC distribution in Kitwe District, Copperbelt, Zambia.

LULC Class	Area in 1990		Area in 2000		Area in 2010		Area in 2020	
	km^2	%	km^2	%	km^2	%	km^2	%
Bare Land *	20.90	2.6	21.70	2.7	22.46	2.8	35.58	4.5
Built-up Area	37.06	4.6	49.11	6.1	52.58	6.6	72.90	9.1
Grassland/Pasture/Agricultural Land	369.43	46.2	398.12	49.8	403.89	50.5	412.96	51.7
Water	5.69	0.7	6.19	0.8	5.59	0.7	6.94	0.9
Forest	366.34	45.8	324.30	40.6	314.90	39.4	271.04	33.9
Total	799.42	100.0	799.42	100.0	799.42	100.0	799.42	100.0

* Bare land includes mining areas.

Table 5. Area and proportion of mining area and bare ground in Kitwe District in 2020.

Sub-Classes	Area (km^2)	Proportion (%)
Mining Area	22.95	64.51
Bare Ground	12.63	35.49
Total (Bare Land)	35.58	100.00

3.2. Field Survey and Accuracy Assessment

The primary focus in selecting accuracy assessment pixels was on areas identifiable in both low- and high-resolution images (Landsat, Google Earth, and Google Maps). A total of 251 points (locations) were generated in the classified image using stratified random sampling based on the sizes of the land use and land cover (LULC) classes in the 2020 classified image (Table 6). The accuracy assessment results for the 2020 LULC map are presented in Table 7, indicating an overall accuracy of 82.47%. Therefore, the classified results are suitable as a data source for post-classification comparisons and further analyses. Producer's accuracy ranged from 64.0% to 96.1%, while user's accuracy ranged from 68.8% to 96.1% (Table 7). The assessed image showed a Kappa coefficient of 0.78 for 2020, signifying good agreement between the classified map and the reference data [63].

Table 6. Accuracy assessment error matrix of the classified image in 2020.

LULC Class	Bare Land	Built-Up Area	Grassland/Pasture/ Agricultural Land	Water	Forest	Ground Truth
Bare Land	38	9	5	0	0	52
Built-up Area	4	32	0	0	0	36
Grassland/Pasture/Agricultural Land	5	9	44	5	1	64
Water	3	0	0	44	1	48
Forest	0	0	1	1	49	51
Total	50	50	50	50	51	251

Table 7. Producer's and user's accuracy assessment of the 2020 classified map.

LULC Class	Producer's Accuracy (%)	User's Accuracy (%)
Bare Land	76.0	73.1
Built-up Area	64.0	88.9
Grassland/Pasture/Agricultural Land	88.0	68.8
Water	88.0	91.7
Forest	96.1	96.1
Overall Accuracy (%)	82.47	
Kappa	0.78	

3.3. LULC Changes

3.3.1. LULC Changes in Kitwe District

The LULC change matrices in each of the periods 1990–2000, 2000–2010, and 2010–2020 are shown in Table 8, and those in the entire period of 1990–2020 are shown in Table 9.

Table 8. LULC change matrices in Kitwe District from 1990–2000, 2000–2010, and 2010–2020.

LULC Class	BL	BUA	F	GPAL	W	Total	Loss
1990/2000							
BL	13.87	2.25	0.36	4.18	0.24	20.90	7.03
BUA	0.50	31.61	0.37	4.58	0.01	37.06	5.45
F	0.29	2.83	253.68	108.30	1.25	366.34	112.66
GPAL	6.89	12.42	68.38	279.93	1.81	369.43	89.50
W	0.15	0.01	1.51	1.14	2.89	5.69	2.80
Total	21.70	49.11	324.30	398.12	6.19	799.43	217.44
Gain	7.83	17.51	70.62	118.19	3.30	217.44	
2000/2010							
BL	14.70	1.20	0.57	5.16	0.07	21.70	7.00
BUA	0.60	38.61	2.93	6.97	0.01	49.11	10.51
F	0.71	0.66	220.33	100.95	1.65	324.30	103.96
GPAL	6.42	12.12	89.47	289.02	1.10	398.12	109.11
W	0.02	0.00	1.60	1.81	2.76	6.19	3.43
Total	22.46	52.58	314.90	403.89	5.59	799.42	234.01
Gain	7.76	13.97	94.57	114.88	2.83	234.01	
2010/2020							
BL	12.45	1.86	1.20	6.90	0.06	22.46	10.01
BUA	1.35	46.52	0.70	4.01	0.00	52.58	6.06
F	6.11	4.51	177.88	124.14	2.26	314.90	137.02
GPAL	15.52	20.00	90.97	276.47	0.93	403.89	127.42
W	0.15	0.01	0.30	1.44	3.69	5.59	1.90
Total	35.58	72.90	271.04	412.96	6.94	799.42	282.42
Gain	23.13	26.38	93.17	136.49	3.25	282.42	

Note: BL = bare land, BUA = built-up area, F = forest, GPAL = grassland/pasture/agricultural land, W = water.

Table 9. Overall LULC change matrices in Kitwe District from 1990 to 2020.

LULC Class	BL	BUA	F	GPAL	W	Total	Loss
1990/2020							
BL	11.02	3.28	1.19	5.04	0.37	20.90	9.89
BUA	0.76	32.53	0.49	3.28	0.01	37.06	4.53
F	7.05	4.30	171.03	181.94	2.03	366.34	195.31
GPAL	16.42	32.77	97.89	220.87	1.48	369.43	148.55
W	0.34	0.02	0.45	1.83	3.05	5.69	2.64
Total	35.58	72.90	271.04	412.96	6.94	799.42	360.92
Gain	24.56	40.37	100.02	192.09	3.89	360.92	

Note: BL = bare land, BUA = built-up area, F = forest, GPAL = grassland/pasture/agricultural land, W = water.

In 1990–2000, major losses were observed in forest and grassland/pasture/agricultural land (Table 8). A total forest area of 112.66 km^2 was lost to the other classes, mainly grassland/pasture/agricultural land and built-up area. The area under forest gained approximately 70.62 km^2, primarily from grassland/pasture/agricultural land, built-up area, and bare land. In terms of total gain and total loss, approximately 118.19 km^2 of grassland/pasture/agricultural land was gained from other classes while about 89.50 km^2 of forest was lost to other classes. Grassland/pasture/agricultural land and forest was converted to built-up area due to urban expansion, and developmental activities such as mining. About 7.83 km^2 was converted from other classes to bare land, of which the major gain was from grassland/pasture/agricultural land. Large patches of bare land are concentrated in the western part of the study area (Figure 3). The area devoid of vegetation in the western region most likely represents an area with mining activities.

