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An Analysis of Land Use and Land Cover Changes, and Implications for Conservation in Mukumbura (Ward 2), Mt Darwin, Zimbabwe, 2002-2022

Musekiwa Innocent Maruza[1*], Edson Gandiwa[2], Never Muboko[2], Ishmael Sango[1], Tawanda Tarakini[1], Nobert Tafadzwa Mukomberanwa[3]

[1]Department of Wildlife Ecology and Conservation, Chinhoyi University of Technology, Chinhoyi, Zimbabwe
[2]Zimbabwe Parks and Wildlife Management Authority, Harare, Zimbabwe
[3]Department of Geoinformatics and Environmental Conservation, Chinhoyi University of Technology, Chinhoyi, Zimbabwe

Email: *mimaruza@gmail.com, egandiwa@gmail.com, nmuboko@zimparks.org.zw, ishsango@gmail.com, ttarakini@cut.ac.zw, nobertmukomberanwa@gmail.com

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Abstract

Understanding trends of land use land cover (LULC) changes is important for biodiversity monitoring and conservation planning, and identifying the areas affected by change and designing sustainable solutions to reduce the changes. The study aims to evaluate and quantify the historical changes in land use and land cover in Mukumbura (Ward 2), Mt Darwin, Zimbabwe, from 2002 to 2022. The objective of the study was to analyse the LULC changes in Ward 2 (Mukumbura), Mt Darwin, Northern Zimbabwe, for a period of 20 years using geospatial techniques. Landsat satellite images were processed using Google Earth Engine (GEE) and the supervised classification with maximum likelihood algorithm was employed to generate LULC maps between 2002 and 2022 with a five (5) year interval, investigating the following variables, forest cover, barren land, water cover and the fields. Findings revealed a substantial reduction in forest cover by 38.8%, water bodies (wetlands, ponds, and rivers) declined by 55.6%, whilst fields (crop/agricultural fields) increased by 93.3% and the barren land cover increased by 26.3% from 2002 to 2022. These findings point to substantial changes in LULC over the observed years. LULC changes have resulted in habitat fragmentation, reduced biodiversity, and the disruption of ecosystem functions. The study concludes that if these deforestation trends, cultivation, and settlement land expansion continue, the ward will have limited indigenous fruit trees. Therefore, the causes for LULC changes must be controlled, sustainable forest resources use practiced, hence the need to domesticate the indigenous fruit trees in arborloo toilets.

Keywords

Anthropogenic Activities, Deforestation, Geospatial Analysis, Land Use/Land Cover, Supervised Classification

1. Introduction

Land use and land cover (LULC) change is a complex and dynamic process influenced by social, economic, and biophysical factors that can cause significant impacts on ecological processes and biodiversity conservation [1]. Land cover refers to the physical and biological cover on the Earth's surface, including natural elements such as forests, wetlands, water bodies, and urban areas [2], while land use describes how the land cover is modified (e.g., agricultural land, built-up area, recreation area, wildlife management areas) [3]. Land use also refers to the land that has been utilized by humans and their territory, commonly highlighting the functional nature of land for economic activities [4]. LULC change reflects the intricate interaction between climate action and intensive human activities and is closely correlated to various terrestrial processes such as biodiversity, earth surface energy balance, atmospheric circulation, and carbon cycle [5]. Therefore, an understanding of LULC and its use has become an essential requirement for fulfilling the needs of the growing population [6].

LULC change is the most prevalent and dynamic landscape phenomenon on the surface of the planet, and it plays a key role in reflecting regional and global environmental changes [7]. LULC change has become a fundamental and essential component in current strategies for monitoring environmental changes and managing natural resources [8]. The impacts of LULC changes are of great concern for community livelihood and conservation globally [9]. LULC changes have become the main cause of global ecosystem service change, and Africa is experiencing substantial changes across the continent [10]. The LULC changes are triggered by the interplay of socioeconomic and natural environmental factors [11]. LULC changes are the main drivers of environmental changes, therefore, studying its dynamics is increasingly essential for land management [12]. In recent decades, there has been a sharp increase in LULC change in Africa, mainly due to rapid population growth and the associated overexploitation of natural resources [13]. The main driving forces of the LULC transition might be connected to multiple factors, such as the increasing human population and accompanying consumption demands, rapid socio-economic development, policies, and institutional factors [14]. Population growth coupled with high demand for food, charcoal, timber, and poles in urban areas are the key drivers contributing to natural resource degradation in rural areas [10]. In many parts of the world, anthropogenic activities such as mining, deforestation, fires, human settlements, and agricultural intensification have been reported as the major drivers of LULC [15]. The bulk of human operations are carried out on lands that in turn consume natural resources, affect the environment, and lead to LULC change [16]. These LULC changes and their effects are mostly discernible over regions having higher population density, deforestation, and agricultural diversification [17]. The current LULC changes are carried out in an unsustainable manner and thus negatively endangering posterity [18]. The LULC change process has a negative impact on biodiversity, climate, soil, air, and the ecosystem in general, and it has become the most serious environmental concern for humans in recent years [19]. One of the most significant global challenges is related to the management of the transformation of the earth's surface that occurs due to changes in land use [20].

LULC is under continuous change mainly because of societal development and natural causes [21]. However, climate-induced changes (e.g., drought, precipitation variability, forest fire, invasive species, and other disturbances) can also pressure LULC alterations [14]. Analyzing LULC changes is one of the most precise techniques to understand how the land was used in the past, what types of changes are to be expected in the future, as well as the forces and processes behind the changes [22]. Understanding changes in LULC is one of the most important aspects of managing the earth's resources and hence, acquired much attention from researchers, environmentalists, and decision-makers [23]. LULC can be used to assess ecosystem changes and their environmental implications at various temporal and spatial scales, making it useful for understanding environmental changes [19]. The LULC changes have directly or indirectly contributed to a decrease in the availability of natural resources [24], which have ultimately compromised the ability of the ecosystem to provide goods and services for human sustenance in communities that are heavily and directly dependent on natural resources.

The ecosystem health and natural resource management are influenced by the social, political, economic system, and institutional framework in a region [25]. Thus, LULC changes play an important role in the study and analysis of global environmental changes [26]. Making data available on LULC changes is essential for providing critical input to decision-making on ecological management and environmental planning for the future [26]. Several researchers have addressed the problem of accurate monitoring of LULC changes in numerous environments using different techniques [26]. LULC change, where forest cover change is the main feature, is recognized as the main driving force of global environmental change and is thus central to the sustainable development debate [27]. The timely and accurate detection of LULC change is important for the macro and micro-level sustainable development of any region [28]. LULC is vital to investigate land use patterns and help forecast future sustainable land management [29].

There has been an increase in studies on LULC changes following Zimbabwe's fast-track land reform program on the country's ecological environment since the year 2000. One such research was to establish the status of land use and land cover changes for the Shurugwi district as well as to determine the extent of these changes in three different years (1991, 2000, and 2009) using Geographic Information System and remote sensing techniques [30]. Timely and precise information about LULC change detection of the Earth's surface is extremely important for understanding relationships and interactions between human and natural phenomena for better management of decision-making [31], and for understanding the contribution of forest products to household income. There has been an annual natural forest loss of 10.6 million ha per year globally for the period 1990 to 2000 [32]. The LULC changes cause the loss of 13 million ha of the world's tropical forest each year including 14,000 and 40,000 species [9]. (It is estimated that global LULC changes have caused ecosystem service values to decrease from US $145 trillion year^{-1} in 2007 to US $125 trillion year^{-1} in 2011 [14]. In Africa, 5% of woodlands and grasslands and 16% of natural forest cover disappeared from 1975 to 2000; more than 50,000 km^2 of natural vegetation was lost per year [10]. The majority of vegetation cover has been changed into agricultural and settlement land covers [23]. The data available on LULC changes and the rate of change provide critical information to aid in the decision-making of ecological management and environmental planning for the future [18].

Major direct causes of forest clearance and degradation include: the expansion of agricultural land, over-harvesting of industrial wood, fuelwood, and other forest products, and overgrazing [19]. Hence, there is a need to restore the degraded forests using the arborloo toilet technology and the *Ziziphus mauritiana* tree species, the main Indigenous fruit tree in the ward. The main drivers of LULC changes include poverty, population growth, and trade in forest products so the need to domesticate the multipurpose, *Ziziphus mauritiana* fruit tree species [33] in arborloo toilets to reduce poverty levels in the ward.

The contribution of forest products to household income showed that forest products are vital in sustaining rural household needs [34] [35]. Forests remain an important source of products and services that are critical to household livelihood support and emergency safeguards [36]. Access to these forest products is associated with individual characteristics such as gender, age of the household head, household size, education level, and total household income, among others [36]. Natural processes like floods, landslides, droughts, and climate change affect LULC, although they are induced by anthropogenic activities to a certain degree [37]. The availability of precise and reliable LULC change information is critical for environmental planning for sustainable development as it enhances understanding of the anthropogenic influence on the terrestrial ecosystem [38]. Analyzing LULC change is therefore relevant to scientists, environmentalists, planners, economists, policymakers, and everyone who cares about the sustainability of natural resources [39]. Accordingly, this study analyses the status of LULC change in Mukumbura Ward in northern Zimbabwe and, detects the rate of land use and the changes that have occurred from 2002 to 2022 using geospatial techniques. LULC changes play an important role in the study area and analysis of global changed scenarios today. The data available on such changes is essential for providing critical input to decision-making of ecological management and environmental planning for the future [26]. The other objective was to examine the temporal dynamics of LULC changes, identifying trends, patterns, and the rate of change over the study period from 2002 to 2022. LULC changes can be used to assess ecosystem changes and their environmental implications at various temporal and spatial scales, making it useful for understanding environmental changes [19].

Geospatial techniques such as GIS and remote sensing are an efficient tool for developing land use classification maps. Satellite remote sensing and GIS are the most common methods for the quantification, mapping, and detection of patterns of LULC because of their accurate georeferencing procedures, the digital format of data suitable for computer processing, and the repetitive data acquisition [23]. GIS offered an environment for gathering, storing, presenting, and examining digital data for change discovery [40]. Hence the main objectives of the study were, i) to analyze the changes in land use and land cover in Mukumbura (Ward 2) over the 20-year period from 2002 to 2022, ii) to identify the main trees being targeted in deforestation. iii) to create detailed maps showing the spatial distribution of different land use and land cover types in 2002, 2007, 2012, 2017 and 2022 iv) to identify critical habitats and ecosystems that are under threat from land use changes, and lastly, to use remote sensing and GIS tools to visualize and quantify changes over time.

