Research manuscript

An analysis of land use and land cover changes, and implications for conservation in Ward 2 (Mukumbura), Mt Darwin, Zimbabwe, 2002–2022

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Abstract

Understanding trends of land use land cover (LULC) changes are important for biodiversity monitoring and conservation planning, and identifying the areas affected by change and designing sustainable solutions to reduce the changes. The objective of the study was to analyse the LULC changes in Ward 2 (Mukumbura), Mt Darwin, Northern Zimbabwe, for 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. The forest cover declined 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. The study findings point to the need to domesticate the indigenous fruit trees in arborloo toilets.

Key Words: 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 (Cianciullo et al., 2023). 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 (Ayele et al., 2018). 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 (Zhang, Cheng & Wu, 2023). The bulk of human operations are carried out on lands that in turn consume the natural resources, affect the environment and lead to LULC change (Islam et al., 2021). 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 (Nedd et al., 2021), while land use describes how the land cover is modified (e.g., agricultural land, built-up area, recreation area, wildlife management areas) (Gunathilaka et al., 2022). Land use refers to the land that has been utilized by humans and their territory, commonly highlighting the functional nature of land for economic activities (Mariye, Maryo and Li, 2021). Therefore, an understanding of LULC and its use has become an essential requirement for fulfilling the needs of the growing population (Srivastava et al., 2023).

LULC is under a continuous change mainly because of societal development and natural causes (Hailu, Mammo, and Kidane, 2020). 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 (Munthali et al., 2020). Analysing 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 (Alemayehu, Tolera, and Tesfaye, 2019). 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 (Wolf, Sobhani and Esmaeilzadeh, 2023). 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 (Anteneh, 2022). The LULC changes have directly or indirectly contributed to a decrease in the availability of natural resources, 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 (Ramachandra & Setturu, 2019). The LULC changes are triggered by the interplay of socioeconomic and natural environmental factors (Debie, Anteneh and Asmare, 2022). Thus, LULC changes play an important role in the study and analysis of global environmental changes (Hassan et al., 2016). Making data available on LULC changes is essential for providing critical input to decision-making on ecological management and environmental planning for the future (Hassan et al., 2016). Several researchers have addressed the problem of accurate monitoring of LULC changes in numerous environments using different techniques (Hassan et al., 2016). 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 (Alemie & Amsalu, 2020). The timely and accurate detection of LULC change is important for the macro and micro level sustainable development of any region (Kumar & Singh, 2021). LULC is vital to investigate land use patterns and helping forecast future sustainable land management (Seyam, Haque and Rahman, 2023).

There is an increase on studies on LULC changes following Zimbabwe's fast-track land reform programme 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 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 (Matsa & Muringaniza, 2011). 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 (Lu et al., 2004) 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 (Banerjee, Kauranne & Mikkila, 2020). Major direct causes of forest clearance and degradation include the expansion of agricultural land, overharvesting of industrial wood, fuelwood, and other forest products, and overgrazing (Anteneh, 2022). Hence, there is 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 (Kaudo et al., 2022) 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. Forests remain an important source of products and services that are critical to household livelihood support and emergency safeguards (Handavu, Chirwa and Syampungani, 2019). 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 (Handavu, Chirwa and Syampungani, 2019). Natural processes like floods, landslides, droughts and climate change affect LULC, although they are induced by anthropogenic activities to a certain degree (Näschen et al., 2019). Accordingly, this study analyses the status of LULC change in Mukumbura Ward in northern Zimbabwe and to detect 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 scenario today as the data available on such changes is essential for providing critical input to decision-making of ecological management and environmental planning for the future (Hassan et al., 2016). The other objective was to examine the temporal dynamics of LULC changes, identifying trends, patterns, and the rate of change over the study period, which is from 2002 to 2022.

2. Materials and Methods

2.1 Study area

Mt Darwin has a total population of 240 728 and 58 071 households (Zimstat, 2022) and is the most populous and largest district in the province. Mt Darwin has forty wards, accounting for 20% of the provincial population (Zimstat, 2013). 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 millimetres (Mavhura *et al.*, 2015). The area receives its rainfall from November to March and 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 (ZimVAC, 2011). The area is largely composed of flat undulating terrain, clay loams soils which are fertile for agricultural production (ZimVAC, 2011; Fig. 1). Ward 2 (Mukumbura) is in the Zambezi valley with a total population of 12 954 and 3247 households (ZimStat, 2022). Ward 2 (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 (ZimStat, 2002), 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.