For the period 2000–2010, bare land, grassland/pasture/agricultural land, and built-up areas showed an increase, in contrast with a decrease in the change rate of the forest class (Table 8). Similar to the changes observed during 1990 and 2000, about 7.76 km^2 of bare land was converted from other classes. The total gain in built-up area was 13.97 km^2 from grassland/pasture/agricultural land and bare land. About 100.95 km^2 of forest was converted to grassland/pasture/agricultural land.

Table 8 presents the change matrix for 2010–2020. During this period, approximately 90.97 km^2 of land was converted from grassland/pasture/agricultural land to forest. In contrast, approximately 124.14 km^2 of forest was degraded to grassland/pasture/agricultural land. Grassland/pasture/agricultural land changed into built-up area, bare land, and water. Between 2010 and 2020, about 26.38 km^2 of built-up area and 23.13 km^2 of bare land was gained from other classes.

The results on the overall change show that 45.2% of the entire study area (360.92 of 799.42 km^2) experienced LULC changes (Table 9). Bare land gained 117.5% of the area in 1990 in 2020 due to LULC conversion, of which the conversion from grassland/pasture/agricultural had the largest share (66.9%), followed by forest (28.7%). The gain from built-up areas was not significant. A total of 53.3% of the forest in 1990 was converted to other LULC types, with grassland/pasture/agricultural land being the highest (93.2%) (Table 9). Built-up areas gained 108.9% of the area in 1990 in 2020, of which grassland/pasture/agricultural land had the highest conversion (81.2%), followed by forest (10.7%). Out of the total area of grassland/pasture/agricultural land in 1990, 40.2% was converted to other LULC types, with the greater proportion of change to forest (65.9%), followed by built-up area (22.1%) and bare land (11.1%). Compared with the other LULC types, water did not show a significant transition.

3.3.2. LULC Changes Related to Mining Activities

Table 10 indicates net changes in LULC from 1990–2000, 2000–2010, 2010–2020, and 1990–2020. The overall gain in the grassland/pasture/agricultural class over the last three decades was found to be 43.53 km^2 (Figure 3 and Table 10). The major reason for this change may be the conversion of forest area into grassland/pasture/agricultural land, mostly due to population increase (increased settlement and farmland) and infrastructure development (access roads, mining facilities, and residential areas).

Table 10. Summary of the net changes in LULC in each period (km^2).

LULC Class	Net Change in 1990–2000	Net Change in 2000–2010	Net Change in 2010–2020	Overall Change in 1990–2020
Bare Land	0.79	0.76	13.11	14.67
Built-up Area	12.05	3.47	20.32	35.84
Grassland/Pasture/Agricultural Land	28.70	5.76	9.07	43.53
Water	0.50	–0.60	1.35	1.25
Forest	–42.04	–9.40	–43.86	–95.30

The forest class in the study area has a decreasing trend. During 1990 and 2020, the overall forest loss was 95.30 km^2 due to mineral exploration activities after the privatization of mines, forest harvesting in some plantations such as ZAFFICO for use in mines, poles for electricity supply, and house construction due to population increase (Figure 4). Other studies have documented a decrease in vegetation cover due to mining activities [64–67]. However, the loss in forest was highest in 1990–2000 and 2010–2020 (42.04 and 43.86 km^2, respectively) (Figure 3 and Table 10). This was partly due to the drought conditions that were experienced in Zambia from 1992 to 1999 (for 1990–2000) [68], settlement expansion due to both natural population growth and rural–urban migration, and timber harvesting for the construction of mining-related facilities, mostly during 2011–2020 (Figure 4).

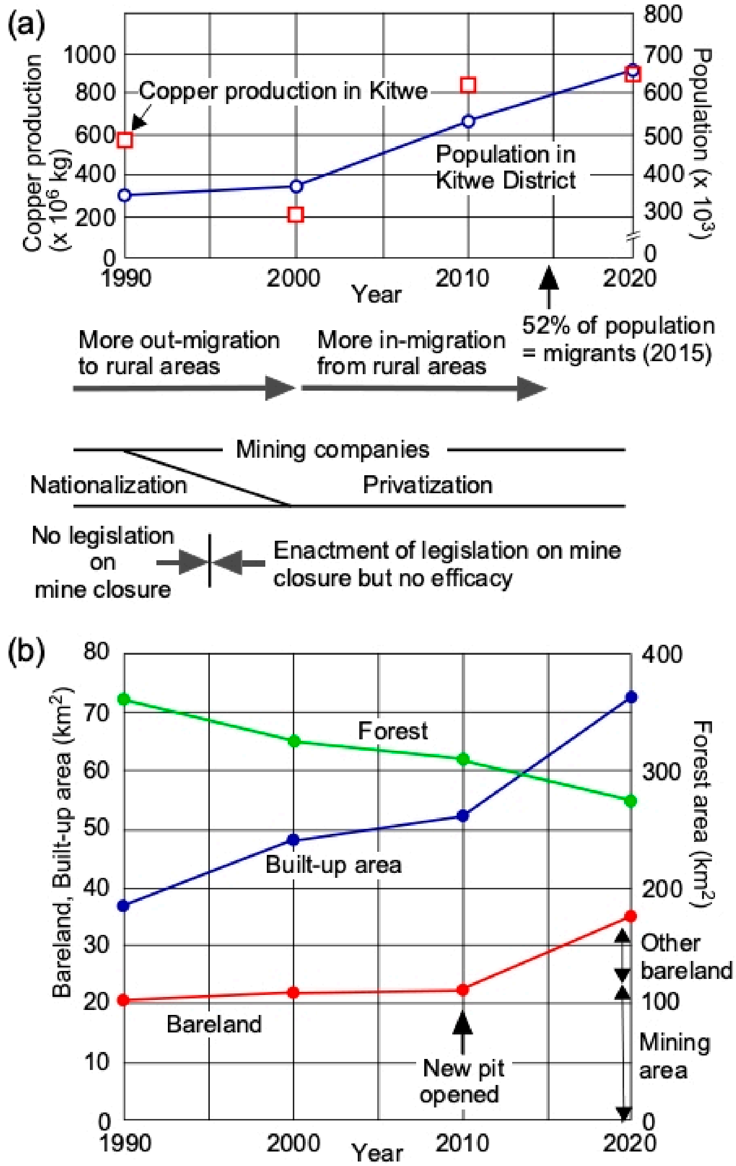

Figure 4. (**a**) Copper production and population in Kitwe District from 1990 to 2020 (source: [69] and Bank of Zambia Annual Reports from 1995 to 2021 [20,24]) and events related to population dynamics and changes of mining-company ownership; and (**b**) changes of bare land and built-up area in Kitwe District from 1990 to 2020 (source: this study).