2. Materials and Methods

2.1. Study Area

Mt Darwin has a total population of 240,728 and 58,071 households [41], and is the most populous and largest district in the province. Mt Darwin has forty wards, accounting for 20% of the provincial population [42]. The Lower Zambezi Valley in Mt Darwin is bounded by latitude 16.30S, longitude 31.57E, and latitude 16.17S, longitude 31.30E, and covers an area of about 153 square kilometers (GIS, 2023). It is a semi-arid to arid region located in the agro-ecological regions 4 and 5 which is characterized by low annual rainfall of between 450 to 650 millimeters [43]. The area receives its rainfall from November to March and is usually associated with mid-season dry spells that affect crop growth and maturity. The region is characterized by very high temperatures. Minimum temperatures in the area range between 15 to 25 degrees Celsius during the winter in June to July and maximum ranges between 35 to 40 degrees Celsius during summer in September and October [44]. The area is largely composed of flat undulating terrain, clay loams soils which are fertile for agricultural production [44] (**Figure 1**). Mukumbura is in the Zambezi Valley with a total population of 12 954 and 3247 households [41]. Mukumbura has a total area of 15 345.601 hectares (GIS, 2023). The 2002 population for the ward was 13,078 and 2,916 households [45], which showed a decrease in total population and an increase in the households. There was an increase of 331 households from 2002 to 2022, an increase of about 11.4%. The Ward has a total area of 15,345.60 hectares (GIS, 2023) and is made up of 23 villages. The Ward is popularly known as the Mukumbura or Gombe by the locals because of availability of Masawu tree species.

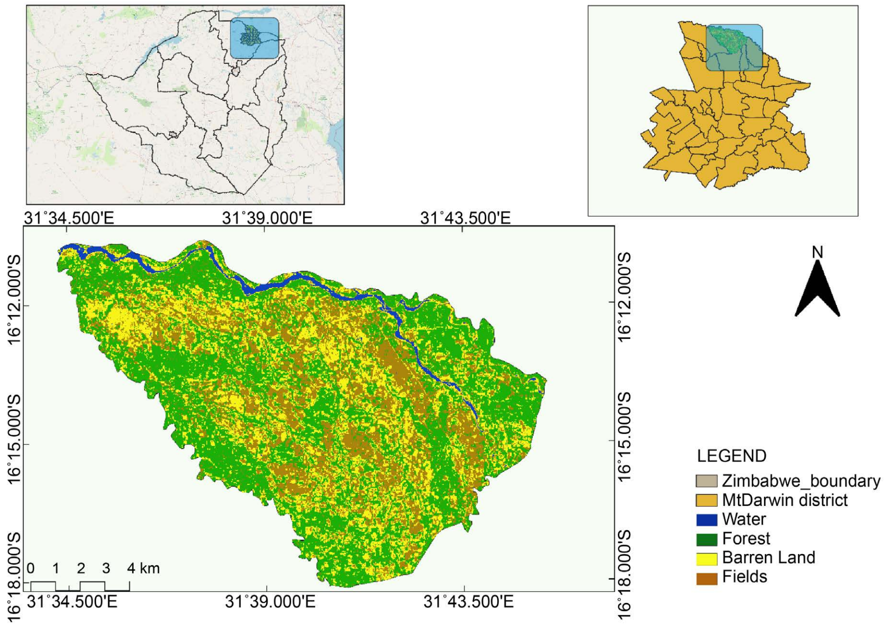

Figure 1. Location of Mukumbura (Ward 2), Mt Darwin District, Northern Zimbabwe.

2.2. Research Approach

The image classification for the study period was performed by supervised classification using a maximum likelihood classifier. The classified images were assigned to the respective classes which are forest land, water body, cultivated land and bare land. The satellite images for the years 2002 to 2022 were used to identify the LULC in the ward and a ground truthing and Focus Group Discussions (FGDs) were done to the identify the possible reasons. Satellite images were processed using Google Earth Engine (GEE) cloud computing software. GEE was preferred due its computation power, hence a powerful tool for processing large Earth observation data [46]. A java script and Google Earth Engine (GEE) java script were used for the classification. Using the GEE we selected the random forest classifier algorithm. Random forest is reported to be robust to outliers, and noise, and it is computational lighter than decision tree methods such as gradient boosting [47]. To perform a supervised classification of Landsat 7 and 8 images in GEE, the following steps were employed to 1) collect training data: this was done by drawing polygons on the map to represent different land cover classes or by importing predefined training data from an Earth Engine table asset. Training data is instrumental in supervised image classification. The training dataset is a labeled set of data that is used to inform or "train" a classifier. The trained classifier can then be applied to new data to create a classification. In the study, land cover training data contained examples of each class in the study's legend. Based on these labels, the classifier can predict the most likely land cover class for each pixel in an image. The categorical classification and the training labels are therefore categorical. 2) Assemble features: We selected the bands that we wanted to use as predictors and created a feature collection that includes the class labels and predictor variables. 3) Instantiate a classifier: We then choose a classifier from the ee.Classifier package, such as ee.Classifier.cart or a Classification and Regression Trees (CART) classifier. 4) Train the classifier: The next step was to use the train method to train the classifier on the training data. 5) Classify the image: Finally, we used the classify method to classify the image or feature collection. To extract the area of each class in hectares, we employed the ee.Image. pixel Area method to calculate the area of each pixel in square meters, then multiply by the number of pixels in each class and divide by 10,000 to convert to hectares. The methodology used was adopted to obtain land use land cover changes in Mukumbura is illustrated in Figure 2.

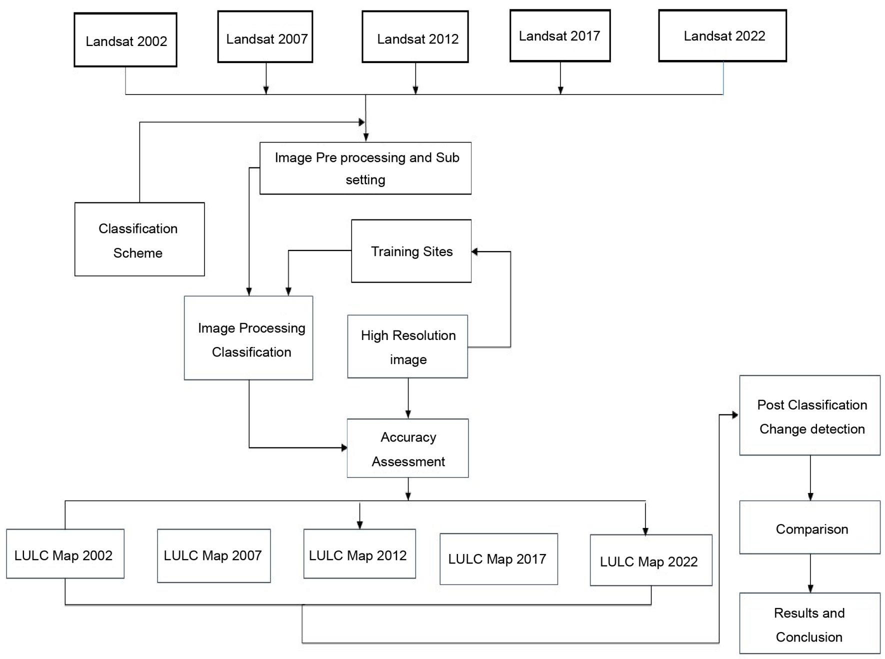

Figure 2. Flow chart showing the methodology of LULC change detection in Mukumbura (Ward 2) Mt Darwin, Northern Zimbabwe. Source: [29].

2.2.1. Landsat Data Acquisition

Spatial land use land cover dynamics were derived from Landsat satellite data for a 5-year interval between the years 2002 to 2022 using the maximum likelihood classification technique. Landsat images were used because they are freely available and have relatively moderate resolution considering the size of the study [48]. The Landsat satellite imagery for the study area was divided into wet (November-March), transitional (April-June), and dry periods (July-October). LULC changes for the three categories from 2002 to 2022 were compared. The reason was that there are changes in LULC throughout the year and need to identify the possible reasons in the next objective. Medium resolution Landsat imagery with a spatial resolution of 30 m × 30 m was obtained for the years 2002, 2007, 2012, 2017 and 2022 to comprehensively cover the study area. These datasets were sourced from the United States Geological Survey (USGS) EarthExplorer website (https://earthexplorer.usgs.gov/) ensuring reliable and consistent data for analysis. Specifically, the study utilized a series of images captured by Landsat 7 (Enhanced Thematic Mapper, ETM), and Landsat 8 (Operational Land Imager, OLI), providing a robust temporal dataset for detailed assessment of surface water changes over two decades. The specifics of the datasets used are elaborated in Table 1, illustrating the extensive temporal and spectral coverage provided by these satellite missions.

2.2.2. Pre-Processing

Layer stacking was performed using Google Earth Engine (GEE) cloud computing software to combine three bands of each Landsat image representing the red, green, and blue (RGB) wavelengths of the electromagnetic spectrum. For Landsat 7, the bands 4 (near-infrared, NIR), 3 (red), and 2 (green) were used. For Landsat 8, bands 5 (NIR), 4 (red), and 3 (green) were utilized. As Landsat Level-2 images were used, no atmospheric correction was necessary (USGS, 2024). The Landsat images, originally in Universal Transverse Mercator (UTM) zone 35N for the scenes in Zimbabwe, required reprojection. The stacked image layers were reprojected to the WGS84/UTM zone 35S coordinate system. Subsequently, a shapefile of Mukumbura was employed to subset the study area from the reprojected image layers.

2.2.3. Classification

The study utilized supervised classification within the Google Earth Engine (GEE) cloud computing platform. GEE was chosen for its substantial computational power, making it an effective tool for processing extensive Earth observation data [46]. The Random Forest classifier algorithm was employed to generate Land Use/Land Cover (LULC) maps for the years 2002, 2013, and 2022. Random Forest is noted for its robustness to outliers and noise and is computationally more efficient than decision tree methods such as gradient boosting [47]. Training sites were selected, and spectral signature files for chosen LULC classes—including

Table 1. Specifications of landsat satellite data used in this study.