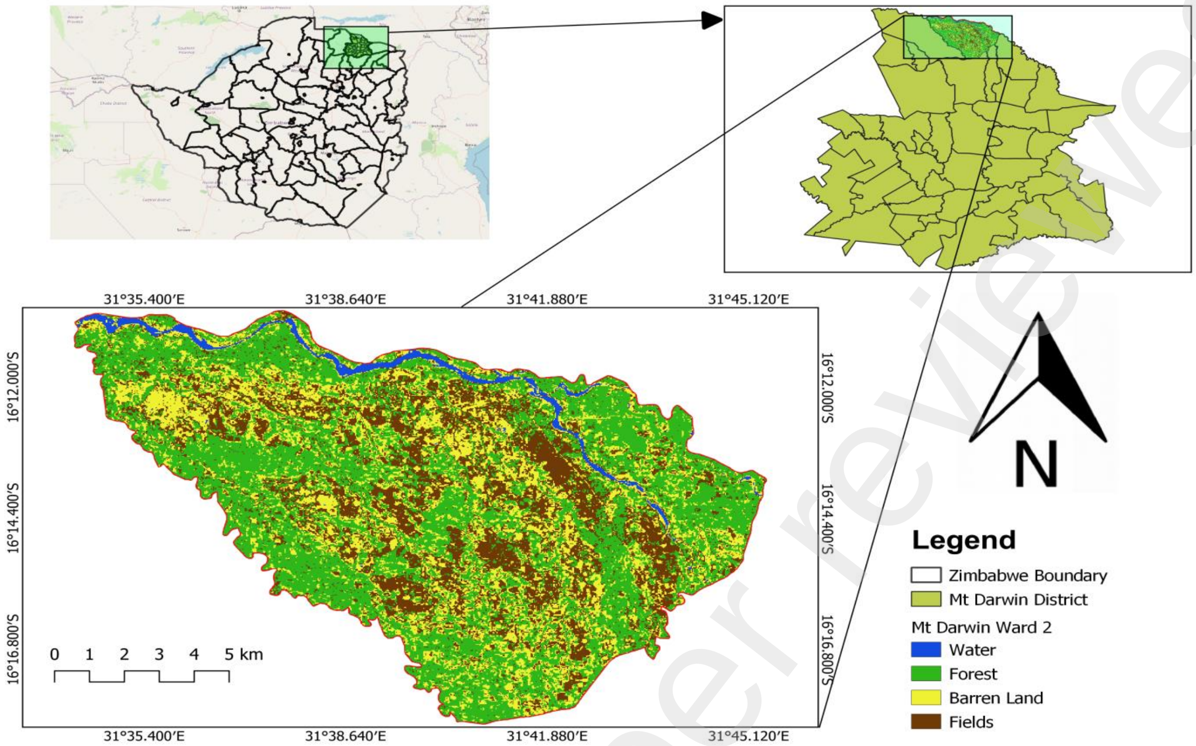

Figure 1: Location of Ward 2 (Mukumbura), Mt Darwin District, Northern Zimbabwe

2.2 Research Approach

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 (Chisadza et al., 2023). 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. 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 (GEE) cloud computing software. GEE was preferred due its computation power, hence a powerful tool for processing large Earth observation data (Velastegui-Montoya et al., 2023). 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 (Simon, Glaum & Valdovinos, 2023). 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 to 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 create 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 Ward 2 is illustrated in Fig. 2.