The second significant change related to mining activities observed during the study period was bare land, which increased in the first period (1990–2000). This indicates that the area under mining increased, although a large portion of the bare land originated from historic mining before 1990 (Table 4). Figure 4a shows that copper production declined from 545,677 metric tons in 1990 to 221,167 metric tons in 2000. The decline in copper production can be attributed to the privatization of mines by the Zambian government. During 2000 and 2010 (second decade), the increase in bare land slowed slightly (Figure 4b). According to reference [69], the copper production in Zambia increased from 221,167 metric tons in 2000 to 852,566 metric tons in 2010 (Figure 4a). After privatization, the copper production increase was due to the revamping of mines by new mine owners. In the third decade (2010–2020), bare land showed an increasing trend but was faster than in previous decades. The newly opened pit mine developed in the south-central part of Kitwe District was supported by an increase in copper production to 882,061 metric tons in 2020 (Figure 4a). Due to the need to increase copper production in the mines, labor increased, which resulted in migration from both rural areas and other districts, leading to a population increase (Figure 4a). As a result, built-up areas increased (Figures 3 and 4b, Table 4).

The third class, which has experienced significant changes over the past three decades, was developed, consequently resulting in increased built-up area. During this period, urban expansion may have been linked to industrial development and population growth, as supported by the census data indicating the rapid population growth of the study area (Figure 4a). Concurrently, there was a close relationship among spatial urban expansion, the distance from mines, and the geometric center of a city. This suggests that the primary driving force for the urban expansion was mining.

The rapid population growth in the urban area of Kitwe was mainly derived from both natural growth and migration from other parts of the country in search of better employment [70]. The population of the study area almost doubled between 2000 and 2010 (Table 1 and Figure 4a), during the time when the mines were privatized. New mine owners invested more money in the mines and needed additional labor to maximize production. The observed land use pattern of built-up area and bare land gain (Table 10) agrees with research conducted elsewhere in the world where mining activities are performed, in which the increase in activities led to settlement expansion [71].

4. Mine Closure Legislation in Zambia

4.1. Status of Mine Closure Legislation

The issue of LULC changes related to mining activities has gained significant attention, particularly in regions burdened with the environmental legacies of unsafe mine waste dumps. Zambia is one such region burdened with abundant unsafe mine waste dumps, mostly from the previous mining operations, without rehabilitation [72]. Mine waste dumps, constituting environmental legacies, are commonly found in Copperbelt Province (>100 km^2) and Central Province (2.5 km^2). Their presence has resulted in a missed opportunity in forestry, agriculture, livestock grazing, and housing for the local population [72]. During the mid-1990s privatization of mines, the state entered agreements with new mine owners, guaranteeing that none of the historical environmental legacies or their impacts would be the responsibility of the new owners [12]. Instead, the state, through the ZCCM, would take care of rehabilitation actions and monitor historical sites [73,74]. Unfortunately, this has yet to be achieved [12]. This underscores the urgency of understanding LULC changes and the legislative framework related to mining activities in Zambia and addresses the implications for sustainable land use management. Monitoring spatiotemporal LULC changes in mining areas provides critical data for policymaking in Zambia, helping the government and other stakeholders assess environmental impacts, plan resource allocation, and mitigate socioeconomic risks associated with mining activities.

A comprehensive legislative framework to govern environmentally sound mine closures had been missing in Zambia before 1995 [75]. However, the privatization of mines in the mid- and late-1990s made the state realize the need for provision of legal guidance to new mine owners regarding the expected mine closure standards. Consequently, various mine closure provisions were incorporated into different mining-related statutes [76]. Mainly, these provisions focused on environmental rehabilitation, reflecting the fundamental perception on mine closure during that period [18]. Since 1995, when the country enacted legislation that highlighted mine closures, there have been no substantial changes in the legislation. Despite the mine closure framework being developed in response to the closure of mines at that time, it has not been effectively implemented. The state, which accepted most of the environmental liabilities during the privatization process, has particularly struggled with its enforcement [18].

Nowadays, the concept of mine closures extends beyond just environmental considerations. It now includes aspects related to promoting the social and economic well-being of local mining communities after closure [77]. In 2016, a document was prepared to illustrate the correlation between mining activities and the United Nations Sustainable Development Goals established in 2015. The document utilized examples from ongoing industry initiatives, along with knowledge and resources in the field of sustainable development, to map out this relationship [78].

In Zambia, the urgency to address mine closure impacts has intensified due to the recent shutdowns of multiple mining operations as a result of the decline in copper prices and the power shortage experienced [79]. Two mines operated by Glencore and China Non-Ferrous Mining Corporation Limited in Zambia, for instance, were placed under care and maintenance in 2015 [80].

4.2. Statutes Applicable to Mine Closure in Zambia

One key legal framework governing mine closure in Zambia is the Mines and Minerals (Environmental) Regulations of 1997, also known as the Mines Environmental Regulations [81]. This legislation is particularly informative regarding mine closures in the country, mandating developers to submit an Environmental Project Brief (EPB) or an Environmental Impact Statement (EIS) to the director of mine safety prior to engaging in any mining related activity (Table 11) [81].

The second statute applicable to mine closures in Zambia is the Environmental Protection Fund Regulations 1998. The Environmental Protection Fund regulation has two objectives for the fund. The first objective is to assure to the director (mine safety) that the EIS shall be executed according to the Mines Environmental Regulations. The second objective is to safeguard the government from the potential obligation to carry out the rehabilitation of a mining site when this responsibility is neglected by mining license holders [82].

Table 11. Summary of specific provisions of statutes applicable to mine closure in Zambia and their gaps (source: [81–84]).

Statute	Provision	Focus	Gap
Mines Environmental Regulations 1997	Regulation 5(2)	Environmental Project Brief (EPB) or an EIS	Limited mine closure planning stipulations required to be included in the EIS Inadequate provisions directly addressing review of mine closure provisions Relinquishment and post-closure obligations Socioeconomic requirements
	Regulation 6	Mine closure certificate issuance for any mine closed and the mining right or permit	
	Regulation 22	Checklist on the contents of a decommissioning and closure plan for mine dump	
	Regulation 65	Developer's contribution to the Fund established under Section 86 of the Mines Act	
	Regulation 66	Classifying developers to determine their fund contribution	
Environmental Protection Fund Regulations 1998	Regulation 3(5)	Approving withdrawals of funds from the Fund and the overall good management of the Fund	Lack of diverse financial assurance forms Ineffectiveness of concession provision for environmental protection fund contributions
	Regulation 7(1)	Developers to be paid from the Fund moneys required for the objectives of the Fund and refunds to holders of licenses in accordance with the Mines Act	