Satellite/Sensor	Date	Path/Row	Spatial Resolution	Spectral Resolution
Landsat 7 (ETM+)	2002/07/11	169/071	30 m	Multispectral (8 bands)
Landsat 7 (ETM+)	2007/07/17	169/071	30 m	Multispectral (11 bands)
Landsat 7 (ETM+)	2012/08/19	169/071	30 m	Multispectral (11 bands)
Landsat 8 (OLI/TIRS)	2017/08/19	169/071	30 m	Multispectral (11 bands)
Landsat 8 (OLI/TIRS)	2022/08/19	169/071	30 m	Multispectral (11 bands)

vegetation, built-up areas, bare soil, and water bodies—were created using GEE software (**Table 2**). The resulting classified images were validated through ground-truthing, involving field visits to the study area. For each predetermined LULC type, training samples were obtained by delineating polygons around representative sites [19]. Spectral signatures for these land cover types were extracted from the satellite imagery using the pixels within these polygons [49]. In cases where ground truth data was unavailable, training sites were identified based on information from Google Earth.

Table 2. Detail disruption of Land Use Land Cover (LULC) classes.

LULC Types	LULC Description
Water	Rivers, dams, dams, ponds
Forest	Forest, vegetated lands, parks, etc.
Barren land	Open land, unused and empty areas, fallow areas, bare soil,
Fields	Crop fields

2.2.4. Accuracy Assessment

In the accuracy assessment, QGIS software was employed to compare supervised image pixels with reference pixels representing specific land cover classes. Satellite imagery, utilizing a Stratified Randomization Technique (SRT), was utilized to classify various Land Use and Land Cover (LULC) categories within the study area [50]. Each class underwent evaluation using 120 points derived from both visual interpretation and ground-truth data. The process included the application of error matrices to statistically evaluate the classification results against reference data, a widely accepted method in accuracy assessment. Additionally, Kappa statistics were computed using the confusion matrix to assess agreement between identified and reference pixels for each land cover class, while also determining user and producer accuracy [51].

3. Results and Discussion

3.1. Analysis

In this study, comprehensive data analysis was conducted to assess changes in Land Use and Land Cover (LULC) over the years 2002, 2007, 2012, 2017, and 2022. Tables and pie charts were constructed to systematically compare the areas occupied by different land use types across these years. This approach enabled a detailed examination of trends and shifts in LULC patterns over time. Additionally, percentage changes in land area were calculated, providing quantitative insights into the magnitude of these changes.

To visually depict temporal trends, multiple line graphs were employed. These graphs effectively illustrated the dynamic nature of LULC changes from 2002 to 2022, offering a clear visualization of how specific land use categories evolved over the studied period. This combined analytical approach, utilizing both tabular and graphical representations, facilitated a robust understanding of the spatial and temporal dynamics of LULC within the study area.

The images for Mukumbura (Ward 2) from 2002 to 2022 were first independently classified, and afterwards, change detection processes were performed. The percentage of land use/land cover change detection was made using the following formula:

$$\text{Percentage LULC Change} = \frac{\text{Area final year} - \text{Area initial year} \times 100}{\text{Area initial year}}$$

If the Percentage LULC Change < 0, the land cover type is in a state of depletion. The larger the absolute value of Percentage LULC Change, the more intensively land has been depleted. Percentage LULC Change ≥ 0 means just the opposite (the land cover type is in a state of expansion) [19]. Finally, a Chi-Square test was conducted to investigate the potential dependence between land cover and changes in the year. The Null Hypothesis (H0) stated that land cover and year are independent variables, while the Alternative Hypothesis (H1) suggested that they are dependent. The test statistic for this analysis was achieved by summing the squared differences between the observed and expected frequencies of land cover types for each year, divided by the expected frequencies.

3.2. LULC Changes in Mukumbura (Ward 2) from 2002 to 2022

LULC change is the human modification of Earth's terrestrial surface by direct and indirect activities of human actions when securing essential resources [39]. Ward 2's economy and Mt Darwin at large rely to a great extent on the use of natural resources and therefore has land use and cover issues. Human well-being and the functioning of the global economy depend on ecosystem services, but these services are under threat because of the intricate interplays between people and the environment, which result in ecosystem degradation and biodiversity loss, and lead to economic impoverishment [14]. Results from the Maximum likelihood techniques indicate that during the wet season of 2002 to 2007, the forest declined by 1412.97 hectares which was equivalent to 19.38% of the total area. There were several anthropogenic activities which resulted in the decline of forests, so the need to domesticate the indigenous trees being removed. During the same period, the barren land increased by 1,330.58 hectares which was 26.46% whilst the fields increased by 628.65 hectares which was equivalent to 29.55%. The transitional period (April to June) was characterized by a decline in the forest by 4784.10 hectares (65.61%), barren land increase by 6339.58 hectares (125.98%, water declined by 422.36 hectares (47.23%) and the fields declined by 1130.08 hectares (53.12%). During the dry period (July to October), the forest decreased by 5690.30 hectares (78.04%), the barren land increased by 5022.25 hectares (99.8%), which was almost 100% increase. The increase in barren land has severe impacts to biodiversity in the area. The marginalised community also rely on ecosystem goods for survival hence the need to domesticate *Ziziphus mauritiana* fruit trees in arborloo toilets. The water decreased by 249.43 hectares (27.89%) whilst the fields also decreased by 692.68 hectares (32.56%) (Figures 3-5).

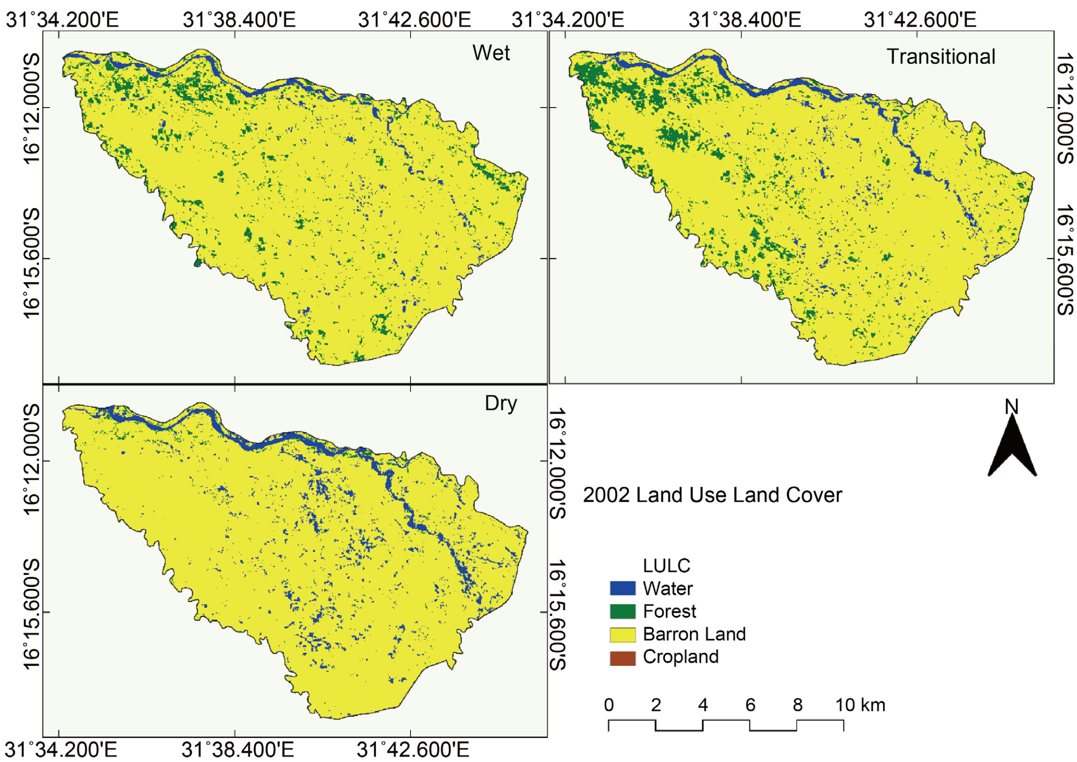

Figure 3. 2002 land use land cover for Mukumbura (Ward 2), Mt Darwin District, Northern Zimbabwe.

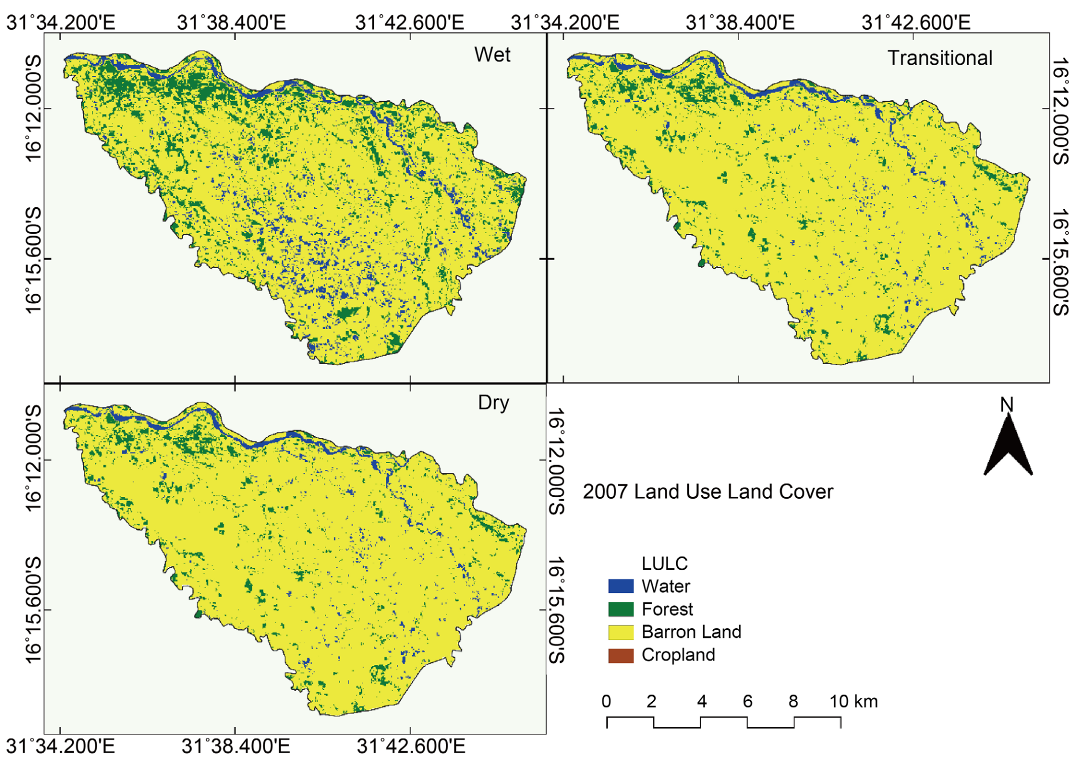

Figure 4. 2007 land use land cover for Mukumbura (Ward 2), Mt Darwin District, Northern Zimbabwe.