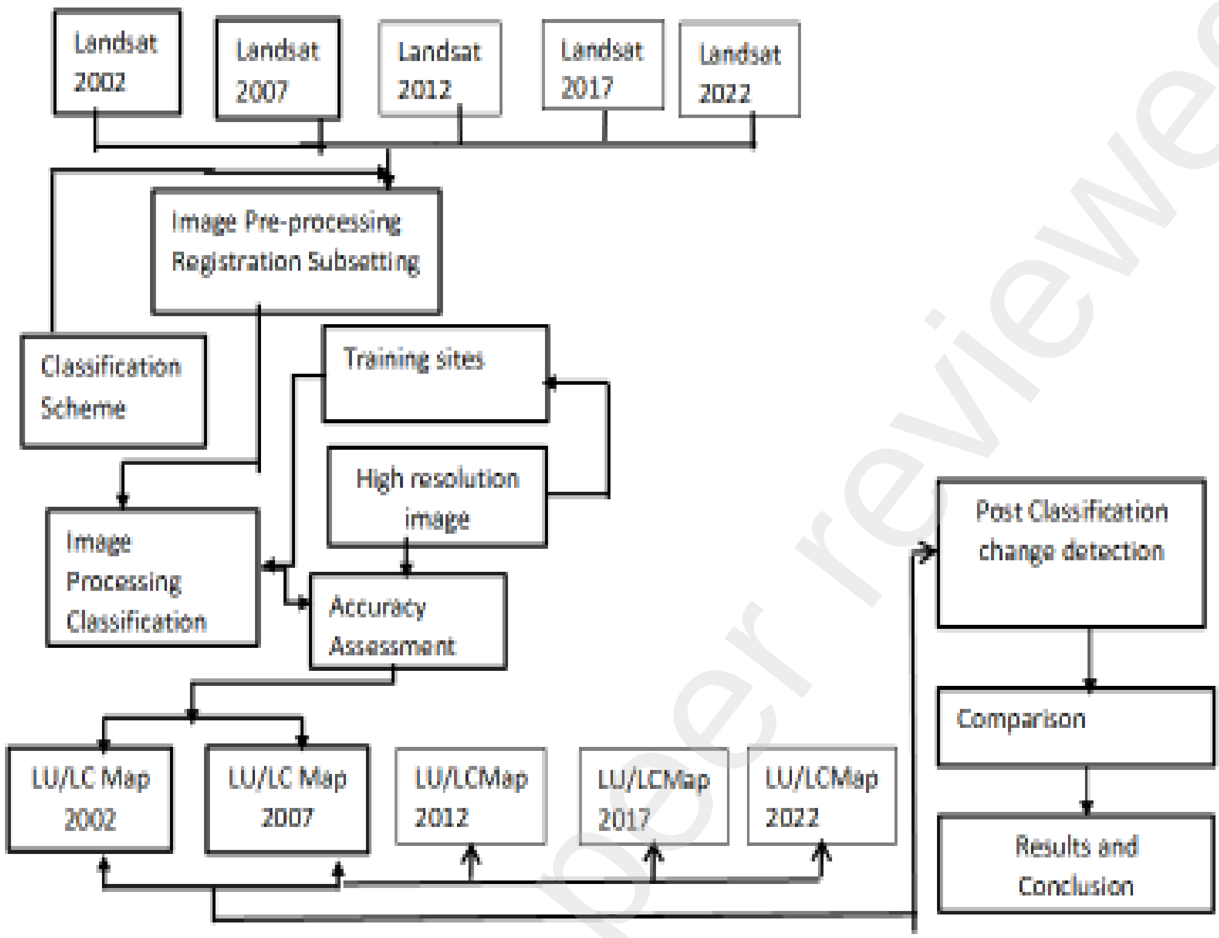

Figure 2: Flow chart showing methodology of LULC change detection (Seyam, Haque, & Rahman, 2023) in Ward 2 (Mukumbura) Mt Darwin, Northern Zimbabwe.

2.3 Data Analysis

The study used spatial analysis in a GIS environment to produce land cover maps of the study area over time for all four-satellite land cover image dates. Changes of land cover classes were determined by comparing land cover images of earlier dates against later date images to establish percent changes. Each year was categorized into Wet Season (November-March), Transition Season (April-June), and Dry Season (July-October).

The images for 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:

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

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 in a state of expansion) (Anteneh, 2022). 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. Results and Discussion

3.1 LULC changes in Ward 2 (Mukumbura) from 2002 to 2022

Results from the Maximum likelihood techniques indicate that during the wet season of 2002 to 2007, the forest declined by 1,412.97 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%) (Figs. 3 and 4).