Table 11. *Cont.*

Statute	Provision	Focus	Gap
Environmental Management Act 2011	Section 5	Citizen's duty to safeguard and enhance the environment	Inadequate provisions regarding mine closure planning/plans Stakeholder engagement and public participation
	Section 29	Environmental Impact Statement (EIS).	
Mines and Minerals Development Act, 2015	Section 4	Exploitation of minerals shall ensure safety, health, and environmental protection	No guidance as to what this rehabilitation plan should contain
	Section 81	Rehabilitation, levelling, re-grassing, reforesting, or contouring	
	Section 82	Clear away all mining and mineral processing plant	
	Section 83	Backing up Section 82 by the government disposing	
	Section 86	Environmental protection fund	

The Environmental Management Act 2011 ("Environmental Act") is another statute that looks at mine closure in Zambia. It is the principal legislation addressing comprehensive environmental protection from human activities [83]. It prohibits individuals from initiating projects that could harm the environment without written consent from the Zambia Environmental Management Agency (ZEMA) [83]. ZEMA grants this approval after assessing the Environmental Impact Statement (EIS) (Table 11). The Environmental Act's mandate for an Environmental Impact Assessment (EIA) is crucial for mine closures, as closure commitments are specified in the EIS [83].

Lastly, the primary legislation governing mining activities in Zambia is the Mines and Minerals Development Act of 2015, commonly referred to as the "Mines Act" [84]. In relation to mine closures, the Mines Act acknowledges specific principles that form the foundation of the current understanding of such closures. Section 4 emphasizes the principles of sustainable development, urging the utilization and development of mineral resources in a way that takes into account the needs of both present and future generations [84]. It also examines the conditions under which a mining right is granted or renewed, including requirements for leveling, re-grassing, reforesting affected land from exploration, mining, or mineral processing operations, as well as the filling, sealing, or fencing of excavations, shafts, tunnels, and rehabilitation (Table 11) [84].

4.3. Assessment of the Legal Framework on Mine Closure

A review of the Zambian legal framework described above found that these pieces of legislation have inadequate provisions regarding mine closure planning, as reference [75] pointed out. In Zambia, the mine closure planning process is integrated into the Environmental Impact Assessment (EIA) process. Specifically, according to the Environmental Act outlined in the Mines Environmental Regulations, developers must secure ZEMA's written approval for an Environmental Impact Statement (EIS) or an Environmental Project Brief (EPB) before initiating any operations (Table 11) [85]. The EIS is expected to include specific information related to mine closures.

The requirement of providing a rehabilitation plan should be considered to adhere to best practices. However, the contents of the rehabilitation plan do not have a guideline. In general, rehabilitation plans primarily focus on specific environmental restoration activities [86]. Relying solely on a rehabilitation plan for the entire mine closure process is inadequate if it addresses only the environmental aspect. Adhering to best practices requires a closure plan to offer comprehensive details, which ensures the sustainable closure of a mine by covering all aspects for effectiveness [86].

In terms of environmental, health, and safety criteria, the Zambian mine closure regulations generally lack specific technical requirements for comprehensive environmental rehabilitation, typically deferring to regulations [87]. Various applicable statutes contain general provisions on specific aspects. Developers, under the Mines Act, are obligated to clear all plants and equipment from land not covered by mining rights [84]. Commitments from developers include the sealing or fencing of excavations, shafts, tunnels, and filling in [83]. Developers are also expected to include a post-mining topography plan for physical stability within the Environmental Impact Statement (EIS) [82].

Other mine closure statutes in Zambia include relinquishment and post-closure obligations. However, the legal framework for mine closures seems inadequate in addressing the relinquishment criteria recommended by international best practices (Table 11) [88]. The legal framework specifically offers broad statements about the criteria for relinquishment and the closure certification process [76]. As previously noted, mine environmental regulations only specify the actual closure of a mine [76].

Within its legal framework, Zambia does not address socioeconomic requirements concerning mine closure (Table 11) [89]. Nevertheless, the Environmental Protection and Pollution Control (Environmental Impact Assessment) Regulations of 1997 ("EIA Regulations") mandate developers to incorporate the project's socioeconomic impacts in the EIS [81].

During mine closures, public participation and stakeholder engagement are additional regulations to consider [90]. Public participation and stakeholder engagement are integral to the EIA process, which includes mine closure considerations. However, there is no specific requirement for special attention to mine closure in the EIS. Public participation and stakeholder engagement occur at different stages of the EIA process. External stakeholders or the public lack opportunities to participate in alterations to the EIS during its validity. Consequently, this often results in the absence of stakeholder/public involvement in the changes to closure provisions made throughout the mine's lifespan [75].

5. Discussion

The trends of general decrease in forest coupled with subsequent increments of grassland/pasture/agricultural land, mines/bare land, and built-up areas in the study area are attributed to population expansion, rapid urbanization of the district, influx of small-scale mine operators (usually unemployed youth), and expansion of commercial (private) mining activities. When the changes in LULC shown in Table 10 are extrapolated, some potential threats are expected to arise in Kitwe District in the near future. One future concern is the continuation of urban expansion due to the constant increase in population from both natural growth and rural-to-urban migration [91]. The United Nations predicts that Kitwe's population will be 1,005,000 in 2030 [92]. In general, urban expansion negatively impacts the environment because more land and building materials are required for the construction of houses and other buildings [93]. This means that more forest resources are needed to construct houses and other buildings, which increases pressure on the remaining forests in the district [94]. Second, as the population increases, the demand for food also increases. This implies that grassland/pasture/agricultural land is likely to increase in the future to meet the demand for food, with further pressure on forests, as land needs to be cleared when preparing for cultivation [25]. Third, due to the current increase in the mining area and copper production, new bare land (mining area) will be created, which implies that there will be further loss in the area covered by forest and vegetation among the grassland/pasture/agricultural land classes (Table 10).

When mineral resources are depleted, mines are closed. This implies that tailings dams and open pits should also be considered. According to mine closure legislation in Zambia, mines must be sustainably closed. However, the Zambian legal framework has inadequate provisions regarding mine closure planning and plans, financial assurance, incomprehensive relinquishment, and post-closure obligations [75]. Furthermore, little is known about the socioeconomic dimensions from the perspective of mine closures because mine closures related to socioeconomic dimensions do not have legislation. While mine closure planning practices and the necessity to plan for closure are generally acknowledged within Zambia's existing legal framework, reference [75] evaluates that the framework may not be fully comprehensive and might not completely align with sustainable development principles. The evaluation, for instance, identified the absence of provisions mandating the submission of comprehensive mine closure plans. The extent of stakeholder participation in the current mine closure planning process appears somewhat insufficient, primarily dictated by the broader Environmental Impact Assessment (EIS) assessment process [83]. To ensure the successful completion and rehabilitation of mine sites, certain aspects of the current framework must be improved. This study suggests the incorporation of detailed mine closure objectives/standards within the legal framework [95]. Lastly, developers should be granted additional financial instrument options, enhancing provisions on financial assurances to accommodate the unique characteristics of each operation.

