Evaluating the Implications of Land Use Land Cover Change and Climate Variability on the Waterberg District's Biodiversity

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Abstract: The benefits of well-conserved biodiversity are directly related to the management practices a particular land is subject to. South Africa ranks high among nations with the most significant biodiversity, and the Waterberg district is one of the critical areas of biodiversity in the country. Mountain areas are usually rich in biodiversity and sustain the livelihood of 12% of people on Earth. The change in land use, land cover (LULC), and natural resources are reasons for degradation, habitat loss, and extinction of species, and Waterberg biospheres are affected by these activities. Land use activities in Waterberg, such as intense cultivation, producing livestock for commercial purposes, plantations, urbanization, and mining, are some of the primary factors influencing the alteration of LULC. This study assesses the change in land use and land cover over three decades (1990 – 2022) in Waterberg district, Limpopo Province, South Africa. It identifies the interaction between land use, land cover changes, and climate variability, which causes habitat loss for species. The study uses the South African National Land Cover Data Set from Landsat 5 and Sentinel-2 images. The land cover map, which was 72 classes, was reclassified into 11 classes based on the study's objectives. Eight classes were focused on biodiversity: natural woodland, thicket/dense bush, planted forest, shrublands, grasslands, waterbodies, wetlands, and agricultural land (cultivated land). These land classes underwent different transformations. The most significant changes from 1990 to 2022 were with the losses of grassland and thicket/dense bush, which reduced from 21.39% to 3.65% and 10.87% to 0.03%, and consistent increase in natural woodland from 45.96% to67.89% and planted forest from 0.07% to 4.62%. Agricultural land use reduced slightly in the first period but grew, with the usual increase in agricultural-based districts. The study illustrated using a remote sensing approach to measure changes in biodiversity and probably reverse habitat loss in the Waterberg mountainous region.

Key-Words: biodiversity, LULCC, climate change, habitat, remote sensing, Waterberg district.

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1 Introduction

Land use land cover change (LULCC) is usually caused by anthropogenic activities and has become a global environmental issue [1], [2]. LULCC also occurs because of interactions among ecosystem processes, climate variability, and other biodiversity indicators [3], which are some of the reasons for habitat loss and species extinction. The study of LULCC has, therefore, become a dynamic way to understand, map, and monitor environmental change and related processes; they also provide significant information that can be used to address biodiversity loss and climate challenges and achieve more sustainable development and nature management strategies. LULCC has substantial environmental and socio-economic impacts, especially for people living and working in mountain regions. The various effects of LULCC have also been linked to biodiversity loss, invasion of alien species, changes in soil composition and nutrients, deforestation, desertification, carbon sequestration, water cycles, and uncontrolled urban development [4], [5].

Indiscriminate use of land resources and global change challenges, with poor socio-economic impacts, are severe issues for sustainable development [6]. These call for the demand for longer temporal duration and more frequent, accurate, and consistent monitoring of land system science. Improved data availability, computer technology innovation, and advanced science development have facilitated this trend [7]. This research takes advantage of these innovations while retaining the accuracy of previously delivered products requiring substantially more human intervention. These efficiency gains have lowered costs and decreased product generation times, which is significant for monitoring the environment into the future.

Mapping and monitoring LULCC are also helpful to address land use management conflicts in the face of urbanization, which has put pressure on limited natural resources, especially in developing countries of sub-Sahara Africa; it can also help in averting biodiversity loss and mitigating climate challenges. There is a need for detailed, accurate, thorough, and updated spatial data that can be used to inform planning and management decisions. The applications of Geographic Information Systems (GIS) and Remote Sensing (RS) are well-known, cost-effective, and time-saving tools that are effective for mapping and planning land resources as well as understanding and monitoring landscape change over time [8], [9].

Thus, the application of RS and GIS tools has been able to help land experts like researchers, policy and decision-makers understand LULC dynamics, prioritize land usage for the best purposes, conserve and manage resources, and make viable decisions [10], [11]. Therefore, the knowledge generated through applying the tools is instrumental in assessing and monitoring land use and other natural resources [12].

The study of LULCC, climate change, and the role they play on the stability of biodiversity as a habitat for species in the Waterberg district is essential in understanding the current changes and the impacts on the region's natural resources and human livelihood. Globally, it is estimated that 30% of species have been lost since 1500 [13], and about 22% of South Africa's natural habitat has been lost since 1600 [14]. Waterberg District, one of the essential biodiverse areas of South Africa, plays a host and natural habitat to diverse species and, like any other mountainous region in South Africa, has experienced several critical transformations in terms of LULC in the past 30 years. For example, transformations of land use and land cover due to mining, migration, drought history, game farming, and intense agricultural activities transform the habitats of plants and animals from time to time. However, because of the multifunctional benefits of the region to humans, animals, and nature, there is a need for detailed, current, and accurate LULCC maps for the district. This study assessed the LULCC between 1990 and 2022 in the Waterberg District of Limpopo Province, South Africa, to achieve this aim. This study seeks to improve the current knowledge of the change and trend of land use and land cover as it impacts biodiversity and species habitat. Also, it identifies the interaction between LULCC and climate variability and their impact on biodiversity and the socio-economic state of the district. The research anticipates a mountainous landscape context that will increase the benefits for the residents (plants and animals), inform decision-makers to manage land resources against degradation, deforestation, future risks and disasters, address climate challenges, biodiversity and ecosystem management, and sustain development in the region [15].

2 Materials and Method

2.1 Study area

Waterberg district is a mountain region located in the north-eastern part of Limpopo province, South Africa (Figure 1), with the highest elevation of 1133m above sea level and the coordinates of 23.9748°S and 28.2994° E. and a population of 745753 habitants (2016 population census). UNESCO designated it as a Biosphere Reserve in 2001 [16]. It is one of the district municipalities of the province, and it shares boundaries with Capricorn District Municipality on the northeast, Botswana on the northwest, and Greater Sekhukhune District Municipality to the east. Northwest Province is in the southwestern part, while Gauteng Province is to the South of the district. The district has an average rainfall of 600mm to 650mm throughout the year; the land area of 44,913 km² consists of rocks and uplands, with soil good for agricultural development. Agriculture, domestic and industrial mining are the major economic activities in the region. Summer ranges from 10 to 33°C, and winter from 6 to 21°C. The geology is characterized by sedimentary rocks, which are detritus and comprise sandstones, mudstones, and shales.