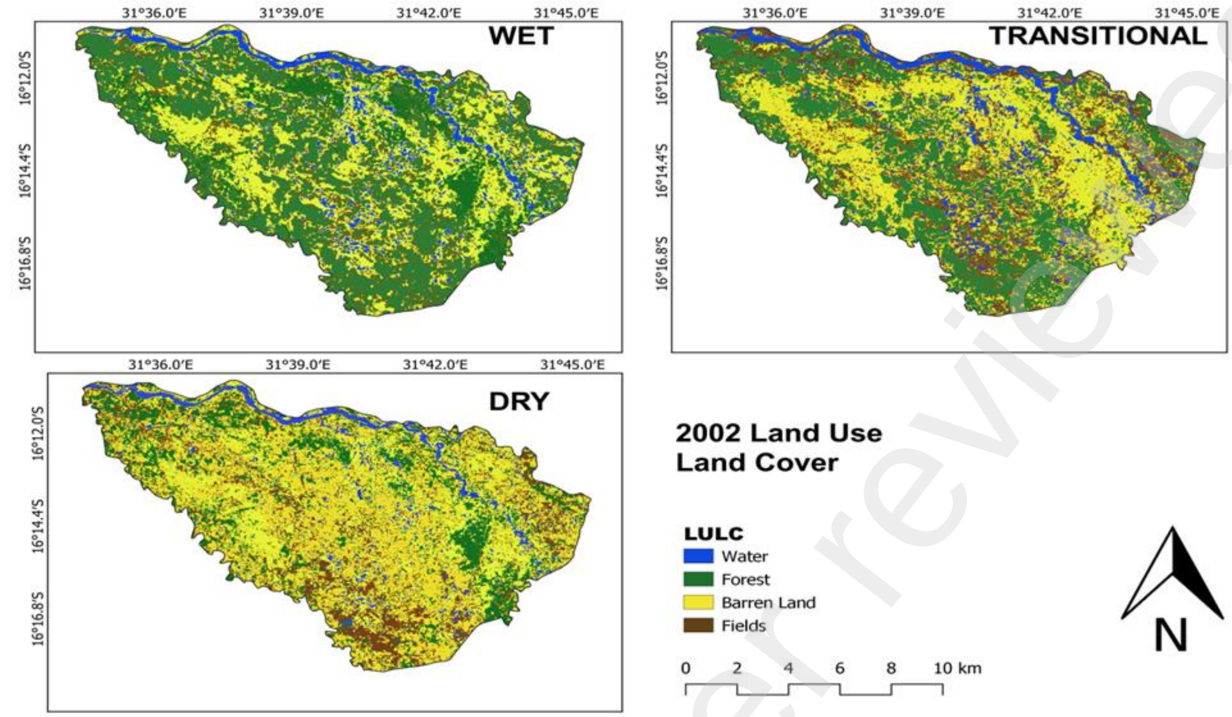

Figure 3: 2002 Land Use Land Cover for Ward 2 (Mukumbura), Mt Darwin District, Northern Zimbabwe