Adequate policies and intervention should be put in place [96] to minimize the above mentioned negative impacts on LULC changes. One of the intervention measures to put in place to minimize the impacts of LULC is putting stringent and rigorous efforts into the re-afforestation of affected areas, such as old tailings dams and overburdens. Resettlement and other measures aimed at restoring degraded land to its original state after mining activities should be intensified by mining companies [81].

For sustainable mine closures, revisions are required in the provisions of mine closure regulations. According to Section 119 of the Mines Act [84], the Minister of Mines and Minerals Development should be empowered to regulate mine decommissioning and closure. This study proposes amending the current Mines Environmental Regulations, the primary legislation on mine closures, to remove the closure provisions. This study also recommends incorporating mine closure provisions in the well-established Environmental Impact Assessment (EIA) process, despite the requirement for specific regulations under Section 119 by the Minister of Mines and Minerals Development. This integration ensures greater visibility for mine closures throughout the process.

Collaboration and coordination are necessary among governmental agencies, such as the ZEMA and the Ministry of Mines and Minerals Development. To improve the sustainability of ecosystems and smart land use, governmental agencies and organizations must refine their planning. These collaborative efforts should encompass social, environmental, and economic factors to ensure the sustainability of services affected by rapid urban expansion. Enhancements are needed in afforestation of mine dumping sites, forest harvesting regulations, and food production. Thus, the emphasis in planning and decision-making should be on safeguarding remaining forest reserves such as Mwekera Forest, which is currently facing encroachment. Incorporating LULC analysis in a mining area is crucial for policymaking as it provides insights into the environmental impact of mining activities, aiding in the formulation of effective regulations. By utilizing LULC data, policymakers can identify areas of concern, such as deforestation or habitat loss, prompting necessary amendments to mine closure legislation to ensure sustainable resource extraction practices and environmental protection.

Finally, the limitations of this study include the lack of high-resolution images from 1990 to 2010, the unavailability of copper production data at the district level, hindering a precise examination of the relationship between mining activities and environmental impacts, and the study's dependence on linear extrapolation for predicting future threats that may generalize the complex socioeconomic and environmental dynamics, potentially resulting in forecasting inaccuracies. Therefore, by integrating advanced remote sensing technologies, acquiring critical data through collaborations (with government agencies), adopting sophisticated modeling techniques, and incorporating qualitative methods, future studies can bridge the identified gaps and provide a more robust foundation for understanding the complex dynamics of LULC changes in Kitwe District, thereby contributing to improved environmental management and policy formulation.

6. Conclusions

Remote sensing and GIS tools were adopted to analyze LULC changes in Kitwe District, Zambia for the first time. This study identified LULC change patterns for 1990–2020. Significant changes in bare land (increased from 20.90 km^2 in 1990 to 35.58 km^2 in 2020, with 64.5% (22.95 km^2 in 2020) being mining area), built-up area (increased from 37.06 km^2 to 72.90 km^2), and grassland/pasture/agricultural area (increased from 369.43 km^2 to 412.96 km^2) were observed. Forest area decreased from 366.34 km^2 in 1990 to 271.04 km^2 in 2020. Population and mining are the main drivers of the overall increase in built-up areas and bare land in the study area. To mitigate the negative impacts of LULC change and sustain community livelihoods, the interactions between the geoecological and socioeconomic processes leading to LULC change and associated land degradation must be understood. This study suggests that ongoing programs for government-initiated sustainable land management should be strengthened. Effective collaboration and coordination among governmental agencies are essential to address the multifaceted challenges posed by rapid urban expansion and mining activities. By integrating LULC analysis into policymaking, stakeholders can proactively identify and mitigate the environmental risks associated with mining, promote sustainable land use practices, and safeguard critical ecosystems for future generations.

Zambia's legislation on mine closures has been problematic with no significant amendments made since 1995, when the country enacted its first legislation on mine closures. Despite the existence of a mine closure framework, the legislation has yet to be effectively implemented, particularly by the state. This knowledge gap should be filled by examining the impact of mines on the environment and the Zambian legal framework for sustainable mine closures.

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References

1. Twisa, S.; Buchroithner, M.F. Land-use and land-cover (LULC) change detection in Wami river basin, Tanzania. *Land* **2019**, *8*, 136. [CrossRef]
2. Rawat, J.S.; Biswas, V.; Kumar, M. Changes in land use/cover using geospatial techniques: A case study of Ramnagar town area, district Nainital, Uttarakhand, India. *Egypt. J. Remote Sens. Space Sci.* **2013**, *16*, 111–117. [CrossRef]
3. Lambin, E.F.; Turner, B.L.; Geist, H.J.; Agbola, S.B.; Angelsen, A.; Bruce, J.W.; Coomes, O.T.; Dirzo, R.; Fischer, G.; Folke, C.; et al. The causes of land-use and land-cover change: Moving beyond the myths. *Glob. Environ. Chang.* **2001**, *11*, 261–269. [CrossRef]
4. Xiao, W.; Lv, X.; Zhao, Y.; Sun, H.; Li, J. Ecological resilience assessment of an arid coal mining area using index of entropy and linear weighted analysis: A case study of Shendong Coalfield, China. *Ecol. Indic.* **2020**, *109*, 105843. [CrossRef]