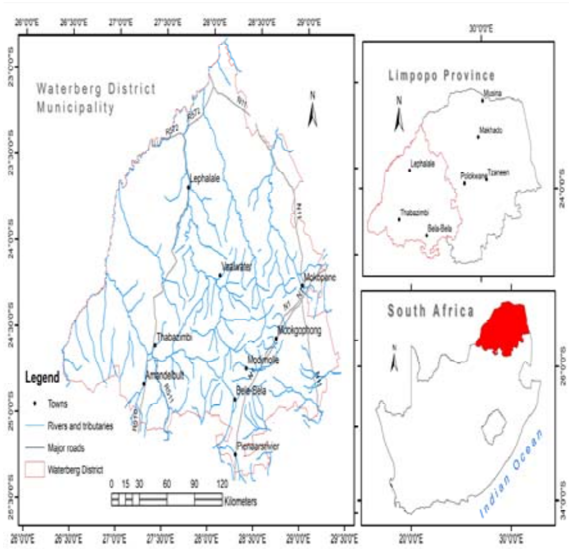

Figure 1: The Study Area, Waterberg District within Limpopo Province and South Africa.

2.2 Data Source

Environmental Geographic Information System (E-GIS) (egis.environment.gov.za) has been providing data on South Africa's national land cover and changes since 1990, at 30m spatial resolution of Landsat, with SANLC 1990, SANLC 2013, SANLC 2018, and SANLC 2022 (ref). The recently released SANLC 2022 dataset is timely for improving South African land cover data updates and related changes.

This research study utilized data from the South African National Land Cover (SANLC) 1990 and 1972 classes of land cover data generated by

GEOTERRAIMAGE. It was derived from the website of the Department of Environmental Affairs-GIS data [17]. The data was derived from Landsat 5, providing digital, multi-seasonal, multispectral images from 1989 to 1991. Over 600 Landsat pictures were utilized to create the land cover information based on an average assessment of 8 distinct acquisition dates for capturing seasonal images. The National Land Cover of 2018 dataset was derived from a multi-seasonal source with a resolution of 20 meters of imagery from the Sentinel 2 satellite. The visual representation utilized encompasses the entire spectrum of time that is accessible to imagery obtained from the Sentinel 2 satellite. This data is extensively utilized in South Africa to know the influences of land cover change on several other sectors. The SANLC 2018 dataset is derived from the recent Land Cover Classification Standard (SANS 19144-2) using 72 classes; the information is compared to the prior data of SANLC from 1990 and 2013-2014. The utilization of the DEFF/DRDLR recommended Albers Equal Area Conic for all Area projections, considered the most accurate and reliable map projection type and change assessment, and reporting in the derivation of SANLC Change for 2018. Table 1 reveals the land use land cover and their descriptions.

Table 1: Land uses land cover and their descriptions.

LULC	**Description**
Indigenous forest	Natural / semi-natural indigenous forest, dominated by tall trees, where tree canopy heights are typically > ± 5m and tree canopy densities are typically > ± 75 %, often with multiple understory vegetation canopies.
Thicket/dense bush	Natural/semi-natural tree and/or bush-dominated areas typically have canopy heights between 2 - 5 m, and canopy density is typically > ± 75% but may include localized sparser areas down to ± 60%22. This includes dense bush, thicket, close woodland, tall, dense shrubs, scrub forests, and mangrove swamps. It can consist of self-seeded bush encroachment areas with sufficient canopy density.
Natural woodland	Natural / semi-natural tree and/or bush-dominated areas, where typically canopy heights are between ± 2 - 5 m, and canopy densities typically between 40 - 75%, but may include localized sparser areas down to ± 15 - 20 %28. Includes sparse-open bushland and woodland, including transitional wooded grassland areas.
Planted forest	Planted forestry plantations are used for growing commercial tree species. They are Mature Trees, Young Trees, and Temporary Clearfelled Stands. The mature tree stands have approximately 70% or greater tree canopy closure. The young tree stands have approximately 40 - 70% tree canopy closure. The temporarily clear-felled stands are those stands that did not appear to have any tree cover in the most recent (i.e., latest) of the multi-date Landsat images used in the land-cover modeling, irrespective of the tree cover conditions in the earlier image dates.
Shrublands	Natural low community, Indigenous, succulent shrubland

Grassland	Natural woody vegetation above 2.5m in grassland-dominated and natural or semi-natural Indigenous grass areas.
Wetlands	Natural or semi-natural, called herbaceous wetlands and wetland vegetation.
Waterbodies	Natural rivers with perennial or non-perennial associated with tributaries, coast areas, oceans and lagoons, lakes, and floodplains that are spatially enough to be detected by the image. Also, artificial water/ sewage dam, pond, and mine pit.
Barren land	Barren land, naturally occurring non-vegetation areas, exposed and consolidated substrate, dunes, and beach sands.
Built-up	Formally or informally planned built-up areas, residential, commercial, industrial, recreational, agricultural smallholdings, mining sites, waste dumps, roads, rail, and other major linear structures along the city.
Agricultural land	Active or recently active cultivated land, agricultural productive land, previously captured as used for cultivated land.
Mines and Quarries	Both active and abandoned mining activities. Class may include open cast pits, sand mines, quarries, and borrow pits. Based on *semi-bare ground surfaces* and water bodies inside mining areas, the mining activity footprint represents permanent or non-permanent water extents.

2.3 Data Pre-Processing

From the E-GIS website, we downloaded a dataset on land cover and its change. Then, the synopsis of production methods and the process for integrating the database into the land cover product was focused on [18]. We also describe the approach for assessing land cover accuracy and the protocol for evaluating the over 30-year land change to the steps used to clean, transform, and prepare raw data for analysis—results, including trends, patterns, and specific thematic outcomes.

This process is used to prepare a dataset from the E-GIS website for analysis. The essential information used to produce the change analysis in 1990/2022 and 2013/2018 results were geographic coordinate formats modified to SANLC datasets into the new, streamlined format [19]. The legend was re-projected and changed to alter the geographic coordinates for the 1990, 2013, 2018, and 2022 datasets. The datasets were transformed to the Albers Equal Area map projection, including a spatial resampling process that involves a single step. The SANLC 2018 dataset has been converted to a resolution of 30 x 30 meters per cell resolution output. The data processing ensured that the pixel-to-pixel record in 30m resolution Albers Equal Area map projection outcome was complete using SANLC datasets 2018 and 2022 as references compared to 1990 and 2013 datasets. This method was like the precision of the Sentinel 2 imagery from which 2018 SANLC was generated, which made it a standard for the previous Landsat imagery used to compile other datasets.

2.4 Methodology

To accurately understand and evaluate the factors affecting biodiversity in Waterberg district, Limpopo Province of South Africa, the study assesses changes in land use land cover. It utilizes a comprehensive national land cover dataset of 72 distinct classes; a 30x30 raster cell was created for South Africa's multi-seasonal Landsat 5 imagery. The class of 72 land cover maps underwent reclassification, resulting in the reclassification of eleven distinct classes (Table 1) are thickets/ dense bush, natural woodlands, planted forest, shrubland, grassland, water bodies, and wetlands, agricultural land, which are all referred to as vegetation natural resources in which the assessments for this study's biodiversity was based. Others are built-up, barren land, mines, and quarries. Though indigenous forest was one of the vegetation in Limpopo province's biosphere, it was missing in the period under study. In other categories of land cover classes, natural woodland was the significant and continued dominant biodiversity in the study area, followed by cultivated (agriculture) land and planted forests with minimal gain over the years. Waterbodies, wetlands, grasslands, and shrublands fluctuated while barren land decreased, and ticket/ dense bush suffered severe losses within the years in the study.