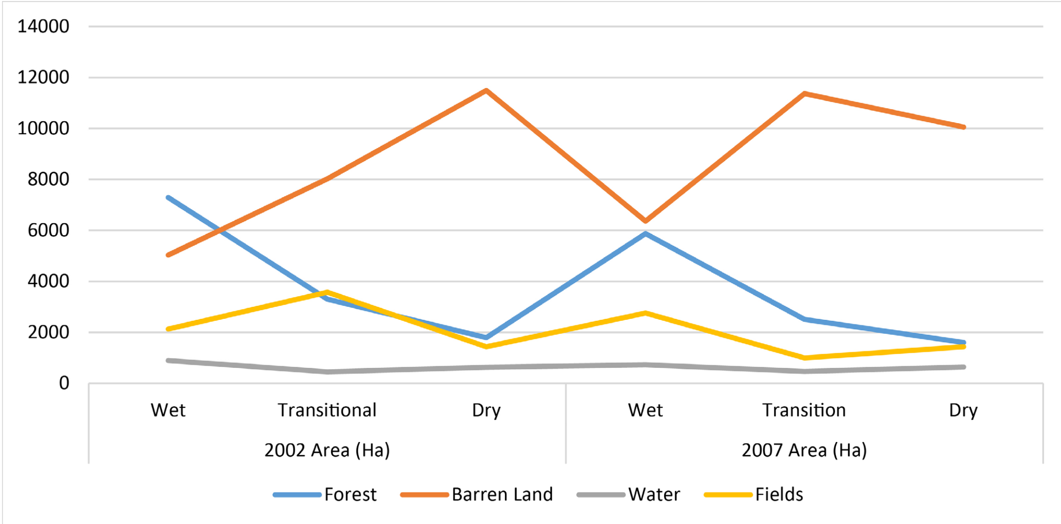

Figure 5. LULC changes for Mukumbura (Ward 2) from 2002 to 2007.

The results indicate that during the dry period, forest cover was cleared to pave the way for fields as well as new settlements according to the results from the fieldwork. The barren land increased during the same time and the fields decreased. In 2002, the fields were concentrated in the Southern part of the ward and spread to the central part in 2007. This suggests that the community was shifting from their fields along Mukumbura and Nyautande Rivers to fields around their homesteads. The study area has witnessed an increase in field cover and a reduction in forest and water bodies. Human activities such as extending fields, settlements, and grazing lands have resulted in massive land use changes in the area. Several studies have witnessed the same trends. The case study of Islamabad, Pakistan from 1992 to 2012 showed that the increase in deforestation was mainly due to increased agricultural use of land but some of the forest areas were shifted to different gardens in the region [26]. LULC change has seriously affected agricultural development in various African countries over the past three decades and this has also impacted rural livelihoods and the overall food security situation in sub-Saharan Africa [52]. This reveals the need to domesticate these indigenous fruit trees for food security and biodiversity. Research carried out in Northern Ethiopia to assess the domestication process of indigenous fruit and fodder trees/shrubs and to analyze their potential contribution to food security [53], showed that marginalised communities benefit from the programs. Mukumbura (Ward 2) has the potential to domesticate the *Ziziphus mauritiana* tree species in arborloo toilets as well. The research carried out by [54] in Western Doon Valley, India, indicated that during the 2001 to 2010 period, the agriculture forest and settlement area increased by 6.22% while the area under other land categories such as water bodies decreased by 6.16%. The rate at which the forests are decreasing shows the need to domesticate the indigenous trees.

Maximum likelihood techniques indicated that during the wet period (November to March) of 2007 to 2012, the forest cover decreased by 559.70 hectares

(9.52%), the barren land increased by 1,690.65 hectares (0.03%), and the fields increased by 2128.02 hectares (77.28%). During the 2007 to 2012 period, the fields increased by almost 48% from the period from 2002 to 2007 (**Figure 6**). The increase in fields showed that more land was converted into agricultural use. During the same period, water cover decreased by 253.07 Hectares (34.93%). The conversion of forest cover into field was supported by evidence of high silt, sand and other sediments deposits along the banks of Mukumbura and Nyautande rivers, which could have resulted in the decrease in water cover in the ward. During the dry season, the forest increased by 950.10 hectares (59.35%), the barren land increased by 794.68 (7.9%), water decreased by 365.88 (56.75%) and the fields increased by 232.37 (16.2%) (**Figure 5**, **Figure 7**).

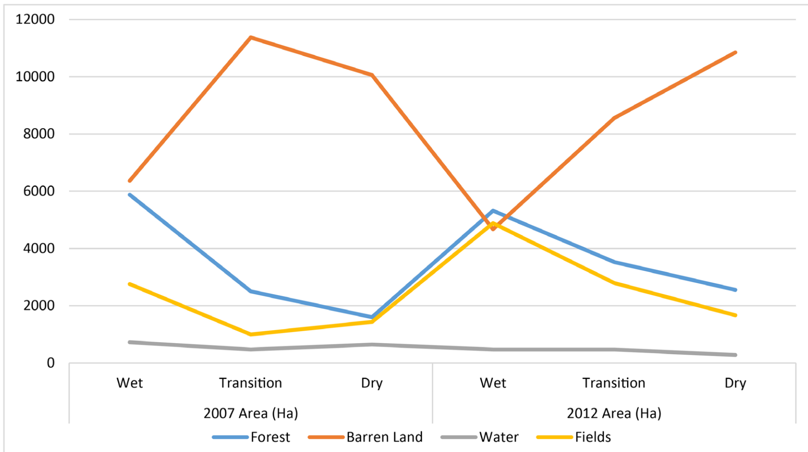

Figure 6. LULC changes for Mukumbura (Ward 2) from 2007 to 2012.

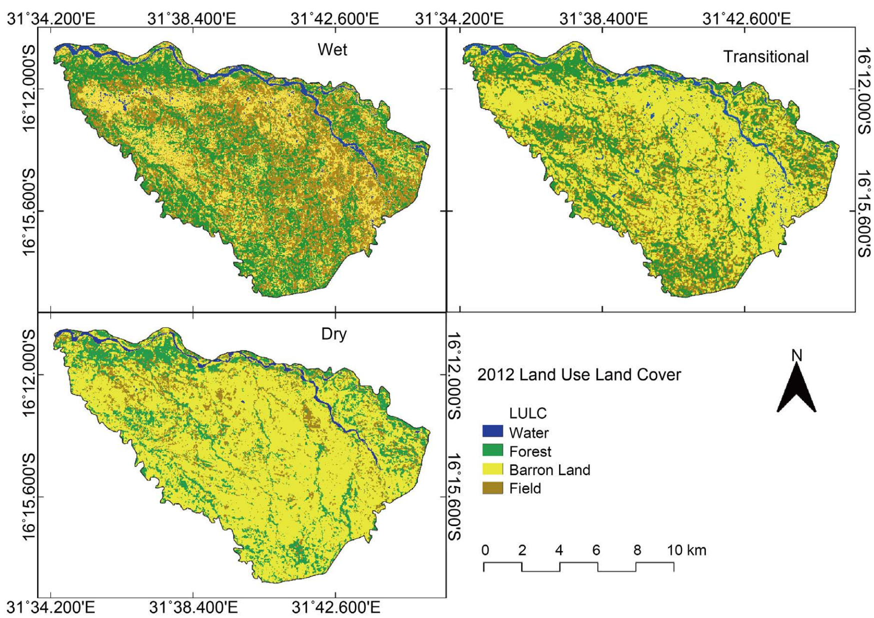

Figure 7. 2012 land use land cover for Mukumbura (Ward 2), Mt Darwin District, Northern Zimbabwe.

During the transitional period, the forest cover increased by 1023.77 hectares (40.85%), barren land decreased by 2814.68 (24.75%), water decreased by 3.49 hectares (0.74%) and the fields increased by 1793.46 hectares (179.86%). The increase in the fields was mainly due to the preparation for the next season. The field observations showed that the farmers were carrying out winter ploughing in preparation to the next growing season. The study carried out by [55] ascertained that in Beshillo catchment of the Blue Nile Basin, North Eastern Highlands of Ethiopia, though there was a change in all land use types, the major change detected was a consistent expansion of farmland/settlements area mainly at the expense of Afro/sub Afro-alpine vegetation areas. LULC in developing countries is characterized by expansion in settlements, barren lands, and fields.

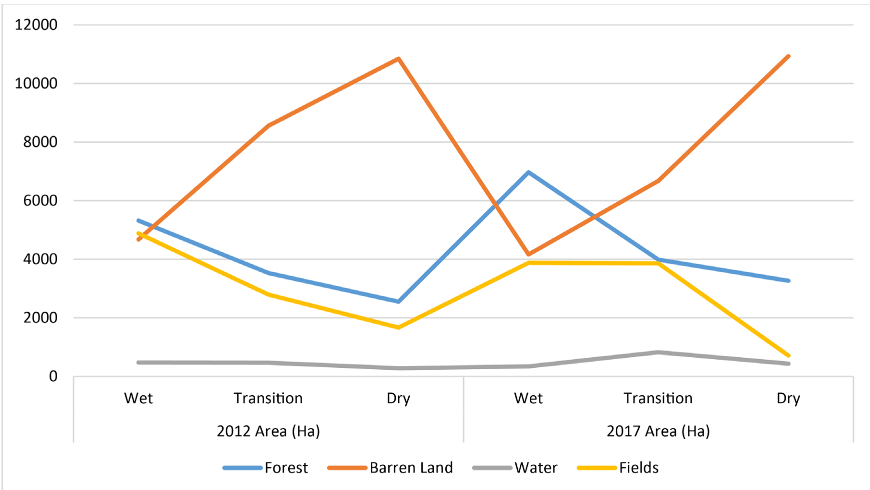

Figure 8. LULC changes from 2012 to 2017.