5. Wang, S.W.; Gebru, B.M.; Lamchin, M.; Kayastha, R.B.; Lee, W.K. Land use and land cover change detection and prediction in the Kathmandu district of Nepal using remote sensing and GIS. *Sustainability* **2020**, *12*, 3925. [CrossRef]
6. Mensah, J. Sustainable development: Meaning, history, principles, pillars, and implications for human action: Literature review. *Cogent Soc. Sci.* **2019**, *5*, 1653531. [CrossRef]
7. Xiao, W.; Deng, X.; He, T.; Chen, W. Mapping annual land disturbance and reclamation in a surface coal mining region using google earth engine and the landtrendr algorithm: A case study of the shengli coalfield in Inner Mongolia, China. *Remote Sens.* **2020**, *12*, 1612. [CrossRef]
8. Schladweiler, B.K. 40 years of the Surface Mining Control and Reclamation Act (SMCRA): What have we learned in the State of Wyoming. *Int. J. Coal Sci. Technol.* **2018**, *5*, 3–7. [CrossRef]
9. Carvalho, F.P. Mining industry and sustainable development: Time for change. *Food Energy Secur.* **2017**, *6*, 61–77. [CrossRef]
10. Song, W.; Song, W.; Gu, H.; Li, F. Progress in the remote sensing monitoring of the ecological environment in mining areas. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1846. [CrossRef]
11. Wu, B.; Zhao, Y.; Fang, C. Detection of spatiotemporal changes of surface mining area in Changting County Southeast China. In Proceedings of the IGARSS 2019–2019 IEEE International Geoscience and Remote Sensing Symposium, Yokohama, Japan, 28 July–2 August 2019; pp. 1606–1609. [CrossRef]
12. Sikamo, J.; Mwanza, A.; Mweemba, C. Copper mining in Zambia—History and future. *J. South. Afr. Inst. Min. Metall.* **2016**, *116*, 491–496. [CrossRef]
13. Perera, N.P. Mining and spoiled land in Zambia: An example of conflicting land use in the third world. *GeoJournal* **1981**, *2*, 95–103. [CrossRef]
14. Limpitlaw, D. Mine Closure in the Zambian Copperbelt: Scenarios for Sustainable Development. In Proceedings of the SAIMM's Mine Closure Colloquium, Saxonwold, South Africa, 17 June 2003.
15. Limpitlaw, D. Mapping Mining Waste and Environmental Impacts in Zambia with Landsat. In Proceedings of the 4th European Congress on Regional Scientific Cartography and Information Systems, Bolga, Norway, 17–20 June 2003; Volume 2, pp. 699–971.
16. Limpitlaw, D.; Woldai, T. Land Use Change Detection as an Initial Stage in Environmental Impact Assessment on the Zambian Copperbelt. In Proceedings of the 28th ISRSE: Information for Sustainable Development, Cape Town, South Africa, 27–31 March 2000.
17. Chirambo, B. *Management of Post Closure Social and Environmental Issues in the Extractive Industry: A Case of Zambia*; University of Reading: Reading, UK, 2010.
18. Clark, A.L.; Clark, J.C. An International Overview of Legal Frameworks for Mine Closure. 2005. Available online: https://www.sciencebase.gov/catalog/item/5140ac89e4b089809dbf5599 (accessed on 27 March 2024).
19. Broughton, D.W. Geology and ore deposits of the central African Copperbelt. *Econ. Geol.* **1936**, *31*, 93–103. [CrossRef]
20. Britannica. Kitwe, Zambia. Britannica. Available online: https://www.britannica.com/place/Kitwe (accessed on 24 August 2020).
21. Tunatazama. Copper Belt/Former Copper Mining Centre in Kitwe, under New Attack, This Time by Illegal and Small Scale Mining. Available online: http://communitymonitors.net/2018/06/former-copper-mining-centre-in-kitwe-under-new-attack-this-time-by-illegal-and-small-scale-mining/ (accessed on 24 August 2020).
22. Munene, H. A History of Rhokana/Rokana Corporation and Its Nkana Mine Division. Ph.D. Thesis, University of the Free State, Bloemfontein, South Africa, 2018.
23. CSO. *2010 Census of Population and Housing: Population Summary Report*; Central Statistical Office: Lusaka, Zambia, 2012.
24. ZSA. *2022 Census of Population and Housing: Population Summary Report*; Zambia Statistics Agency: Lusaka, Zambia, 2022.
25. Mwitwa, J.; Sibajene, M.; Chipoya, G.C.; Namiluko, Y. *City Region Food System Situational Analysis, Kitwe, Zambia*; FAO: Rome, Italy, 2016.
26. Liu, S.; Li, X.; Chen, D.; Duan, Y.; Ji, H.; Zhang, L.; Chai, Q.; Hu, X. Understanding land use/land cover dynamics and impacts of human activities in the Mekong Delta over the last 40 years. *Glob. Ecol. Conserv.* **2020**, *22*, e00991. [CrossRef]
27. USGS (United States Geological Survey). Landsat Collection 1 Level 1 Product Definition. Version 2.0. United States Geological Survey, Department of Interior 2019, Version 2.0. Available online: https://www.usgs.gov/media/files/landsat-collection-1-level-1-product-definition (accessed on 9 November 2023).
28. Xiong, J.; Thenkabail, P.S.; Tilton, J.C.; Gumma, M.K.; Teluguntla, P.; Oliphant, A.; Congalton, R.G.; Yadav, K.; Gorelick, N. Nominal 30-m cropland extent map of continental Africa by integrating pixel-based and object-based algorithms using Sentinel-2 and Landsat-8 data on google earth engine. *Remote Sens.* **2017**, *9*, 1065. [CrossRef]
29. Du, Y.; Teillet, P.M.; Cihlar, J. Radiometric normalization of multitemporal high-resolution satellite images with quality control for land cover change detection. *Remote Sens. Environ.* **2002**, *82*, 123–134. [CrossRef]
30. Chander, G.; Markham, B.L.; Helder, D.L. Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. *Remote Sens. Environ.* **2009**, *113*, 893–903. [CrossRef]
31. Chander, G.; Markham, B.L.; Barsi, J.A. Revised landsat-5 thematic mapper radiometric calibration. *IEEE Geosci. Remote Sens. Lett.* **2007**, *4*, 490–494. [CrossRef]
32. Maas, S.J.; Rajan, N. Normalizing and converting image DC data using scatter plot matching. *Remote Sens.* **2010**, *2*, 1644–1661. [CrossRef]