The land cover data obtained was taken through pre-processing to ensure it had uniform characteristics and pertinent projections trimmed to the boundary of the study zone. A post-classification method was employed to identify and evaluate alterations in natural resources within the research. The land cover images of 1990 - 2018 were initially transformed.

Converting from Universal Transverse Mercator (UTM) to the spatial resolution of GCS_WGS_1984 ALBERS is being referred to, with resolutions of 30 meters by 30 meters to facilitate straightforward data tabulation to conduct change analysis. A table was created to display information to calculate the percentage change in land cover change within the specified research periods in the years 1990, 2013, 2018, and 2022. The land use and land cover classifications within the research section are measured in hectares and then expressed as a percentage change. Comparing land cover and land use types for each year. The percentage change for each year, specifically 1990 and 2013, is required, and then calculation for 2018 and 2022 was performed for the land cover (biodiversity) category.

The percentage change, which is used to identify the change trend, was obtained by dividing the change detected in the prior area (measured in hectares) by 100.

Table 2: Reclassification and Harmonised LULC classes used for change detection analysis

Land cover types	**NLC 1990**	**NLC 2013**	**NLC 2018**	**NLC 2022**	**Reclassification /New classes**
Indigenous forest	1	1	1	1	1
Thicket/dense bush	2	2	2	2	3
Natural woodland	3	3	3 - 4	3 - 4	3
Planted forest	5	5	5 - 7	5 - 7	4
Shrublands	4	4	8	8	5
Grasslands	13	13	12 - 13	12 - 13	6
Water bodies	33	33	14 - 21	14 - 21	7
Wetlands	12	12	22-23, 73	22 – 23,73	8

Barren land (bare land)	34 – 35	34 - 35	25 - 31	25 - 31	9
Agricultural land	6 – 10	6 - 10	32 – 46	32 – 46	10
Built-up areas	11	11	47 - 67	47 - 67	11
Mines and quarries	32	32	68 - 72	68 - 72	12

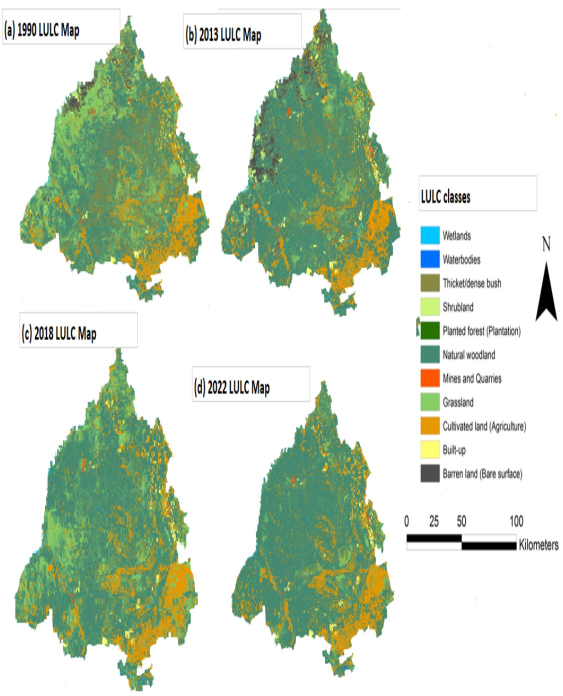

Figure 2: Land use land cover change maps in Waterberg District for 1990, 2013, 2018 and 2022

2.5 Change detection analysis

Change detection is a method that measures the alterations linked to changes in land use and land cover (LULC) in the landscape. It involves analyzing geo-referenced multi-temporal remote sensing pictures obtained over the same geographical region at specific acquisition dates. The study utilized a post-classification comparison (PCC) change detection approach to identify the Land Use and Land Cover (LULC) changes between two independently categorized maps from various dates during the study period. Despite a few shortcomings, post-classification comparison is the prevailing approach for comparing maps from diverse sources. The technique offers extensive and thorough information on land use and land cover (LULC) changes without data normalization between the two dates. This has been demonstrated by many studies [20], [21]. The utilization of the PCC approach yielded a cross-tabulation matrix, specifically a LULC change transition matrix, that was calculated using overlay functions in ArcGIS.

Additionally, net profits and losses were computed for three specific time frames: 1990-2013, 2013-2018, and 2018-2022. The LULC change transition matrix was computed and displayed in Table 3. It comprised rows representing the LULC class category for time 1 (T1) and columns representing the LULC class category for time 2 (T2), as shown in Table 3.

Table 3: General LULC change transition matrix for comparing two maps between observation times

		LULC 1	LULC 2	LULC 3	LULC 4	LULC n	Total T1	Losses
Time 1 (T1)	**LULC 1**	*A11*	*A12*	*A13*	*A14*	*A1n*	*A1+*	*A1 +-A11*
	LULC 2	*A21*	*A22*	*A23*	*A24*	*A2n*	*A2+*	*A2 +-A22*
	LULC 3	*A31*	*A32*	*A33*	*A34*	*A3n*	*A3+*	*A3+ – A33*

	LULC 4	*A41*	*A42*	*A43*	*A44*	*A4n*	*A4+*	*A4 +-A44*
	LULC n	*An1*	*An2*	*An3*	*An4*	*A4n*	*An+*	*A4+ - Ann*
	Total T2	***A+1***	***A+2***	***A+3***	***A+4***		1	
	Gain	***A+1 – A11***	***A+2 – A22***	***A+3 – A33***	***A+4 – A44***	***A+4 - Ann***		

Aij = the land area that experiences transition from LULC category i to LULC category j
Aii = the diagonal elements indicating the land area that shows the persistence of LULC category i while the entries of the diagonal indicate a transition from LULC category i to a different category j
$Ai+$ (total column) = the land area of LULC category i in T1 which is the sum of all j of Aij
A+j (total rows) = land area of LULC category j in time 2 which is the sum of over all of i of Aij
Losses ($Ai+$ – Aii) = proportion of landscape that experiences gross loss of LULC category i between time 1 and 2
Gains ($A+i$ – Aii) = proportion of landscape that experiences gross gain of LULC category j between time 1 and 2

2.6 Rate of Change in Percentage

Authors in [22] define the net change as the absolute difference between gain and loss. The annual rate of change of land use and land cover (LULC) was calculated for four distinct periods (1990-2013, 2013-2018, 1918-2022, and 1990-2022) using the methodologies proposed by [22], [23]. This equation serves as a reference point for comparing LULC changes, regardless of the varying durations of the study periods.

$$r=(1t2-t1)\times ln(A2A1)$$

where: r is the annual rate of change for each class per year; $A2$ and $A1$ are the class areas (ha) at time 2 and time 1 respectively and t is the time (in years) interval between the two periods under consideration.