During the 2012 to 2017 wet period, the forest cover increased by 1651.55 hectares (31.05%), the barren land decreased by 509.32 hectares (10.9%), water surfaces decreased by 133.62 hectares (28.35%) and the fields decreased by 1008.61 hectares (20.65%) (**Figure 8**). During the transitional period, the forest increased by 452.74 hectares (12.83%), mainly because the hedges were planted during the transitional and the dry periods. This is because the hedges contain a milky poisonous sap which will be low in concentration during the transitional and dry periods. The barren land decreased by 1882.45 hectares (21.99%) due to vegetation re-growth in the fields as the villages are shifting to backyard farming. Water increased by 355.99 (76.01%) and fields increased by 1073.72 hectares (38.48%) during the same period. During the dry period, the forest also increased by 713.03 (27.95%), and barren land increased by 84.38 (0.78%) (**Figure 9**). The increase in barren land was due to the cutting of thorn trees to protect the newly grown hedge plants from being destroyed by domestic animals. Water increased by 158.21 hectares (56.73%) and the fields decreased by 955.62 hectares (57.33%) as the villagers abandoned them to backyard farming (**Figure 9**).

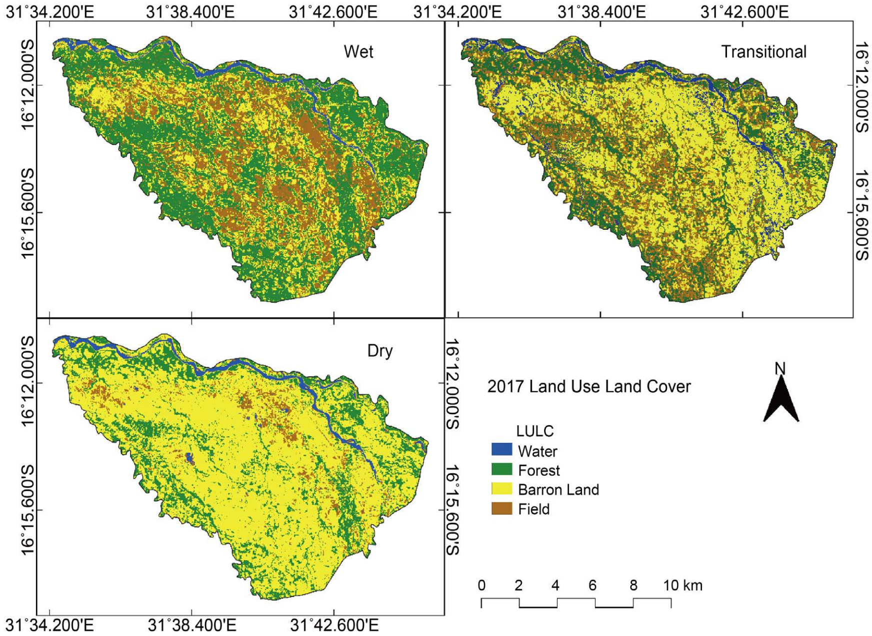

Figure 9. 2017 land use land cover in Mukumbura (Ward 2), Mt Darwin District, Northern Zimbabwe.

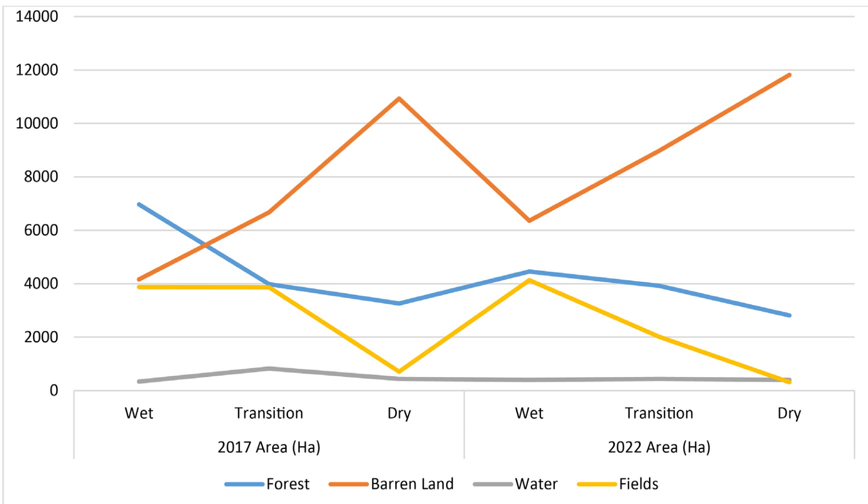

Figure 10. LULC changes for Mukumbura (Ward 2) from 2017 to 2022.

During the period 2017 to 2022, the forest cover further declined by 2509.05 hectares (35.99%), the barren land increased by 2192.32 hectares (52.66%) and the fields increased by 257.82 hectares (6.65%) for the period 2017 to 2022 (Fig. 10). During the transitional period, the forest decreased by 66.08 hectares (1.66%), the barren land increased by 2307.72 hectares (34.57%), water decreased by 389.06 hectares (47.2%) and the fields decreased by 1852.58 (47.94%) (Figure 10). During the dry period, the forest decreased by 451.63 (13.84%), and barren land also decreased by 886.08 (8.1%) however water and fields decreased by 8.3% and 55.98% respectively (Figure 11).

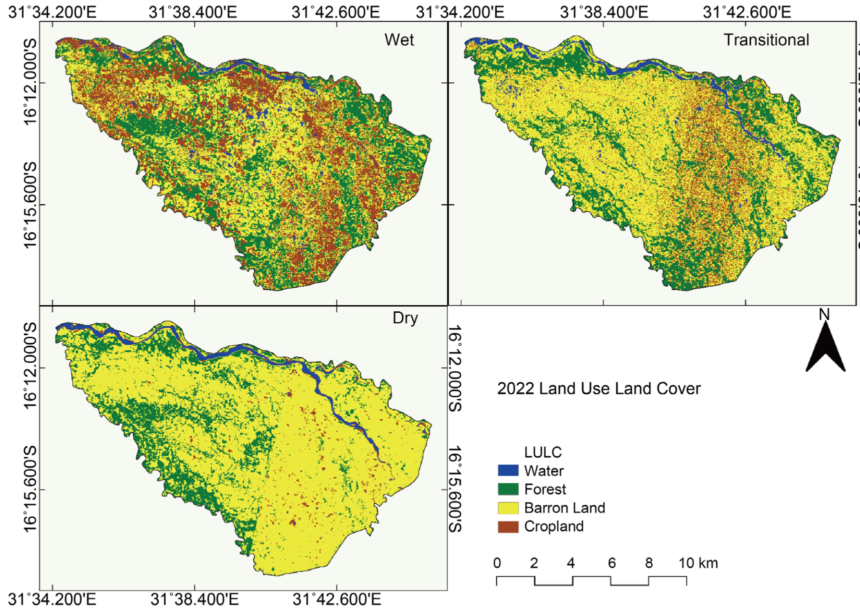

Figure 11. 2022 land use land cover in Ward 2 (Mukumbura), Mt Darwin District, Northern Zimbabwe.

The deterioration and decline rate of vegetation cover occurred throughout the Ward from 2017 to 2022 (**Figure 11**). The vegetation was cleared to expand fields and promote increased cultivation of sesame crops (**Figure 11**). The farmers cleared the land to meet the rising demand for sesame, a versatile and valuable crop with a high demand in Mozambique. Clearing forest and grassland conversion into agricultural lands is a common practice in many developing countries. This is supported by [56] who reported that the present natural forest in Sudan is estimated to have declined to approximately 0.8 billion m^2 standing crop, while it was 2.4 billion m^2 in the mid-seventies. The decline in forests was because of an increase in agricultural land.

3.3. Overall LULC Changes in Ward 2 (Mukumbura) from 2002 to 2022

The findings revealed that there has been a significant change in LULC over the observed years ($P < 0.05$). The Null and Alternative hypotheses for the study were: H0: There was no statistically significant difference in land use and land cover in Mukumbura Ward between 2002 and 2022 and H1: There was a statistically significant difference in land use and land cover in Mukumbura Ward between 2002 and 2022. Consequently, the Null Hypothesis (H0) was rejected hence providing strong evidence to accept the Alternative Hypothesis (H1), indicating that there was a statistically significant dependence between land cover and changes in years. This finding leads to the conclusion that there has been a substantial change in land cover over the observed years. The results from the images showed that the fields and barren land had increased from 2002 to 2022 whilst the forests and water cover changes reduced. The barren land cover increased by 26.3% in the study area. This may be due to increased agricultural land and other anthropogenic activities contributing to deforestation. The forest cover declined by 38.8% and the fields increased by 93.3% during the 2002 to 2022 period, the reason behind the changes was the increase in agricultural land, population, and settlements. Hence there is a need to replace the indigenous trees which are being cut for various purposes. The most dominant tree species in the area is *Ziziphus mauritiana,* so the next objective of the thesis is to domesticate *Ziziphus mauritiana* tree species in arborloo toilets. It has been calculated that the water cover has decreased by 55.6% maybe due to the pattern of human encroachment. For the ground truth verification, the researchers used FDGs and questionnaire surveys. A total of 200 households were involved in the questionnaire surveys, which revealed that the *Ziziphus mauritiana* tree species was the main tree endangered as a result of deforestation. In many developing countries, land degradation as a result of undesired LULC change has led to a reduction in food production and threatened livelihoods [57]. The changes in LULC hinge on human activities that people undertake to earn their living and make their environment comfortable; by so doing, end up transforming their land and land cover and this eventually affects food production [52]. So, there is need to domesticate these trees in used arborloo toilets, which is the main focus of the thesis. **Table 3** shows the actual changes in hectares for the variables, forest, barren land, water, and fields from 2002 to 2022.

3.3.1. Wet Season Changes for Mukumbura (Ward 2) from 2002 to 2022

During the wet season, barren land was more in 2007, and in 2022, the fields were greater in 2012. The fields were less in 2002 and increased during the 2007 to 2012 period. During these years the community relied on cotton as their cash crop. Cotton was grown extensively, and large pieces of land were cleared. The other reason for the increase in fields from 2002 to 2022 (**Figure 12**) was due to the increase in households by 331 from 2002 to 2022 [41]. More fields were cleared by the new households. The forests increased from 2012 to 2017 (**Figure 8**) and decreased from after 2017 to 2022 (**Figure 10**). The fields were cleared to pave the way for the new cash crop, the Sesame seed (**Figure 11**).