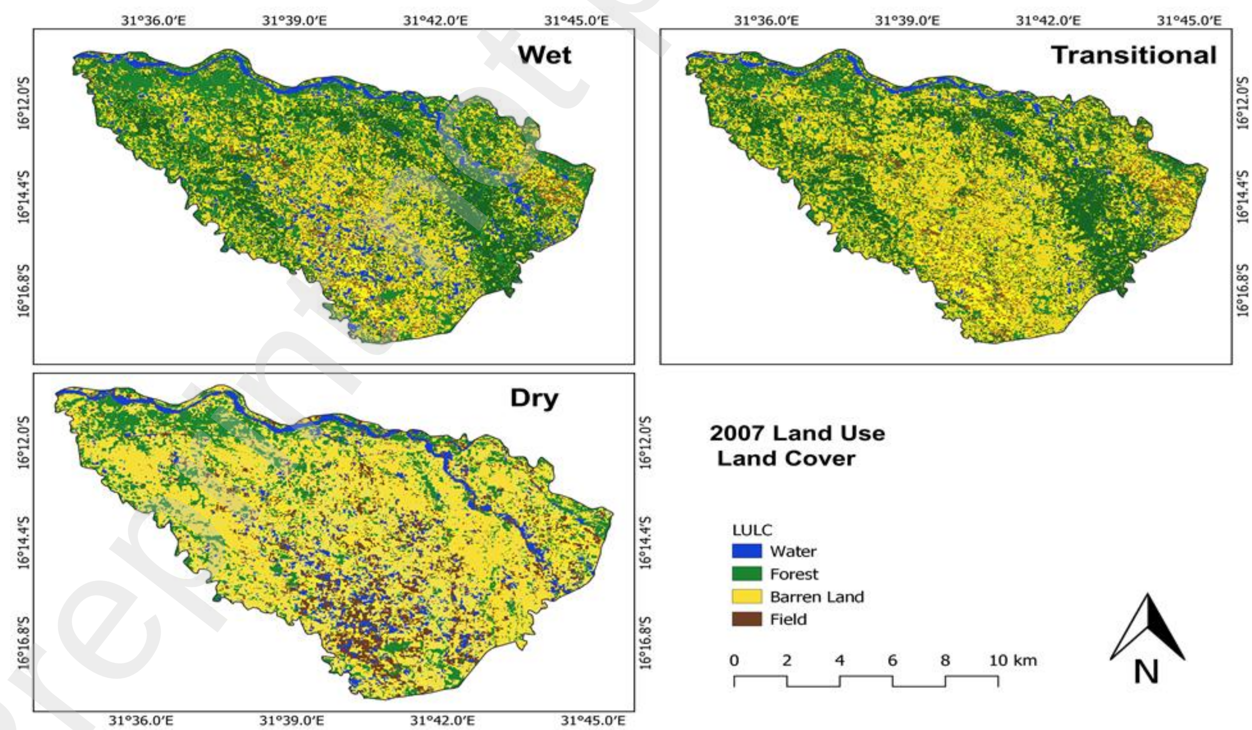

Figure 4: 2007 Land Use Land Cover for Ward 2 (Mukumbura), Mt Darwin District, Northern Zimbabwe

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. 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 (Hassan et al., 2016). 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 (Guyassa et al., 2014), showed that marginalised communities benefit from the programs. Ward 2 has the potential to domesticate the *Ziziphus mauritiana* tree species in arborloo toilets as well. The research carried out by Taloor *et al.* (2020) 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. 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%) (Fig. 5).