3 Findings

To accurately evaluate the changes in biodiversity and the natural environment of Waterberg district municipality, an assessment of land cover change was conducted. The study was done using land-cover data from 72 classes. A grid of 30x30 raster cells was produced for South Africa obtained from Landsat 5 images captured across many seasons. The land cover maps were reclassified, identifying twelve new classes (Table 1). Out of the twelve classes we supposed at the beginning due to literature from the neighboring areas, Vhembe and Tshwane municipality, the study will focus more on these classes as biodiversity and species habitat according to this study; the indigenous forest is not found, so we have, thicket/ dense bush, woodland, agriculture, planted forest, shrubland, grassland, waterbodies, and wetlands. Waterbodies and wetlands are natural habitats, while others, including built-up, bare land, and mining, are transformative habitats [24]. Natural woodland was the most significant biodiversity, followed by agricultural land use (cultivated land); there was also a slight increase in planted forest, which was not so substantial. Wetlands and waterbodies had the least coverage in hectares among the categories. The changes in land cover maps for the Waterberg district in the years under study are in Figure 2.

3.1 Dynamics of Biodiversity in Waterberg Land Cover Change

Figure 2 displays the Land Use and Land Cover (LULC) maps for the 11 classes, as revealed in the reclassification process. Significantly, between 1990 and 2013, grassland lost so much land area, about 75%, majorly to the planted forest and natural woodland. Throughout the research period from 1990 to 2022, natural woodland and agricultural land were the most prevalent land cover (LULC) groups, as shown in Table 4. In 1990, the study area showed 40.96% natural woodland, 21.39% grassland, 13.76% agricultural land, 10.87% thicket/ dense bush, 2.1% shrubland, 0.85% wetlands, and 0.07% water. The percentages of natural woodland and planted forest increased significantly throughout the periods under study, but there was a slight slow-down for planted forest in 2022. Also, shrubland and waterbodies increased significantly over doubled and wetland almost doubled in the year 2013; thicket/dense bush and grassland declined drastically from 10.87% (4876.944ha), 21.39% (9,939.15 ha) in 1990 to 5.58% (2503.531ha), 5.24% (2353.635ha) respectively in 2013. Grassland increased significantly again to 13.17% in 2018 and decreased with so much intensity to 3.65% in 2022. There is a slight decrease in the first period but later a steady and continuous increase in agricultural activities in the study area; this is not far from the fact that the primary activity of most of the dwellers is farming, it can also be assumed for the fluctuations in shrublands and grasslands land coverage to agricultural land.

Though not so relevant to the study, the increase in barren land and built-up between 1990 and 2013 is worth mentioning. The reason may not be far from some policies (for example, Reconstruction and Development Programmes) related to home ownership and social housing schemes by the democratic government [25]. There has been a drastic decline in barren land and little or no significant increase in built-up areas, while barren land decreased from 5.6%, 1.2%, and 0.8% in 2013, 2018, and 2022. From 2013, the built-up remained relatively between 1.25% to 1.27%.

The yearly rate of change exhibited a diverse and fluctuating pattern for each land use and land cover (LULC) category for the whole duration of the research, as shown in Table 4. Over the entire research period (1990 - 2022), the yearly rate of change for mining kept on fluctuating from year to year; this may be due to policies on public and private mining [26], waterbodies and wetlands are fluctuating too, and the reason may be related to the climate/ condition of the study area [27].

3.1.1 Major Transformation in the Biodiversity Land Classes

The rate of transformation that happened in these three classes of land cover, natural woodland, thicket/dense bush, and grassland, is critical to this study. However, an increase in agricultural activities such as game farming, commercial growing of crops, mining, and uncontrolled development are some of the visible reasons for the change. The GIS images analysis transformed thicket/dense bush and grassland into natural woodland and planted forest. However, thicket/ dense bush and grassland provide valuable ecosystem services to the environment; the gradual disappearance of the former with the increase in planted forests suggests encroachments and human interference in the natural environment. Also, there is a significant loss of grassland, evidence of overgrazing, and a decrease in soil nutrient cover; the losses of wetlands and shrublands show deficiencies in ecosystem balance, soil protection, and water retainment level of the land area because of these inabilities, it will be difficult for the environment to provide functions like species habitats, climate mitigation, and carbon sequestration [28].

3.1.2 Habitat for plants and species

A suitable habitat can provide a conducive habitation for plants and species, which are living organisms and parts of the environment; they help contribute to a well-balanced eco-friendly environment and other supportive services such as provisioning, regulating, and cultural [28]. Also, habitat is measured well if it can support and maximize species survival and continuity with complete and uninterrupted ecosystems and less anthropogenic activities. This kind of habitat is referred to as a high biodiversity area, and research has shown that such areas with legal protection help alleviate biodiversity threats [28]. Nonetheless, intense cultivation, wetland loss, and mining reduce the quality of species' habitats.

In the case of the Waterberg district, the losses of grasslands, shrubland, thicket/ dense bush, barren land, and gradual decline in wetland, mining activities, and land degradation indicate a low-quality habitat for species and consequently altered plant and animal species composition and dynamics of flora and fauna population in the area. This low-quality habitat is caused by habitat disruptions, vegetation removal, and intense/conversion of agricultural land use [29]. However, this low-quality habitat with degraded areas is regarded as a poor biodiverse area since the habit has a low tendency to provide species with appropriate living conditions, support provisioning services of the ecosystem, and offer multifunctional benefits to people's well-being [29].

Table 4: Land use land cover and their Percentage Coverage

Land Cover	1990		2013		2018		2022	
	Ha	%	Ha	%	Ha	%	Ha	%
Indigenous forest								

Thicket/dense bush	4876.944	10.87	2503.531	5.58	3.838	0.009	12.563	0.028
Natural woodland	20623.716	45.96	26381.253	58.77	25655.575	57.153	30465.422	67.888
Planted forest	31.485	0.07	1699.892	3.79	2159.307	4.810	2074.459	4.623
Shrubland	944.333	2.10	2267.323	5.05	2029.660	4.522	1311.809	2.923
Grassland	9600.585	21.39	2353.635	5.24	5909.598	13.165	1638.485	3.651
Waterbodies	29.085	0,07	527.114	1.17	376.653	0.839	507.478	1.131
Wetlands	382.939	0.85	663.002	1.48	565.219	1.259	529.030	1.179
Baren land	1676.215	3.74	2510.162	5.59	533.004	1.187	349.629	0.779
Agricultural land	6172.809	13.76	5319.995	11.85	7016.717	15.631	7335.920	16.347
Built up	424.987	0.95	566.822	1.26	567.373	1.264	566.139	1.262
Mines and Quarries	113.336	0.25	97.007	0.21	72.553	0.162	85.504	0.191
Total	44876.434	100	44889.736	100	44889.497	100	44873.438	100

3.2 Net Change in Gains and Losses of LULC

The net change refers to the disparity between the amount gained and lost [22]. The changes in land use and land cover over the research period were determined by comparing the data from one year to another. The crosstabulation table is presented from 1990- 2013, 2013-2018, 2018-2022, and 1990-2022. The post-classification results show the changes observed between two periods using a "two-way table," specifically the relationship between land use land cover classes, both in the decrease and increase.