3.3.2. Transitional Period Changes for Mukumbura (Ward 2) from 2002 to 2022

The barren land increased in the 2007 transitional period, and the forests and

Table 3. Land use land cover change in Hectares from 2002 to 2022.

Variable	2002 Area (Ha)			2007 Area (Ha)			2012 Area (Ha)			2017 Area (Ha)			2022 Area (Ha)		
	Wet	Trans	Dry	Wet	Trans	Dry	Wet	Trans	Dry	Wet	Trans	Dry	Wet	Trans	Dry
Forest	7291.24	3299.63	1795.8	5878.27	2506.14	1600.94	5318.57	3529.91	2551.04	6970.13	3982.66	3264.07	4461.08	3916.57	2812.44
Barren land	5032.19	8021.61	11490.79	6362.77	11371.77	10054.44	4672.12	8557.01	10849.13	4162.8	6674.65	10933.51	6355.11	8982.37	11819.59
Water	894.19	451.04	627.22	724.43	471.83	644.76	471.36	468.34	278.87	337.74	824.33	437.07	396.66	435.27	400.81
Fields	2127.23	3574.61	1433.1	2755.88	997.15	1434.55	4883.89	2790.60	1666.92	3875.29	3864.32	711.31	4133.10	2011.74	313.11

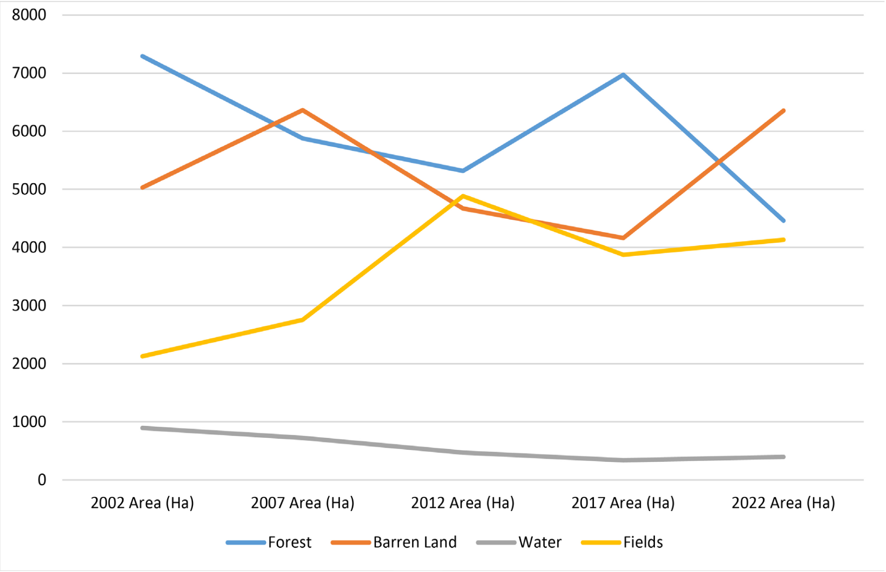

Figure 12. Wet season LULC changes for Mukumbura (Ward 2) from 2002 to 2022.

fields also decreased during the same period. From the ground truthing, during 2007 to 2008, political violence was high in the ward, which forced many people to flee to safer places. Most of the fields were not cultivated as a result of political violence (**Figure 6**). The period 2002 to 2022, saw an increase in barren land and forest cover (**Figure 13**). The barren land during the transitional period increased from 8021.61 hectares in 2002 to 8982.37 hectares in 2022 (**Figure 13**).

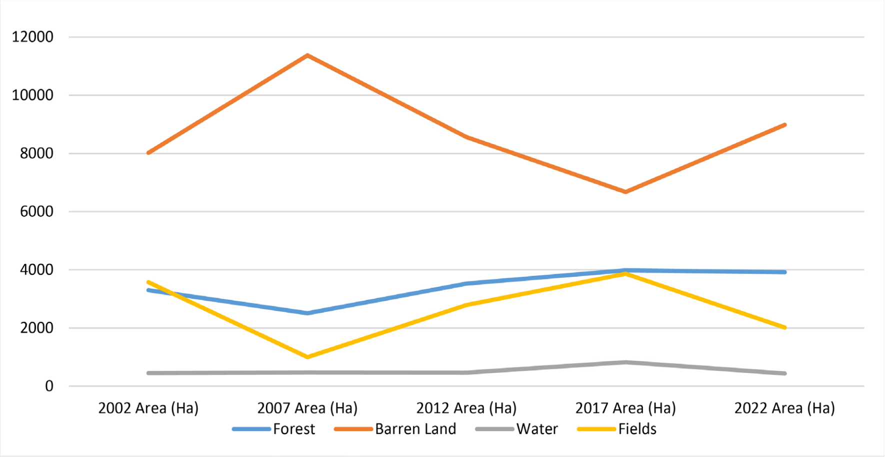

Figure 13. Transitional period LULC changes for Mukumbura (Ward 2) from 2002 to 2022.

3.3.3. Dry season LULC changes for Mukumbura (Ward 2) from 2002 to 2022

During the 2002 to 2022 dry seasons, there were fewer LULC changes. The forest cover increased during the 2012 to 2017 dry season. The barren land decreased during the 2007 dry season (**Figure 4**). During the 2002 to 2022 dry seasons, the barren land increased from 11490.79 in 2002 to 11819.59 in 2022, an increase of 2.9% (**Figure 14**).

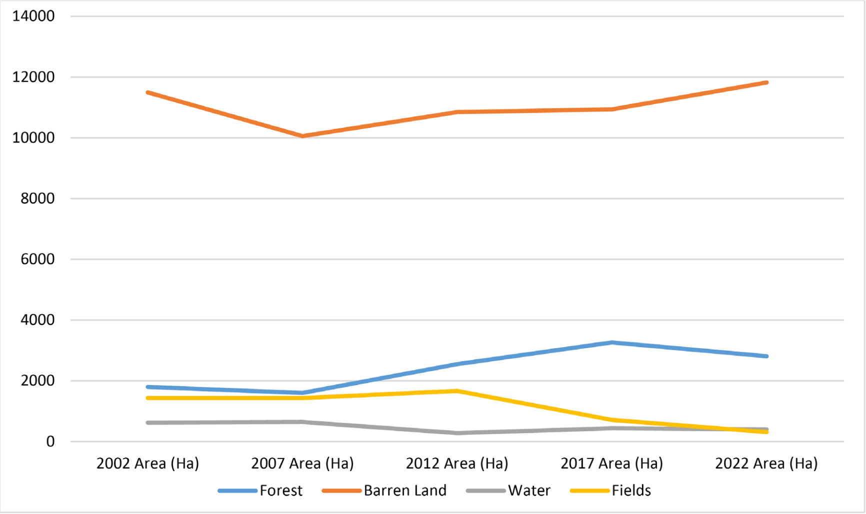

Figure 14. Dry season LULC changes for Mukumbura (Ward 2) from 2002 to 2022.

3.4. Implications for Conservation

Human forces are now known to be altering the natural global landscape at unprecedented magnitudes and different spatial-temporal scales [57]. Population pressure and other socioeconomic and natural drivers lead to unprecedented LULC changes at different spatial and temporal scales in Ward 2, Mt Darwin. While environmental conditions set the stage, human activities, driven by economic needs and population pressures, are the primary forces altering land cover in Ward 2 in Mt Darwin District. Monitoring and mapping of LULC dynamics are crucial as changes observed reflect the status of the environment and provide input parameters for optimum natural resources management and utilization [55]. LULC changes have significant implications for conservation efforts as it leads to the loss and fragmentation of natural habitats. Habitat loss and fragmentation can result in the displacement of wildlife, reduced biodiversity, and increased vulnerability of species to extinction [58]. Changes in land use can disrupt ecosystems, leading to the decline of various plant and animal species. Altering land use can affect the provision of ecosystem services such as water purification, pollination, and climate regulation [59]. Deforestation and changes in land use contribute to greenhouse gas emissions and alter local climate patterns. Changes in land use can affect water quality and quantity, leading to altered hydrological cycles. Conservation strategies should aim to maintain or restore natural landscapes to ensure the continued provision of ecosystem services. Conservation efforts need to address the protection and restoration of critical habitats to maintain biodiversity. LULC changes and land degradation were shown to be the main cause of rural poverty and a threat to sustainable resource utilization in the ward, hence the need to domesticate the *Ziziphus mauritiana* fruit tree in arborloo toilets. LULC changes in response to natural factors and human activities constitute a pressing issue for the conservation of fragile environments, like the agroecological region 5 of Zimbabwe, where the ward is found. Human activities have resulted in increased environmental degradation by causing competition among different land users [60], hence the need to domesticate household *Ziziphus mauritiana* fruit trees in arborloo toilets.

4. Research Gap and Future Scope

Indigenous fruits comprise a critical piece of human diets in numerous African countries, especially during droughts [61]. The domestication of important indigenous trees/shrubs (fruits and fodder species) and their integration in agroforestry practices have been one of the most important forms of biodiversity conservation [53]. The ground truth verification and surveys revealed that *Ziziphus mauritiana* tree species were the highest tree species being cut in the ward.

The overall Thesis aims to advance the use of integrated arborloo toilet design and Indian jujube (*Ziziphus mauritiana* or Masawu) tree species planting as a contribution towards resilience in marginalized communities of Ward 2, Mt Darwin District, Zimbabwe. The overall objective is to evaluate the feasibility of integrating the arborloo toilet design and Indian jujube tree species planting initiatives in promoting holistic rural community well-being in Ward 2. The thesis recommends for Sustainable land management through the promotion of agroforestry to improve soil health and productivity. The arborloo toilets can constructed in the fields for use when working in the fields and avoid open defecation. *Ziziphus mauritiana* tree species are planted when the toilet is full. The integration of the arborloo toilet technology and Ziziphus mauritiana tree species can be used to develop community-based reforestation projects to restore degraded lands.

In Asian countries, the tree has been widely used in traditional medicine for its therapeutic properties, including the treatment of asthma, anxiety, depression, fever, inflammation, and ulcers [62]. *Ziziphus mauritiana* tree parts, such as leaves and fruits, have been traditionally used to treat diarrhea, wounds, abscesses, swelling, gonorrhea, liver diseases, and asthma. *Ziziphus mauritiana* fruits are widely recognized and valued for their nutritional and nutraceutical properties and are consumed in various forms such as dried, candied, pickled, and juice.