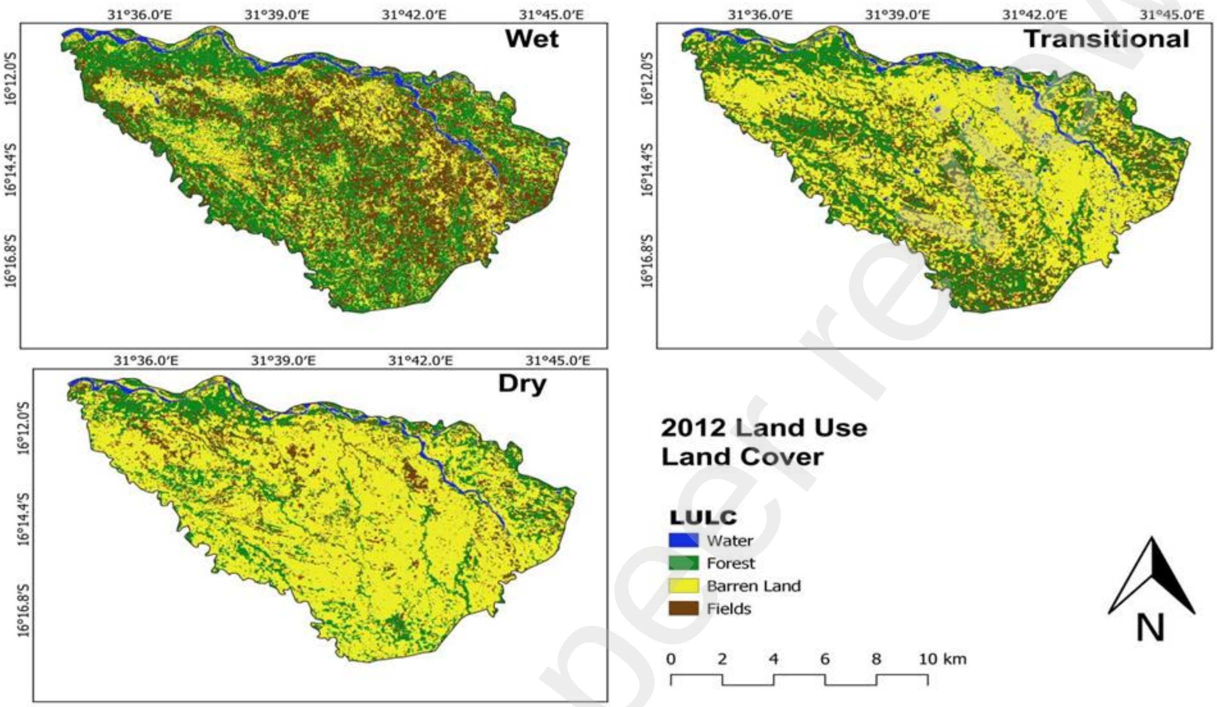

Figure 5: 2012 Land Use Land Cover for Ward 2 (Mukumbura), Mt Darwin District, Northern Zimbabwe

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 Yesuph and Dagnew (2019) 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.

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%). 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%). 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 (Fig. 6).

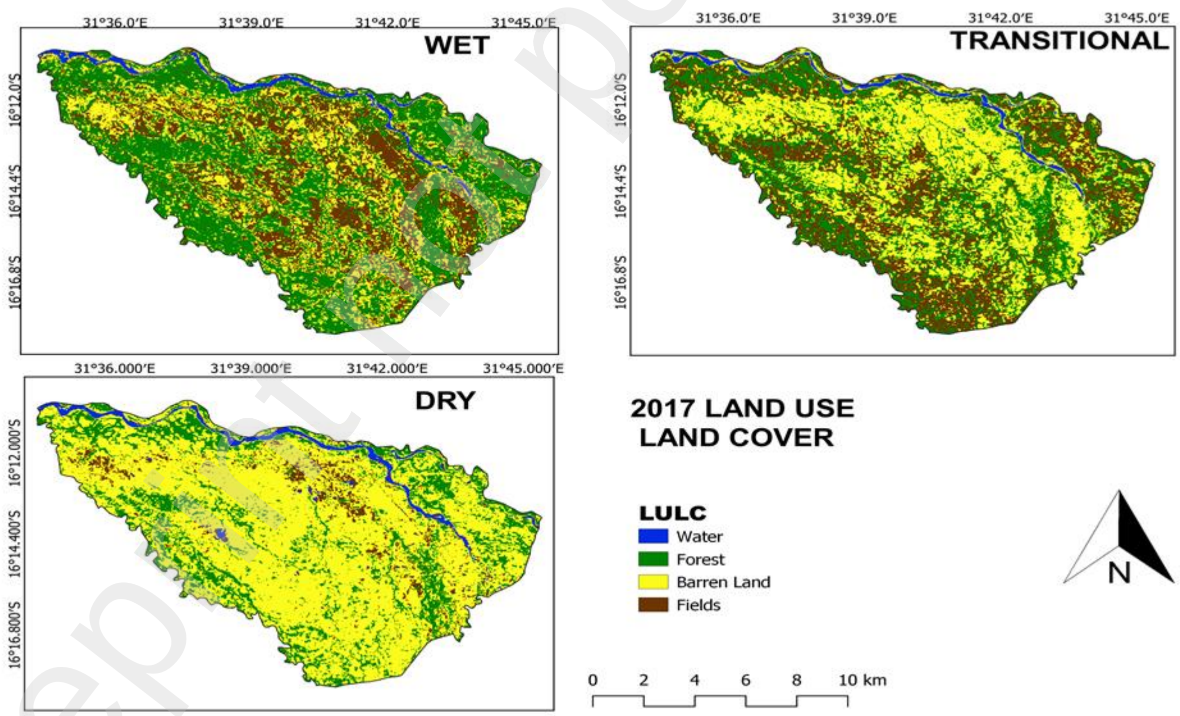

Figure 6: 2017 Land Use Land Cover in Ward 2 (Mukumbura), Mt Darwin District, Northern Zimbabwe

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. 7). 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%). 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.