Table 5: Change matrix 1990-2013

	Thicket/dense bush	Natural woodland	Planted forest	Shrub land	Grass land	Waterbodies	Wetlands	Barren land	Agricultural land	Built-up	Mines and Quarries	**Sum 1990**
Thicket/dense bush	**1410.9669**	3011.4063	86.7636	82.51	172.3923	17.4213	23.9949	16.7679	35.7876	14.8653	4.0464	**4876.9191**
Natural woodland	840.7971	**15362.7561**	777.9159	966.051	1232.32	158.06	169.52	732.05	289.54	75.24	19.39	**20623.64**
Planted forest	5.42	9.47	**6.07**	1.40	2.44	0.48	0.70	1.29	1.91	2.19	0.12	**31.48**
Shrubland	5.17	434.20	81.12	**198.13**	51.89	25.99	11.78	94.51	27.81	13.28	0.48	**944.34**
Grassland	159.25	5849.35	517.69	780.03	**666.20**	147.78	185.83	966.69	266.16	45.35	16.19	**9600.54**
Waterbodies	1.72	4.34	0.90	0.84	0.84	**18.40**	1.08	0.55	0.36	0.05	0.00	**29.09**
Wetlands	37.25	101.70	26.11	16.39	15.40	26.98	**136.25**	5.22	17.07	0.22	0.04	**382.63**
Barren land	6.02	627.05	88.40	96.36	83.88	76.58	53.46	**491.75**	139.85	10.29	2.58	**1676.21**
Agricultural land	28.90	922.18	103.53	114.48	118.92	49.09	71.98	192.15	**4524.14**	36.60	10.86	**6172.83**
Built-up	4.33	15.97	6.13	5.73	4.75	3.31	3.71	6.03	12.49	**361.57**	0.97	**425.00**
Mines and Quarries	2.36	36.75	4.84	4.82	3.74	2.42	2.39	2.99	3.61	7.11	**42.31**	**113.33**
Sum 2013	**2502.18**	**26375.17**	**1699.47**	**2266.75**	**2352.75**	**526.53**	**660.69**	**2509.99**	**5318.72**	**566.76**	**96.99**	**44876.01**

Note: The bold numbers mean the unchanged LULC portions from 1990 to 2013

Table 6: Change matrix 2013-2018

	Thicket/ dense bush	Natural woodland	Planted forest	Shrub land	Grassland	Waterbodies	Wetland	Barren land	Agricultural land	**Built-up**	Mines and Quarries	**Sum 2013**
Thicket/ dense bush	**2.66**	2164.36	83.92	52.20	101.27	11.32	10.23	9.86	64.73	2.26	0.72	**2503.53**
Natural woodland	0.43	**18504.32**	1242.46	1214.43	3273.07	103.03	133.25	179.25	1704.02	22.12	4.88	**26381.25**
Planted forest	0.10	902.43	**173.33**	127.89	266.88	26.66	31.32	26.36	135.39	8.34	1.19	**1699.89**
Shrubland	0.05	1132.55	179.66	**188.26**	484.25	30.53	38.93	39.23	160.58	12.11	1.17	**2267.32**
Grassland	0.04	1300.71	127.36	111.37	**514.79**	29.63	32.08	45.28	181.82	8.40	2.18	**2353.64**
Waterbodies	0.08	188.63	40.95	43.39	101.74	**54.24**	31.01	12.67	48.05	5.37	0.98	**527.11**
Wetlands	0.10	197.40	38.48	43.56	103.22	29.82	**163.85**	18.56	62.22	4.77	1.02	**663.00**
Barren land	0.05	974.97	183.13	173.41	809.03	29.27	30.86	**73.40**	223.86	9.60	2.59	**2510.16**
Agricultural land	0.24	271.79	81.73	68.69	231.53	51.99	85.62	119.37	**4391.28**	16.01	1.75	**5319.99**
Built-up	0.06	14.83	6.10	4.65	9.66	3.70	4.34	6.02	40.83	**472.79**	3.84	**566.82**
Mines and Quarries	0.01	3.77	2.23	1.86	14.23	6.40	3.66	3.02	3.97	5.62	**52.24**	**97.01**
Sum 2018	**3.84**	**25655.76**	**2159.35**	**2029.71**	**5909.68**	**376.59**	**565.13**	**533.01**	**7016.75**	**567.38**	**72.55**	**44889.74**

Note: The bold numbers mean the unchanged LULC portions from 2013 to 2018

Table 7: Change matrix 2018-2022

	Thicket/dense bush	Natural woodland	Planted forest	Shrub land	Grass land	Waterbodies	Wetlands	Barren land	Agricultural land	Built-up	Mines and Quarries	**Sum 2018**
Thicket/ dense bush	**1.52**	1.72	0.13	0.13	0.09	0.09	0.03	0.03	0.08	0.01	0.00	**3.84**
Natural woodland	10.50	**23664.71**	879.67	422.98	361.13	67.07	39.34	22.02	180.91	5.93	1.32	**25655.57**
Planted forest	0.24	1476.34	**258.03**	152.34	123.48	45.61	31.43	21.49	47.32	2.48	0.54	**2159.31**
Shrubland	0.12	1414.81	225.08	**130.70**	107.33	36.84	39.97	22.44	48.87	2.91	0.60	**2029.66**
Grassland	0.10	3772.09	558.06	416.78	**803.97**	78.09	54.10	41.50	169.98	7.74	7.18	**5909.60**
Waterbodies	0.03	44.25	47.52	46.37	50.36	**80.49**	39.25	24.38	38.11	3.24	2.65	**376.65**

Wetlands	0.02	35.69	45.06	59.27	64.67	61.11	**175.47**	32.45	84.61	4.19	2.67	**565.22**
Barren land	0.01	39.36	40.55	46.57	71.21	57.63	54.64	**54.11**	160.47	5.78	2.69	**533.00**
Agricultural land	0.03	16.87	17.19	32.24	50.83	73.37	86.82	121.44	**6574.66**	38.23	5.04	**7016.72**
Built-up	0.00	4.80	3.18	4.19	5.12	7.02	7.61	8.25	29.06	**491.93**	6.21	**567.37**
Mines and Quarries	0.00	0.90	0.47	0.83	1.39	1.80	1.69	1.62	3.39	3.84	**56.61**	**72.55**
Sum 2022	**12.57**	**30471.54**	**2074.93**	**1312.39**	**1639.59**	**509.15**	**530.36**	**349.72**	**7337.46**	**566.27**	**85.51**	**44889.49**