5. Conclusion

The results of this study show that there has been a change in LULC over the observed years. The forest cover declined by 38.8%, water cover declined by 55.6%, whilst fields increased by 93.3% and the barren land cover increased by 26.3% from 2002 to 2022 (**Figures 12-14**). The findings of this study highlight the need for a comprehensive assessment of the socio-economic factors that influence LULC dynamics in the study area and the adaptation of sustainable LULC practices such as close supervision of bare land and forest restoration. Detailed research of the links between land-cover classes that increased in hectares and those that declined is recommended to establish the real drivers of LULC changes in the study area.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Cianciullo, S., Attorre, F., Trezza, F.R., Rezende, M., Ntumi, C., Campira, J., *et al*. (2023) Analysis of Land Cover Dynamics in Mozambique (2001-2016). *Rendiconti Lincei. Scienze Fisiche e Naturali*, **34**, 81-92. https://doi.org/10.1007/s12210-023-01133-9

[2] Nedd, R., Light, K., Owens, M., James, N., Johnson, E. and Anandhi, A. (2021) A Synthesis of Land Use/land Cover Studies: Definitions, Classification Systems, Meta-Studies, Challenges and Knowledge Gaps on a Global Landscape. *Land*, **10**, Article 994. https://doi.org/10.3390/land10090994

[3] Gunathilaka, M.D.K.L., Halwatura, D., Manawadu, L. and Munasinghe, D. (2022) Application of Satellite Remote Sensing and DAPSI(W)R(M) Framework as a Tool to Assess Land Use Impacts on Urban Lakes in Sri Lanka. *Environment and Urbanization ASIA*, **13**, 218-231. https://doi.org/10.1177/09754253221120606

[4] Mariye, M., Maryo, M. and Li, J. (2022) The Study of Land Use and Land Cover (LULC) Dynamics and the Perception of Local People in Aykoleba, Northern Ethiopia. *Journal of the Indian Society of Remote Sensing*, **50**, 775-789. https://doi.org/10.1007/s12524-021-01462-y

[5] Zhang, T., Cheng, C. and Wu, X. (2023) Mapping the Spatial Heterogeneity of Global Land Use and Land Cover from 2020 to 2100 at a 1 Km Resolution. *Scientific Data*, **10**, Article No. 748. https://doi.org/10.1038/s41597-023-02637-7

[6] Srivastava, A., Shukla, S., Singh, P. and Jha, P.K. (2023) Spatio-Temporal Dynamics of Land Use/cover and Land Surface Temperature in Prayagraj City, India. *Indoor and Built Environment*, **32**, 1250-1268. https://doi.org/10.1177/1420326x231159633

[7] Allan, A., Soltani, A., Abdi, M.H. and Zarei, M. (2022) Driving Forces behind Land Use and Land Cover Change: A Systematic and Bibliometric Review. *Land*, **11**, Article 1222. https://doi.org/10.3390/land11081222

[8] Twisa, S. and Buchroithner, M.F. (2019) Land-use and Land-Cover (LULC) Change Detection in Wami River Basin, Tanzania. *Land*, **8**, Article 136. https://doi.org/10.3390/land8090136

[9] Nyanda, H.N., Kegamba, J.J. and Sangha, K.K. (2018) Impacts of Land Cover Change on Conservation, a Linkage of Spatial Analysis and Anthropogenic Activities in Tanzania. *Open Journal of Forestry*, **8**, 344-361. https://doi.org/10.4236/ojf.2018.83022

[10] Abebe, G., Getachew, D. and Ewunetu, A. (2021) Analysing Land Use/Land Cover Changes and Its Dynamics Using Remote Sensing and GIS in Gubalafito District, Northeastern Ethiopia. *SN Applied Sciences*, **4**, Article No. 30. https://doi.org/10.1007/s42452-021-04915-8

[11] Debie, E., Anteneh, M. and Asmare, T. (2022) Land Use/cover Changes and Surface Temperature Dynamics over Abaminus Watershed, Northwest Ethiopia. *Air*, *Soil*

and Water Research, **15**. https://doi.org/10.1177/11786221221097917

[12] Mahamba, J.A., Mulondi, G.K., Kapiri, M.M. and Sahani, W.M. (2022) Land Use and Land Cover Dynamics in the Urban Watershed of Kimemi River (Butembo/D.R.C). *Journal of Geoscience and Environment Protection*, **10**, 204-219. https://doi.org/10.4236/gep.2022.106013

[13] Mulatu, K., Hundera, K. and Senbeta, F. (2024) Analysis of Land Use/ Land Cover Changes and Landscape Fragmentation in the Baro-Akobo Basin, Southwestern Ethiopia. *Heliyon*, **10**, e28378. https://doi.org/10.1016/j.heliyon.2024.e28378

[14] Muche, M., Yemata, G., Molla, E., Adnew, W. and Muasya, A.M. (2023) Land Use and Land Cover Changes and Their Impact on Ecosystem Service Values in the North-Eastern Highlands of Ethiopia. *PLOS ONE*, **18**, e0289962. https://doi.org/10.1371/journal.pone.0289962

[15] Munthali, M.G., Mustak, S., Adeola, A., Botai, J., Singh, S.K. and Davis, N. (2020) Modelling Land Use and Land Cover Dynamics of Dedza District of Malawi Using Hybrid Cellular Automata and Markov Model. *Remote Sensing Applications: Society and Environment*, **17**, Article ID: 100276. https://doi.org/10.1016/j.rsase.2019.100276

[16] Islam, H., Abbasi, H., Karam, A., Chughtai, A.H. and Ahmed Jiskani, M. (2021) Geospatial Analysis of Wetlands Based on Land Use/Land Cover Dynamics Using Remote Sensing and GIS in Sindh, Pakistan. *Science Progress*, **104**. https://doi.org/10.1177/00368504211026143

[17] Gogoi, P.P., Vinoj, V., Swain, D., Roberts, G., Dash, J. and Tripathy, S. (2019) Land Use and Land Cover Change Effect on Surface Temperature over Eastern India. *Scientific Reports*, **9**, Article No. 8859. https://doi.org/10.1038/s41598-019-45213-z

[18] Nyatuame, M., Agodzo, S., Amekudzi, L.K. and Mensah-Brako, B. (2023) Assessment of Past and Future Land Use/cover Change over Tordzie Watershed in Ghana. *Frontiers in Environmental Science*, **11**, Article 1139264. https://doi.org/10.3389/fenvs.2023.1139264

[19] Anteneh, M. (2022) Analysis of Land Use/land Cover Change and Its Implication on Natural Resources of the Dedo Watershed, Southwest Ethiopia. *The Scientific World Journal*, **2022**, Article ID: 6471291. https://doi.org/10.1155/2022/6471291

[20] Ayele, G.T., Tebeje, A.K., Demissie, S.S., Belete, M.A., Jemberrie, M.A., Teshome, W.M., *et al*. (2018) Time Series Land Cover Mapping and Change Detection Analysis Using Geographic Information System and Remote Sensing, Northern Ethiopia. *Air, Soil and Water Research*, **11**. https://doi.org/10.1177/1178622117751603

[21] Hailu, A., Mammo, S. and Kidane, M. (2020) Dynamics of Land Use, Land Cover Change Trend and Its Drivers in Jimma Geneti District, Western Ethiopia. *Land Use Policy*, **99**, Article ID: 105011. https://doi.org/10.1016/j.landusepol.2020.105011

[22] Fasika, A., Motuma, T. and Gizaw, T. (2019) Land Use Land Cover Change Trend and Its Drivers in Somodo Watershed South Western, Ethiopia. *African Journal of Agricultural Research*, **14**, 102-117. https://doi.org/10.5897/ajar2018.13672

[23] Wolf, I.D., Sobhani, P. and Esmaeilzadeh, H. (2023) Assessing Changes in Land Use/ Land Cover and Ecological Risk to Conserve Protected Areas in Urban-Rural Contexts. *Land*, **12**, Article 231. https://doi.org/10.3390/land12010231

[24] Mehra, N. and Swain, J.B. (2024) Assessment of Land Use Land Cover Change and Its Effects Using Artificial Neural Network-Based Cellular Automation. *Journal of Engineering and Applied Science*, **71**, Article No. 70. https://doi.org/10.1186/s44147-024-00402-0

[25] Ramachandra, T.V. and Setturu, B. (2019) Sustainable Management of Bannerghatta

National Park, India, with the Insights in Land Cover Dynamics. *FIIB Business Review*, **8**, 118-131. https://doi.org/10.1177/2319714519828462

[26] Hassan, Z., Shabbir, R., Ahmad, S.S., Malik, A.H., Aziz, N., Butt, A., *et al*. (2016) Dynamics of Land Use and Land Cover Change (LULCC) Using Geospatial Techniques: A Case Study of Islamabad Pakistan. *SpringerPlus*, **5**, Article No. 812. https://doi.org/10.1186/s40064-016-2414-z

[27] Alemie, B.K. and Amsalu, T. (2020) Does Land Tenure Insecurity Affect Forest Cover Change? Evidence from Gerejeda State Forest in Ethiopia. *Journal of Land and Rural Studies*, **8**, 101-120. https://doi.org/10.1177/2321024920914781

[28] Kumar, S. and Singh, R. (2021) Geospatial Applications in Land Use/Land Cover Change Detection for Sustainable Regional Development: The Case of Central Haryana, India. *Geomatics and Environmental Engineering*, **15**, 81-98. https://doi.org/10.7494/geom.2021.15.3.81

[29] Seyam, M.M.H., Haque, M.R. and Rahman, M.M. (2023) Identifying the Land Use Land Cover (LULC) Changes Using Remote Sensing and GIS Approach: A Case Study at Bhaluka in Mymensingh, Bangladesh. *Case Studies in Chemical and Environmental Engineering*, **7**, Article ID: 100293. https://doi.org/10.1016/j.cscee.2022.100293

[30] Matsa, M. and Muringaniza, K. (2011) An Assessment of the Land Use and Land Cover Changes in Shurugwi District, Midlands Province, Zimbabwe. *Ethiopian Journal of Environmental Studies and Management*, **4**, 88-100. https://doi.org/10.4314/ejesm.v4i2.10