33. Song, C.; Woodcock, C.E.; Seto, K.C.; Lenney, M.P.; Macomber, S.A. Classification and change detection using Landsat TM data: When and how to correct atmospheric effects? *Remote Sens. Environ.* **2001**, *75*, 230–244. [CrossRef]
34. Yarbrough, L.D.; Navulur, K.; Ravi, R. Presentation of the kauth-thomas transform for Worldview-2 reflectance data. *Remote Sens. Lett.* **2014**, *5*, 131–138. [CrossRef]
35. Firozjaei, M.K.; Alavipanah, S.K.; Liu, H.; Sedighi, A.; Mijani, N.; Kiavarz, M.; Weng, Q. A PCA-OLS model for assessing the impact of surface biophysical parameters on land surface temperature variations. *Remote Sens.* **2019**, *11*, 2094. [CrossRef]
36. Aguilar, R.; Zurita-Milla, R.; Izquierdo-Verdiguier, E.; de By, R.A. A cloud-based multi-temporal ensemble classifier to map smallholder farming systems. *Remote Sens.* **2018**, *10*, 729. [CrossRef]
37. Crawford, C.J.; Manson, S.M.; Bauer, M.E.; Hall, D.K. Multitemporal snow cover mapping in mountainous terrain for Landsat climate data record development. *Remote Sens. Environ.* **2013**, *135*, 224–233. [CrossRef]
38. Hu, Y.; Dong, Y. Anautomatic approach for land-change detection and land updates based on integrated NDVI timing analysis and the CVAPS method with GEE support. *ISPRS J. Photogramm. Remote Sens.* **2018**, *146*, 347–359. [CrossRef]
39. Dong, J.; Xiao, X.; Menarguez, M.A.; Zhang, G.; Qin, Y.; Thau, D.; Biradar, C.; Moore, B.I. Mapping paddy rice planting area in northeastern Asia with Landsat 8 images, phenology-based algorithm and Google Earth Engine. *Physiol. Behav.* **2019**, *176*, 139–148. [CrossRef] [PubMed]
40. Orengo, H.A.; Petrie, C.A. Large-scale, multi-temporal remote sensing of palaeo-river networks: A case study from Northwest India and its implications for the Indus civilisation. *Remote Sens.* **2017**, *9*, 735. [CrossRef]
41. White, J.C.; Wulder, M.A.; Hobart, G.W.; Luther, J.E.; Hermosilla, T.; Griffiths, P.; Coops, N.C.; Hall, R.J.; Hostert, P.; Dyk, A. Pixel-based image compositing for large-area dense time series applications and science. *Can. J. Remote Sens.* **2014**, *40*, 192–212. [CrossRef]
42. Goldblatt, R.; You, W.; Hanson, G.; Khandelwal, A.K. Detecting the boundaries of urban areas in India: A dataset for pixel-based image classification in google earth engine. *Remote Sens.* **2016**, *8*, 634. [CrossRef]
43. Shelestov, A.; Lavreniuk, M.; Kussul, N.; Novikov, A.; Skakun, S. Exploring Google Earth Engine platform for big data processing: Classification of multi-temporal satellite imagery for crop mapping. *Front. Earth Sci.* **2017**, *5*, 232994. [CrossRef]
44. Pelletier, C.; Valero, S.; Inglada, J.; Champion, N.; Dedieu, G. Assessing the robustness of random forests to map land cover with high resolution satellite image time series over large areas. *Remote Sens. Environ.* **2016**, *187*, 156–168. [CrossRef]
45. Deilmai, B.R.; Ahmad, B.; Zabihi, H. Comparison of two Classification methods (MLC and SVM) to extract land use and land cover in Johor Malaysia. *IOP Conf. Ser. Earth Environ. Sci.* **2014**, *20*, 012052. [CrossRef]
46. Atik, C.; Kut, R.A.; Yilmaz, R.; Birant, D. Support Vector Machine Chains with a Novel Tournament Voting. *Electronics* **2023**, *12*, 2485. [CrossRef]
47. Vapnik, V.N. *The Nature of Statistical Learning Theory*, 2nd ed.; Springer: New York, NY, USA, 1995.
48. Kotsiantis, S.B. Supervised machine learning: A review of classification techniques. *Hyperfine Interact.* **2007**, *237*, 3–24. [CrossRef]
49. Janssen, L.L.F.; van der Wel, F.J.M. Accuracy assessment of satellite derived land-cover data: A review. *Photogramm. Eng. Remote Sens.* **1994**, *60*, 419–426.
50. Erasu, D. Remote sensing-based urban land use/land cover change detection and monitoring. *J. Remote Sens. GIS* **2017**, *6*, 168–173. [CrossRef]
51. Syifa, M.; Panahi, M.; Lee, C.W. Mapping of post-wildfire burned area using a hybrid algorithm and satellite data: The case of the Camp Fire wildfire in California, USA. *Remote Sens.* **2020**, *12*, 623. [CrossRef]
52. Liu, J.G.; Mason, P.J. *Essential Image Processing and GIS for Remote Sensing*; John Wiley & Sons: Hoboken, NJ, USA, 2013; pp. 1–443.
53. Wang, Y.; Song, H.; Zhang, Y. Spectral-spatial classification of hyperspectral images using joint bilateral filter and graph cut based model. *Remote Sens.* **2016**, *8*, 748. [CrossRef]
54. Qian, Y.; Zhang, K.; Qiu, F. Spatial contextual noise removal for post classification smoothing of remotely sensed images. *Proc. ACM Symp. Appl. Comput.* **2005**, *1*, 524–528. [CrossRef]
55. Jawak, S.D.; Luis, A.J.; Fretwell, P.T.; Convey, P.; Durairajan, U.A. Semiautomated detection and mapping of vegetation distribution in the Antarctic environment using spatial-spectral characteristics of WorldView-2 imagery. *Remote Sens.* **2019**, *11*, 1909. [CrossRef]
56. Perveen, M.F.; Nagasawa, R.; Shawkat Ali, S.M.; Husnain, H. Evaluation of aster spectral bands for agricultural land cover mapping using pixel-based and object-based classification approaches. In Proceedings of the 2nd International Conference on Geographic Object-Based Image Analysis, Calgary, AB, Canada, 5–7 August 2008.
57. Tottrup, C. Improving tropical forest mapping using multi-date Landsat TM data and pre-classification image smoothing. *Int. J. Remote Sens.* **2004**, *25*, 717–730. [CrossRef]
58. Dash, P.; Sanders, S.L.; Parajuli, P.; Ouyang, Y. Improving the Accuracy of Land Use and Land Cover Classification of Landsat Data in an Agricultural Watershed. *Remote Sens.* **2023**, *15*, 4020. [CrossRef]
59. Anand, A. Unit 14 Accuracy Assessment. In *Processing and Classification of Remotely Sensed Images*; IGNOU: New Delhi, India, 2017; pp. 59–77.
60. Morales-Barquero, L.; Lyons, M.B.; Phinn, S.R.; Roelfsema, C.M. Trends in remote sensing accuracy assessment approaches in the context of natural resources. *Remote Sens.* **2019**, *11*, 2305. [CrossRef]
61. Thapa, R.B.; Murayama, Y. Urban mapping, accuracy, & image classification: A comparison of multiple approaches in Tsukuba City, Japan. *Appl. Geogr.* **2009**, *29*, 135–144. [CrossRef]