Note: The bold numbers mean the unchanged LULC proportions from 2018 to 2022

Table 8: Change matrix 1990-2022

	Thicket/dense bush	Natural woodland	Planted forest	Shrubland	Grassland	Water bodies	Wetlands	Barren land	Agricultural land	Built-up	Mines and Quarries	**Sum 1990**
Thicket/dense bush	**7.45**	4240.37	182.45	107.75	141.55	38.26	30.97	14.39	94.30	16.49	2.97	**4876.94**
Natural woodland	2.39	**16879.83**	1023.11	604.68	715.71	161.91	140.19	85.40	899.55	92.71	18.25	**20623.72**
Planted forest	0.09	9.08	**10.62**	1.54	2.35	1.10	1.49	0.88	1.67	2.66	0.01	**31.48**
Shrubland	0.02	621.77	93.30	**61.98**	56.09	17.58	14.83	9.79	53.94	14.30	0.74	**944.33**
Grassland	0.53	7238.53	546.41	339.23	**493.91**	93.28	78.01	52.05	687.27	54.68	16.69	**9600.59**
Waterbodies	0.03	2.30	0.96	1.24	1.29	**22.14**	0.66	0.18	0.26	0.03	0.00	**29.09**
Wetlands	1.73	108.59	24.69	26.95	29.99	41.20	**115.42**	6.19	27.80	0.32	0.05	**382.94**
Barren land	0.02	1107.86	124.67	84.58	86.02	28.09	22.96	**19.37**	189.22	9.75	3.67	**1676.21**
Agricultural land	0.22	201.38	52.41	69.05	93.42	92.58	112.07	151.00	**5356.81**	32.56	11.30	**6172.81**
Built-up	0.08	23.94	6.16	5.85	6.22	6.94	8.15	7.09	20.28	**337.64**	2.65	**424.99**
Mines and Quarries	0.00	31.77	9.68	8.96	11.92	4.40	4.28	3.29	4.81	5.02	**29.19**	**113.34**
Sum 2022	**12.56**	**30465.42**	**2074.46**	**1311.81**	**1638.49**	**507.48**	**529.03**	**349.63**	**7335.92**	**566.14**	**85.50**	**44876.44**

Note: The bold numbers mean the unchanged LULC portions from 1990 to 2022

Table 9: Percentage of land cover change 1990-2013

	Year 1990	**Year 2013**	**Difference**	**Year 1990 % of Total**	**Year 2013 % of Total**	**% Difference**

Thicket/dense bush	4876.9443	2503.5309	-2373.4134	10.8675	5.5771	-48.6660
Natural woodland	20623.7160	26381.2527	5757.5367	45.9567	58.7690	27.9171
Planted forest	31.4847	1699.8939	1668.4092	0.0702	3.7868	5299.1110
Shrubland	944.3331	2267.3232	1322.9901	2.1043	5.0509	140.0978
Grassland	9600.5853	2353.6350	-7246.9503	21.3934	5.2432	-75.4845
Waterbodies	29.0853	527.1138	498.0285	0.0648	1.1742	1712.3031
Wetlands	382.9392	663.0012	280.0620	0.8533	1.4770	73.1348
Barren land	1676.2149	2510.1621	833.9472	3.7352	5.5918	49.7518
Agricultural land	6172.8093	5319.9945	-852.8148	13.7551	11.8513	-13.8157
Built-up	424.9872	566.8218	141.8346	0.9470	1.2627	33.3739
Mines and Quarries	113.3361	97.0065	-16.3296	0.2526	0.2161	-14.4081

Table 10: Percentage of land cover change 2013-2018

	Year 2013	**Year 2018**	**Difference**	**Year 2013 % of Total**	**Year 2018 % of Total**	**% Difference**
Thicket/dense bush	2503.5309	3.8376	-2499.6933	5.5771	0.0086	-194.3008
Natural woodland	26381.2527	25655.5746	-725.6781	58.7690	57.1527	37.3057
Planted forest	1699.8939	2159.3061	459.4122	3.7868	4.8103	120.1824
Shrubland	2267.3232	2029.6593	-237.6639	5.0509	4.5215	16.2075
Grassland	2353.6350	5909.5971	3555.9621	5.2432	13.1648	-338.2895
Waterbodies	527.1138	376.6527	-150.4611	1.1742	0.8391	90.7569
Wetlands	663.0012	565.2189	-97.7823	1.4770	1.2591	22.0348
Barren land	2510.1621	533.0034	-1977.1587	5.5918	1.1874	-52.8486
Agricultural land	5319.9945	7016.7168	1696.7223	11.8513	15.6311	21.8630
Built-up	566.8218	567.3726	0.5508	1.2627	1.2639	24.9023
Mines and Quarries	97.0065	72.5526	-24.4539	0.2161	0.1616	-28.6914

Table 11: Percentage land cover change 2018-2022

	Year 2018	**Year 2022**	**Difference**	**Year 2018 % of Total**	**Year 2022 % of Total**	**% Difference**
Thicket/dense bush	3.8376	12.5631	8.7255	0.0086	0.0280	-126755.8161

Natural woodland	25655.5746	30465.4221	4809.8475	57.1527	67.8874	38.3609
Planted forest	2159.3061	2074.4586	-84.8475	4.8103	4.6226	94.6125
Shrubland	2029.6593	1311.8085	-717.8508	4.5215	2.9232	18.1053
Grassland	5909.5971	1638.4851	-4271.1120	13.1648	3.6511	-134.7317
Waterbodies	376.6527	507.4776	130.8249	0.8391	1.1308	127.0115
Wetlands	565.2189	529.0299	-36.1890	1.2591	1.1789	25.8467
Barren land	533.0034	349.6284	-183.3750	1.1874	0.7791	-248.8889
Agricultural land	7016.7168	7335.9198	319.2030	15.6311	16.3469	16.5763
Built-up	567.3726	566.1387	-1.2339	1.2639	1.2616	24.8781
Mines and Quarries	72.5526	85.5036	12.9510	0.1616	0.1905	-38.3618

Table 12: Percentage landcover change 1990-2022

	Year 1990	**Year 2022**	**Difference**	**Year 1990 % of Total**	**Year 2022 % of Total**	**% Difference**
Thicket/dense bush	4876.9443	0.0280	-4864.3812	10.8675	0.0280	-99.7424
Natural woodland	20623.7160	30465.4221	9841.7061	45.9567	67.8874	47.7203
Planted forest	31.4847	2074.4586	2042.9739	0.0702	4.6226	6488.7831
Shrubland	944.3331	1311.8085	367.4754	2.1043	2.9232	38.9137
Grassland	9600.5853	1638.4851	-7962.1002	21.3934	3.6511	-82.9335
Waterbodies	29.0853	507.4776	478.3923	0.0648	1.1308	1644.7907
Wetlands	382.9392	529.0299	146.0907	0.8533	1.1789	38.1498
Barren land	1676.2149	349.6284	-1326.5865	3.7352	0.7791	-79.1418
Agricultural land	6172.8093	7335.9198	1163.1105	13.7551	16.3469	18.8425
Built-up	424.9872	566.1387	141.1515	0.9470	1.2616	33.2131
Mines and Quarries	113.3361	85.5036	-27.8325	0.2526	0.1905	-24.5575