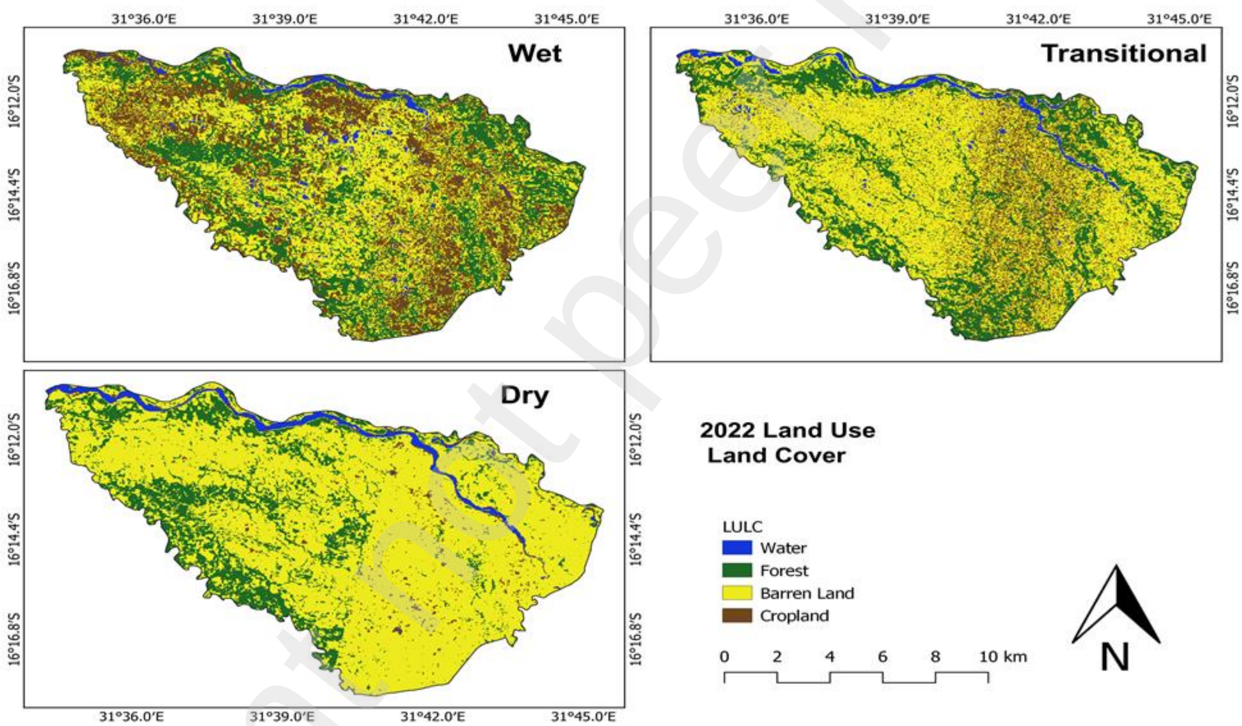

Figure 7: 2022 Land Use Land Cover in Ward 2 (Mukumbura), Mt Darwin District, Northern Zimbabwe

The deterioration and decline rate of vegetation cover occurred throughout the Ward from 2017 to 2022. The vegetation was cleared to expand fields and promote increased cultivation of sesame crops. 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

Yagoub et al. (2017) who reported that the present natural forest in Sudan is estimated to have declined to approximately 0.8 billion m² 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.

3.2 Overall LULC changes in Ward 2 (Mukumbura) from 2002 to 2022

The findings revealed that that there has been a significant change in LULC over the observed years ($P < 0.05$). The Null and Alternative hypothesis 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 and the reason behind this may be deforestation due to increase in agricultural land and other anthropogenic activities which contribute 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 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. The table below shows the actual changes in hectares for the variables, forest, barren land, water, and fields from 2002 to 2022.

Table 1: Land use land covers 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

3.3 Implications for conservation

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 (Semper-Pascual et al., 2021). 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 (Yuan, Zhang, & Zhang, 2024). 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 *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 (Chetcuti, Kunin, & Bullock, 2020), hence the need to domesticate household *Ziziphus mauritiana* fruit trees in arborloo toilets.

4. Conclusion

The results of this study show that there has been a substantial 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. 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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Conflict of interest

The authors declare no conflict of interest.

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