[31] Lu, D., Mausel, P., Brondízio, E. and Moran, E. (2004) Change Detection Techniques. *International Journal of Remote Sensing*, **25**, 2365-2401. https://doi.org/10.1080/0143116031000139863

[32] Banerjee, S., Kauranne, T. and Mikkila, M. (2020) Land Use Change and Wildlife Conservation—Case Analysis of LULC Change of Pench-Satpuda Wildlife Corridor in Madhya Pradesh, India. *Sustainability*, **12**, Article 4902. https://doi.org/10.3390/su12124902

[33] Kaudo, B.O., Mwenja, P., Epasit, D., Ekai, D., Isacko, D. and Owino, J. (2022) Effect of Potting Tube Size on Growth and Development of Zizyphus Mauritiana Seedlings. *East African Journal of Forestry and Agroforestry*, **5**, 118-129. https://doi.org/10.37284/eajfa.5.1.795

[34] Chama, E., Shibru, S., Gebre, T., Demissew, S. and Woldu, Z. (2023) Forest Products Monetary Contribution to Households' Income: A Means to Improve the Livelihood of a Low-Income Rural Community in South Ethiopia. *Heliyon*, **9**, e21553. https://doi.org/10.1016/j.heliyon.2023.e21553

[35] Suleiman, M.S., Wasonga, V.O., Mbau, J.S., Suleiman, A. and Elhadi, Y.A. (2017) Non-timber Forest Products and Their Contribution to Households Income around Falgore Game Reserve in Kano, Nigeria. *Ecological Processes*, **6**, Article No. 23. https://doi.org/10.1186/s13717-017-0090-8

[36] Handavu, F., Chirwa, P.W.C. and Syampungani, S. (2019) Socio-Economic Factors Influencing Land-Use and Land-Cover Changes in the Miombo Woodlands of the Copperbelt Province in Zambia. *Forest Policy and Economics*, **100**, 75-94. https://doi.org/10.1016/j.forpol.2018.10.010

[37] Näschen, K., Diekkrüger, B., Evers, M., Höllermann, B., Steinbach, S. and Thonfeld, F. (2019) The Impact of Land Use/land Cover Change (LULCC) on Water Resources in a Tropical Catchment in Tanzania under Different Climate Change Scenarios. *Sustainability*, **11**, Article 7083. https://doi.org/10.3390/su11247083

[38] Kibet, R., Olatubara, C.O., Ikporukpo, C.O. and Jebiwott, A. (2021) Land Use Land Cover Changes and Encroachment Issues in Kapkatet Wetland, Kenya. *Open Journal of Ecology*, **11**, 493-506. https://doi.org/10.4236/oje.2021.117032

[39] kullo, E.D., Forkuo, E.K., Biney, E., Harris, E. and Quaye-Ballard, J.A. (2021) The Impact of Land Use and Land Cover Changes on Socioeconomic Factors and Livelihood in the Atwima Nwabiagya District of the Ashanti Region, Ghana. *Environmental Challenges*, **5**, Article ID: 100226. https://doi.org/10.1016/j.envc.2021.100226

[40] Das, N., Mondal, P., Sutradhar, S. and Ghosh, R. (2021) Assessment of Variation of Land Use/Land Cover and Its Impact on Land Surface Temperature of Asansol Sub-division. *The Egyptian Journal of Remote Sensing and Space Science*, **24**, 131-149. https://doi.org/10.1016/j.ejrs.2020.05.001

[41] Zimbabwe National Statistics Agency (Zimstat) (2022) Zimbabwe Population Census. Mt Darwin. https://zimbabwe.opendataforafrica.org/arfkbif/zimbabwe-population-census-2022?districts=1000190-mount-darwin

[42] Zimbabwe National Statistics Agency (Zimstat) (2012) Census 2012. Preliminary Report. https://mdgs.un.org/unsd/demographic-social/census/documents/Zimbabwe/ZWE_CensusPreliminary2012.pdf

[43] Mavhura, E., Manatsa, D. and Mushore, T. (2015) Adaptation to Drought in Arid and Semi-Arid Environments: Case of the Zambezi Valley, Zimbabwe. *Jàmbá: Journal of Disaster Risk Studies*, **7**, Article No. 144. https://doi.org/10.4102/jamba.v7i1.144

[44] Zimbabwe: Vulnerability Assessment Committee (ZIMVAC) (2011) Rural Livelihoods Assessment Results.

[45] Zimbabwe National Statistics Agency (Zimstat) (2002) Census 2002. https://www.zimstat.co.zw/2002-population-11631657/

[46] Velastegui-Montoya, A., Montalván-Burbano, N., Carrión-Mero, P., Rivera-Torres, H., Sadeck, L. and Adami, M. (2023) Google Earth Engine: A Global Analysis and Future Trends. *Remote Sensing*, **15**, Article 3675. https://doi.org/10.3390/rs15143675

[47] Simon, S.M., Glaum, P. and Valdovinos, F.S. (2023) Interpreting Random Forest Analysis of Ecological Models to Move from Prediction to Explanation. *Scientific Reports*, **13**, Article No. 3881. https://doi.org/10.1038/s41598-023-30313-8

[48] Chisadza, B., Ncube, F., Macherera, M., Bangira, T. and Gwate, O. (2023) Spatio-temporal Variations in the Ecological Vulnerability of the Upper Mzingwane Sub-Catchment of Zimbabwe. *Geomatics, Natural Hazards and Risk*, **14**, Article ID: 2190857. https://doi.org/10.1080/19475705.2023.2190857

[49] Laborte, A.G., Maunahan, A.A. and Hijmans, R.J. (2010) Spectral Signature Generalization and Expansion Can Improve the Accuracy of Satellite Image Classification. *PLOS ONE*, **5**, e10516. https://doi.org/10.1371/journal.pone.0010516

[50] Wei, X., Zhang, W., Zhang, Z., Huang, H. and Meng, L. (2023) Urban Land Use Land Cover Classification Based on GF-6 Satellite Imagery and Multi-Feature Optimization. *Geocarto International*, **38**, Article ID: 2236579. https://doi.org/10.1080/10106049.2023.2236579

[51] Adepoju, K.A. and Adelabu, S.A. (2019) Improving Accuracy of Landsat-8 OLI Classification Using Image Composite and Multisource Data with Google Earth Engine. *Remote Sensing Letters*, **11**, 107-116. https://doi.org/10.1080/2150704x.2019.1690792

[52] Lahai, M.K., Kabba, V.T.S. and Mansaray, L.R. (2022) Impacts of Land-Use and Land-Cover Change on Rural Livelihoods: Evidence from Eastern Sierra Leone. *Applied Geography*, **147**, Article ID: 102784.

https://doi.org/10.1016/j.apgeog.2022.102784

[53] Guyassa, E., Raj, A.J., Gidey, K. and Tadesse, A. (2014) Domestication of Indigenous Fruit and Fodder Trees/Shrubs in Dryland Agroforestry and Its Implication on Food Security. *International Journal of Ecosystem*, **4**, 83-88. https://doi.org/10.5923/j.ije.20140402.06

[54] Taloor, A.K., Kumar, V., Singh, V.K., Singh, A.K., Kale, R.V., Sharma, R., *et al*. (2020) Correction To: Land Use Land Cover Dynamics Using Remote Sensing and GIS Techniques in Western Doon Valley, Uttarakhand, India. In: Sahdev, S., Singh, R. and Kumar, M., Eds., *Geoecology of Landscape Dynamics*, Springer, C1. https://doi.org/10.1007/978-981-15-2097-6_23

[55] Yesuph, A.Y. and Dagnew, A.B. (2019) Land Use/cover Spatiotemporal Dynamics, Driving Forces and Implications at the Beshillo Catchment of the Blue Nile Basin, North Eastern Highlands of Ethiopia. *Environmental Systems Research*, **8**, Article No. 21. https://doi.org/10.1186/s40068-019-0148-y

[56] Yagoub, Y.E., Musa, O.S., Siddig, A.A., Bo, Z., Li, Z. and Wang, F. (2017) Assessing the Impacts of Land Use Changes on Vegetation Cover in Eastern Sudan. *International Journal of Research in Agricultural Sciences*, **4**, 70-76. https://ijras.org/administrator/components/com_jresearch/files/publications/IJRAS_505_FINAL.pdf

[57] Kilama Luwa, J., Bamutaze, Y., Majaliwa Mwanjalolo, J., Waiswa, D., Pilesjö, P. and Mukengere, E.B. (2020) Impacts of Land Use and Land Cover Change in Response to Different Driving Forces in Uganda: Evidence from a Review. *African Geographical Review*, **40**, 378-394. https://doi.org/10.1080/19376812.2020.1832547

[58] Semper-Pascual, A., Burton, C., Baumann, M., Decarre, J., Gavier-Pizarro, G., Gómez-Valencia, B., *et al*. (2021) How Do Habitat Amount and Habitat Fragmentation Drive Time-Delayed Responses of Biodiversity to Land-Use Change? *Proceedings of the Royal Society B*: *Biological Sciences*, **288**, Article ID: 20202466. https://doi.org/10.1098/rspb.2020.2466

[59] Yuan, R., Zhang, N. and Zhang, Q. (2024) The Impact of Habitat Loss and Fragmentation on Biodiversity in Global Protected Areas. *Science of the Total Environment*, **931**, Article ID: 173004. https://doi.org/10.1016/j.scitotenv.2024.173004

[60] Yan, Z., Guo, Y., Sun, B., Gao, Z., Qin, P., Li, Y., *et al*. (2024) Combating Land Degradation through Human Efforts: Ongoing Challenges for Sustainable Development of Global Drylands. *Journal of Environmental Management*, **354**, Article ID: 120254. https://doi.org/10.1016/j.jenvman.2024.120254

[61] Sulieman, A.M.E. and Mariod, A.A. (2019) Domestication of Indigenous Fruit Trees. In: Mariod, A., Ed., *Wild Fruits*: *Composition*, *Nutritional Value and Products*, Springer, 59-81. https://doi.org/10.1007/978-3-030-31885-7_6

[62] Jha, D., Hangargekar, P., Akbar, M., Parihar, A.S., Kashyap, S., Joshi, A., *et al*. (2024) REMOVED: Ziziphus Mauritiana: An In-Depth Review of Its Medicinal Attributes and Pharmacological Activities. *Intelligent Pharmacy*, **2**, 274-283. https://doi.org/10.1016/j.ipha.2023.12.001