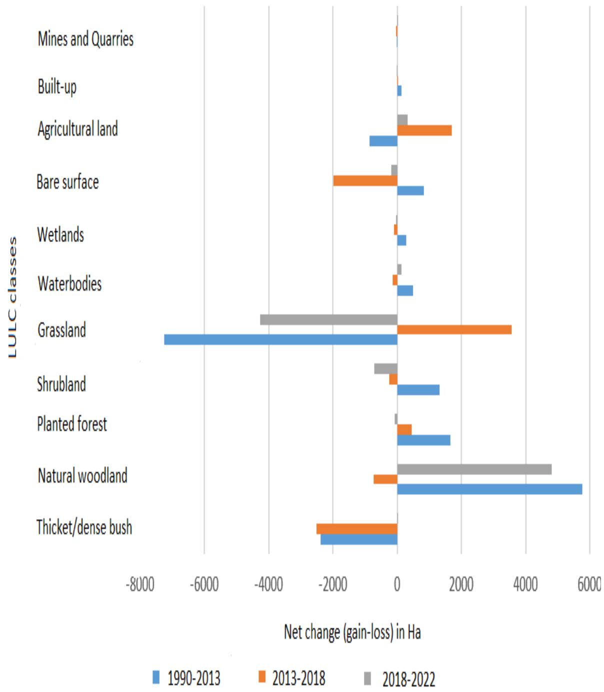

Figure 3: Net changes (Gains - losses) for each LULC class for the 1990-2013, 2013-20218, and 2018-2022 period

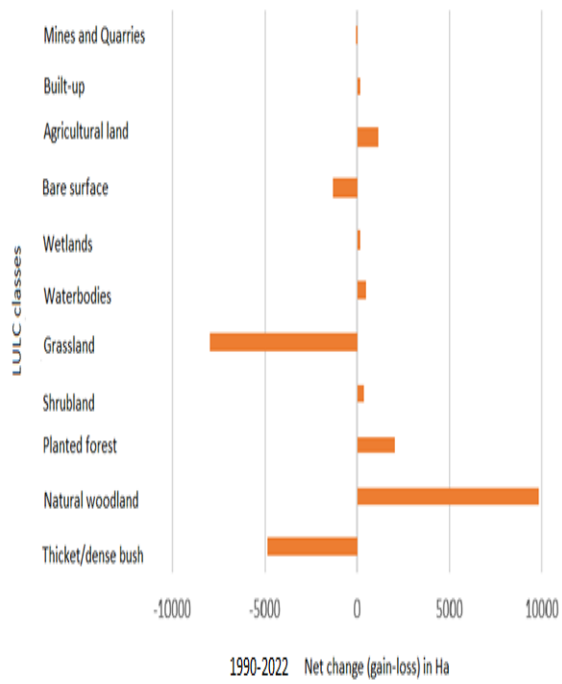

Figure 4: Overall Net Changes (Gains - losses) for each LULC class (1990-2022)

3.3 The land use and land cover change matrix represents the transition between different types of land use and land cover.

The LULC change matrix, including Tables 5, 6, 7, and 8, provides information on the changes in land use and land cover for 1990-2013, 2013-2018, 2018-2022, and 1990-2022. It illustrates the distribution of the critical transitions across the eleven LULC categories analyzed in this study. The analysis has shown significant changes and shifts within the eleven Land Use and Land Cover (LULC)classes. Between 1990 and 2013, grassland experienced the highest transition, losing majorly to planted forests (Table 5). Overall, in 1990 -2022 (Table 8), agricultural land use had a minor transaction, maintaining 80 – 90% in the period's understudy; while the building is relatively the same, other land uses are experiencing conversions. The Post-classification comparison of the classified images based on the transition matrix depicts that over 75% of the total grassland in 1990 has been transitioned to natural woodland in 2022, while about 2.70% % of thicket/dense bushland cover and barren land in 1990 have been converted to planted forest in 2022.

During 1990 and 2022 in Table 12/ Figure 4, thicket/dense bush and grassland experienced the highest transition in term of loss, with 10.87% (4876.9443ha) and 21.39% (9600.5853ha) of the total land coverage to 0.0280% (0.0280ha) and 3.65% (1638.4851ha), losses amounting to -4864.3812ha (-99.74%) and -7962.1002ha (-82.93%) respectively (Table 12). Mining activities also suffered some losses during this period. During this same period, planted forests and waterbodies gained so much, 0.0702% (31.4847ha) and 0.0648% (29.0853ha) of the total land area to 4.6226% (2074.4586ha) and 1.1308% (507.4776ha), the gains amounting to (6488.7831%) 2042.9739ha and (1644.7907%) 478.3923ha respectively. Between 1990 and 2022, natural woodland grew steadily all through the period, increasing from 45.97% to 67.89%, but remarkably, shrubland a growth of 2.10% (944.3331ha) to 2.92% (1311.8085ha), amounting to 38.91% difference in increment. Furthermore, wetlands and built-up experienced an overall increase in the same period, gaining 146.0907ha and 141.1515ha, respectively.

3.4 Climate Variability on Waterberg Biodiversity

Climate change is a global issue and a factor responsible for vegetation distribution, including thicket dense bush, grassland, shrubland, natural woodland, and planted forest [30]. However, climate elements such as temperature, humidity, and precipitation significantly regulate the presence, absence, increasing, and reducing environmental biodiversity. However, these effects of climate elements are more complex than one would have thought.

South Africa is a country that experienced a remarkable climate variety of weather conditions, and the Waterberg District Environmental Management Framework reported that the district has varied climatic conditions. While the north and western parts experience a hot and semi-arid climate, the south and east receive more rainfall and are somewhat cooler. The climate is an essential determinant of vegetation distribution and agricultural potentials; therefore, rain and temperature distributions may also be related to the losses recorded in some land cover. Generally, rainfall is low, with an average of 400 and 600mm annually, and this may also persist into the future. Nevertheless, the literature confirmed the effects of drought on the areas covered by water bodies in 2005, 2006, and 2015 -2016 [31].