62. Foody, G.M. Status of land cover classification accuracy assessment. *Remote Sens. Environ.* **2002**, *80*, 185–201. [CrossRef]
63. Congalton, R.G.; Green, K. *Assessing the Accuracy of Remotely Sensed Data Principles and Practices*, 3rd ed.; CRC Press: Boca Raton, FL, USA, 2005; ISBN 978-1498776660. [CrossRef]
64. Huang, Y.; Tian, F.; Wang, Y.; Wang, M.; Hu, Z. Effect of coal mining on vegetation disturbance and associated carbon loss. *Environ. Earth Sci.* **2015**, *73*, 2329–2342. [CrossRef]
65. Garai, D.; Narayana, A.C. Land use/land cover changes in the mining area of Godavari coal fields of southern India. *Egypt. J. Remote Sens. Space Sci.* **2018**, *21*, 375–381. [CrossRef]
66. Emmanuel, A.Y.; Jerry, C.S.; Dzigbodi, D.A. Review of environmental and health impacts of mining in Ghana. *J. Health Pollut.* **2018**, *8*, 43–52. [CrossRef] [PubMed]
67. Obeng, E.A.; Oduro, K.A.; Obiri, B.D.; Abukari, H.; Guuroh, R.T.; Djagbletey, G.D.; Appiah-Korang, J.; Appiah, M. Impact of illegal mining activities on forest ecosystem services: Local communities' attitudes and willingness to participate in restoration activities in Ghana. *Heliyon* **2019**, *5*, e02617. [CrossRef]
68. Libanda, B.; Zheng, M.; Ngonga, C. Spatial and temporal patterns of drought in Zambia. *J. Arid Land* **2019**, *11*, 180–191. [CrossRef]
69. BOZ. *Bank of Zambia 2020 Annual Report*; Bank of Zambia: Ndola, Zambia, 2020.
70. UN-HABITAT. *Regional Technical Cooperation Division. Zambia: Kitwe Urban Profile*; UN-HABITAT: Nairobi, Kenya, 2009.
71. Xu, X.; Cai, H.; Sun, D.; Hu, L.; Banson, K.E. Impacts of mining and urbanization on the Qin-Ba mountainous environment, China. *Sustainability* **2016**, *8*, 488. [CrossRef]
72. Simutanyi, N. *Background: Mining in Zambia*; Institute for Security Studies: Cape Town, South Africa, 2008.
73. Lindahl, J. Environmental Impacts of Mining in Zambia, towards better environmental management and sustainable exploitation of mineral resources. *Geol. Surv. Swed.* **2014**, *27*, 1–27. [CrossRef]
74. Fraser, A.; Larmer, M. *Zambia, Mining, and Neoliberalism: Boom and Bust on the Globalized Copperbelt*; Palgrave Macmillan: New York, NY, USA, 2010.
75. World Bank Group Zambia. *Mining Investment and Governance Review*; Bank of Zambia: Lusaka, Zambia, 2016.
76. IIED. *MMSD Working Paper No. 44 Research on Mine Closure Policy*; IIED: London, UK, 2002; pp. 1–92. Available online: https://www.iied.org/g00541 (accessed on 27 March 2024).
77. Starke, L. *Breaking New Ground: Mining, Minerals and Sustainable Development*; Routledge: London, UK, 2002; pp. 197–230. [CrossRef]
78. Columbia Center on Sustainable Investment. *Mapping Mining to the Sustainable Development Goals: An Atlas*; Columbia Center on Sustainable Investment: New York, NY, USA, 2016.
79. AFRODAD. *Impacts of Fluctuating Commodity Prices on Government Revenue in the SADC Region: The Case of Copper for Zambia*; AFRODAD: Harare, Zimbabwe, 2016; ISBN 978-0-7974-8205-0.
80. Phiri, D. Thousands Lose Jobs as Baluba Mine Shuts Down Due to Loadshedding. Available online: https://twitter.com/zambiawatchdog/status/640874856268070913 (accessed on 10 January 2022).
81. Government of Zambia. *The Mines and Minerals (Environmental) Regulations*; Government of Zambia: Lusaka, Zambia, 1997.
82. Government of Zambia. *The Mines and Minerals (Environmental Protection Fund) Regulations*; Government of Zambia: Lusaka, Zambia, 1998.
83. Government of Zambia. *The Environmental Management Act*; Government of Zambia: Lusaka, Zambia, 2011; pp. 87–178.
84. Government of Zambia. *Mines and Minerals Development Act*; Government of Zambia: Lusaka, Zambia, 2015.
85. Sishekanu, M.; Katati, M. Subjectivity in the logic of Zambia's environmental impact assessments (EIA) process: The bedrock of controversial EIA approvals. *Law Environ. Dev. J.* **2021**, *17*, 40–54.
86. DMP; EPA. *Guidelines for Preparing Mine Closure Plans. (Revision of the Guidelines for Preparing Mine Closure Plans, June 2011)*; Department of Mines and Petroleum Mineral House: Perth, Australia, 2015; Volume 51, pp. 39–54.
87. Silwamba, E.S.; Jalasi, J.A.L.L. Mining Regulation in Zambia. Available online: http://www.dentonsmininglaw.com/mining-regulation-in-zambia/ (accessed on 10 January 2022).
88. Ndulo, M. *Mining Rights in Zambia*; Kenneth Kaunda Foundation: Lusaka, Zambia, 1987; ISBN 9982010018.
89. Kangwa, J. *Mining Minerals Sustainable Development Southern Africa*; African Institute of Corporate Citizenship: Johannesburg, Gauteng, South Africa, 2001; pp. 1–23.
90. Pring, G. *The Law of Public Participation in Mining and Resources Development*; Working Paper No. 21a; Oxford University Press Inc.: New York, NY, USA, 2002; 710p, ISBN 0-19-925378-1.
91. Kawashima, T.; Korcelli, P. (Eds.) *Human Settlement Systems: Spatial Patterns and Trends*; IIASA Collaborative Paper; IIASA: Laxenburg, Austria, 1982. [CrossRef]
92. Population Stat. Population Stat Kitwe, Zambia Population. Available online: https://populationstat.com/zambia/kitwe (accessed on 24 November 2023).
93. Enshassi, A.; Kochendoerfer, B.; Rizq, E. An evaluation of environmental impacts of construction projects. *Rev. Ing. Constr.* **2014**, *29*, 234–254. [CrossRef]
94. Contreras-Hermosilla. The underlying causes of forest decline, The CGIAR System. *CIFOR Occas. Pap.* **2000**, *30*, 1–25.

95. Chibbabbuka, R.H.; Masinja, J.; Franco, I.B. Legal Reforms as a Tool for Sustainable Development in Former Mining Communities: A Case Study of Kabwe Lead-Zinc Mine, Zambia. *J. Sustain. Dev. Law Policy* **2021**, *12*, 226–257. [CrossRef]
96. Yesuph, A.Y.; Dagnew, A.B. Land use/cover spatiotemporal dynamics, driving forces and implications at the Beshillo catchment of the Blue Nile Basin, North Eastern Highlands of Ethiopia. *Environ. Syst. Res.* **2019**, *8*, 21. [CrossRef]