4 Discussion

The accuracy assessment is a crucial stage in image classification, as the validity of the thematic map derived from satellite imagery depends on it. Though the study used the South Africa National Land Cover dataset, it is crucial to share information about the accuracy of the classified maps before reclassification that was done to generate the analysis. The accuracy assessment of the SANLC showed different results for each year under study. For 2022, the overall accuracy was 84.22%, with a mean class accuracy of 83.55 - 90%. The kappa coefficient of the satellite-derived was 0.838, indicating a solid agreement above the 80% threshold [32]. For 2018, the overall accuracy is 90.14%, mean class accuracy is 89.63% and 90%, and the Kappa coefficient is 0.899. For 2013, there was an overall map accuracy of 81.73%, user and producer accuracies of 80%, mean class accuracy of 91.27%, and Kappa coefficient of 0.803. There is no accuracy assessment for the 1990 dataset/map because there was no reliable historical reference. The findings were satisfactory for following an ongoing comparison of change detection activities.

The change detection analysis indicates notable land use and land cover (LULC) changes in the 32-year research period from 1990 to 2022. Agriculture is the primary source of economic activity in the Waterberg district, as indicated by the municipality. The majority of the districts exhibit a significant reliance on agriculture [33], and the fact that Waterberg farmers are beneficiaries of resettlements, land acquisition grants [34], and the South African land reform program are some of the reasons for the continuous increase in agricultural land use. Furthermore, the findings indicated that although natural woodland and agricultural land usage have been the most prevalent in the region, because of their continuous increase, which could have been a result of other activities such as safari, tourism for fun seekers, and animal gaming which need well-conserved biodiversity to thrive. This reason could also be responsible for overgrazing, vegetation cover degradation, and grassland loss [35]. Though de Klerk, 2003 mentioned a low level of agricultural activity in 2003 [36], this may be a result of the abandonment of farming activity for mining and stone digging, which are threats to biodiversity [37]. However, mining activities have declined because the region is a protected area where commercial mining is illegal.

The transformation of grassland and shrubland into natural woodland and planted forest indicates a significant shift and imbalance in the ecosystem, which has consequences on functional biodiversity [38]. A similar study reveals ten significant changes that occur when there is a transformation from grassland and shrubland to woodland; the situation influences the production of animal and plant species, plant species richness, carbon, and soil conductivity [39].

The analysis reveals a significant decrease in the wetlands and fluctuations in water bodies, indicating that wetlands may be transforming into natural woodland, planted forest, and probably agricultural land. Recent data suggests a global decline in wetlands, caused mainly by the clearing of land and drainage resulting from intense agriculture and industrial growth [40]. However, this trend is occurring slower, unlike thicket/dense bush and grassland with drastic land use change patterns. These factors threaten the provision of sustainable ecosystem services in the region.

Biodiversity is a natural resource widely recognized as crucial for providing multiple benefits [41]. The study findings indicate a substantial decrease in thicket/dense bush, grassland, and shrubland in the Waterberg district between 1990 and 2022, coupled with a reduction of barren land, which may be a clear sign of escalating deforestation and forest degradation. Gibson reiterated that Waterberg may be going through land and forest degradation because of the grazing of domestic animals, and he approximated 13.23% of the land degraded because of the subsistence and commercial cultivation of dryland. Also, increased forest plantation and irrigation contribute to land degradation [42]. Furthermore, the region is known as a less-water area, which reasons for fluctuations throughout the study period; the most significant water surface body, Makolo River, was the primary source of water for farming and mining, and when the region experienced drought between 2005-and 2006 and 2015 - 2016, many farmers converted their farmland to game farming. [43].

Also, climate variability is a global change issue and a factor for spatiotemporal change in biodiversity [44]; the region is more or less a rural area with sparse settlement; another study on the region stated that there was a mass exodus because of the unavailability of water, loss of soil nutrients and subsidy removal on crop produce which affect most farmers and led to migration to the nearest town Leseding [45].

Loss of biodiversity might be attributed to unsustainable agricultural practices, cutting down trees for charcoal and firewood, and expanding human settlements in the research region. Research by Maggie G 2019 et al. revealed the need to develop a more sustainable natural resources management strategy in Dedza district, Malawi, due to the high transformation rate in land use land cover. The loss of waterbodies, forest land, wetlands, and agricultural land used to build up barren land. The transition matrix showed that from 1991 to 2015, forest land lost 61.48% to barren land, and agricultural land lost 2.7% to built-up area. GoM (2013) explained that forest resources will continue to decline because there is a higher demand for charcoal, fuelwood, poles, and lumber. This demand is a consequence of the population expansion in Lilongwe City and the neighboring districts, which creates markets for these forest products. Approximately 94% of Malawi's population lacks access to electricity and relies on biomass as their primary source of energy (Ruhiinga, 2012). Also, similar research by Nuwarinda et al. 2021 on the Vhembe biosphere in South Africa corroborated the decreasing trend of critical natural resources. They revealed that the shrubland, Indigenous-forest, and dense bush suffered −100%, -44%, and −93%, respectively, in the Vhembe biosphere from 1990 to 2018 at the expense of natural woodland, built-up, and cultivated land use [46].

Hence, the decrease in biodiversity can be ascribed to the presence of socioeconomic instability and the rapid expansion of the population, which generate significant pressure, competition, and excessive use of natural environments like forests, water, and land. This leads to an unsustainable environment, imbalance in biodiversity, unhealthy habitat ecosystem services, and may impact dwellers' livelihoods.

5 Conclusion

The study has shown that combining remote sensing and GIS approaches in measuring the characteristics and trends of land use and land cover changes enhances our comprehension of the process of such changes. Also, the study demonstrated the involvement of anthropogenic activities in biodiversity and habitat loss, which hinders the delivery of multifunctional biodiversity benefits to the environment. A healthy environment must accommodate biodiversity conservation, other land use activities, and being a habitat for all. The main finding of this study is that Waterberg district has experienced significant changes in land use and land cover (LULC) from 1990 to 2022. In 32 years, the research region has seen a decrease in thicket/dense bush, grassland, and wetlands and a fluctuation in water bodies and shrubland. The research region is expected to see a decline in some significant biodiversity, mainly owing to anthropogenic activities, such as game farming and the increasing need for more land to cultivate for economic reasons. The findings indicate that the decline will have significant consequences for the well-being of individuals, the diversity of plant and animal species, and the multifunctional benefits of the natural environment. The changes in land use and land cover (LULC) seen over the years are a direct consequence of the effects of some of the local and national policies and human activities on the study region. The conversion of a large portion of thicket/dense bush and grassland land (and a decrease in wetland) into planted forest and natural woodland regions has significant implications, such as land degradation, erosion, and loss of ecosystem services. The significant LUCC transformations identified in this study necessitate immediate action from the government, environmentalists, decision-makers, and other stakeholders to tackle the problems of forest degradation, deforestation, and loss of wetlands and water bodies in the study area.

This research presents comprehensive information on land use and land cover (LULC) changes in the Waterberg district from 1990 to 2022. The provided information will serve as crucial planning tools for planners, researchers, environmentalists, and other stakeholders involved in the sustainable management of the mountainous region of the Waterberg district. According to the results of this study, further investigation is advised regarding the interaction between LULC change and climate variability in the specific region of study.

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