# A quantitative assessment of forest rejuvenation activities by a community on the borders of Hwange National Park using GIS and Remote Sensing

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## Abstract

*Various natural and human activities have led to land degradation in the Hwange National Park and in the surrounding communal areas. The deforestation has in turn upset the natural ecosystem, with the desecrated vegetation leading to reduced soil moisture-holding capacity, reduced carbon sequestration by the forest and the subsequent loss of biodiversity. There has been attempts to rejuvenate the forest through activities that include holistic grazing methods, the use of swales, the mulching of fields, the cultivation of cover crops, the use of gabions, erosional restoration works, and the use of rocket stoves to minimise the reliance of inhabitants on firewood. These have been followed up by the application of scientific methodologies to assess the effectiveness of the various methods used. By applying the Normalized Difference Vegetation Index (NDVI) and assessing the land use / land cover changes (LULC), the impacts of the aforementioned rejuvenation activities were studied over a period of five years (2017-2022). Annual mean NDVI values were computed to reduce the bias in respect of changes in leaf phenology caused by variations in rainfall. The results show an increase of NDVI from a mean of 0.304 in 2020 to a mean of 0.345 in 2021. More so, there was a 30% increase in 2021 and a 46% increase in 2022 from the previous years for forest cover in the study area. The results show the positive impact of the performed rejuvenation activities.*

## 1. Introduction

Land regeneration entails rejuvenating soil health by minimising topsoil erosion, retaining more carbon than that which has been depleted, boosting biodiversity and maintaining proper water and nutrient cycling(Lal, Negassa and Lorenz, 2015). Successful regenerative agriculture is defined in terms of the creation of beneficial ecological outcomes. Hwange National Park covers an area of 1.4 million hectares, making it the largest protected area in Zimbabwe. It is home to a rich biodiversity and adjacent to important land concessions. However, the need for firewood and cropland has resulted in the logging of tree species, as is currently the case in different parts of Africa, including Zimbabwe(Gerhardt and Todd, 2009). More so, national parks, such as the Hwange National Park, and areas of high commercial value that are located close to the park and used for, amongst others, communal grazing, have been subjected to the felling of trees for income generation. Additionally, other human activities have also contributed to the destruction of forests (e.g., humans have used fire as a basic tool for managing vegetation for thousands of years (Nyamadzawo *et al.*, 2013)). However, the improper use of fires often leads to veld fires, which could result in the destruction of extensive tracts of forest and grasslands and may result in the loss of biodiversity and even of human life (Nyamadzawo *et al.*, 2013). Thus, the contribution of human activities in communal grazing areas, of natural processes, such as the burgeoning increase in animal species, such as elephants, in the park (Ferry *et al.*, 2021), have led to the destruction of forests and the vegetation cover of the park and the adjacent communal grazing areas. In other areas of the park, however, the vegetation loss can be attributed to the proximity of water sources. One might assume that the vegetation closest to water sources in dry areas would be denser and healthier. However it has been shown that gatherings of animals around water holes have complex effects on plant survival (Titcomb *et al.*, 2021). The findings by Titcomb concerning a semi-arid savanna region in Kenya show that, under more arid conditions, increased herbivore activity around water holes/ courses has led to fewer plants and plant species. Only the hardiest of species have been able to withstand these conditions.

The direct effects resulting from the destruction of forests are to reduce carbon sequestration in forests (Sedjo, 2001), to destroy the vegetation cover and roots − both of which serve to preserve soil moisture − and ultimately to reduce the biomass (Wicaksono *et al.*, 2015). In fact, much of the research has proposed different methods to promote forest rejuvenation, and in so doing to improve carbon sequestration, soil moisture retention and, ultimately, the above ground biomass (AGB). However, considering the effectiveness of Geographical Information Systems (GIS) and remote sensing − methods which are used extensively to monitor vegetation −, these valuable tools have hardly been employed to assess the effectiveness of these methods . To this end, this study seeks to assess the success of the forest rejuvenation activities carried out by the Soft Foot Alliance, a community-based trust registered in Zimbabwe. These activities include holistic grazing methods, the use of swales, the mulching of fields, the cultivation of cover crops, the use of gabions, erosional restoration works and the use of rocket stoves to minimise the reliance of inhabitants on firewood. These methods serve several purposes, including the protection of rural families from cooking-smoke-related diseases, the reduced need for collecting large amounts of wood, which can be time consuming and might bring the collectors in close contact with the local wildlife − a threat to their safety. In addition, the mere fact of removing less wood from the environment will enable the indigenous trees to regenerate.

To assess the success of this project, the study used the Normalized Difference Vegetation Index (NDVI), which monitors variations in vegetation health and density over time and space (Kinyanjui, 2011). NDVI uses plant reflectance characteristics that are recorded by satellite imagery (Kinyanjui, 2011). Variations in the land cover were also used to determine the spatio-temporal changes of the forest cover over time.

## 2. Study Area

The study was carried out in an area of less than five square kilometres on the border of the Hwange National Park. The park, in North-western Zimbabwe, is classified as a savannah ecosystem. The vegetation is principally woodland and bushland savanna, with less than 10 % of the entire area composed of grassland patches, and is mostly dominated by *Colophospermum mopane, Combretum spp., Acacia spp, Baikiaea plurijuga* and *Terminalia sericea* (Morandin *et al.*, 2014). Figure 1 shows the map of the study area.

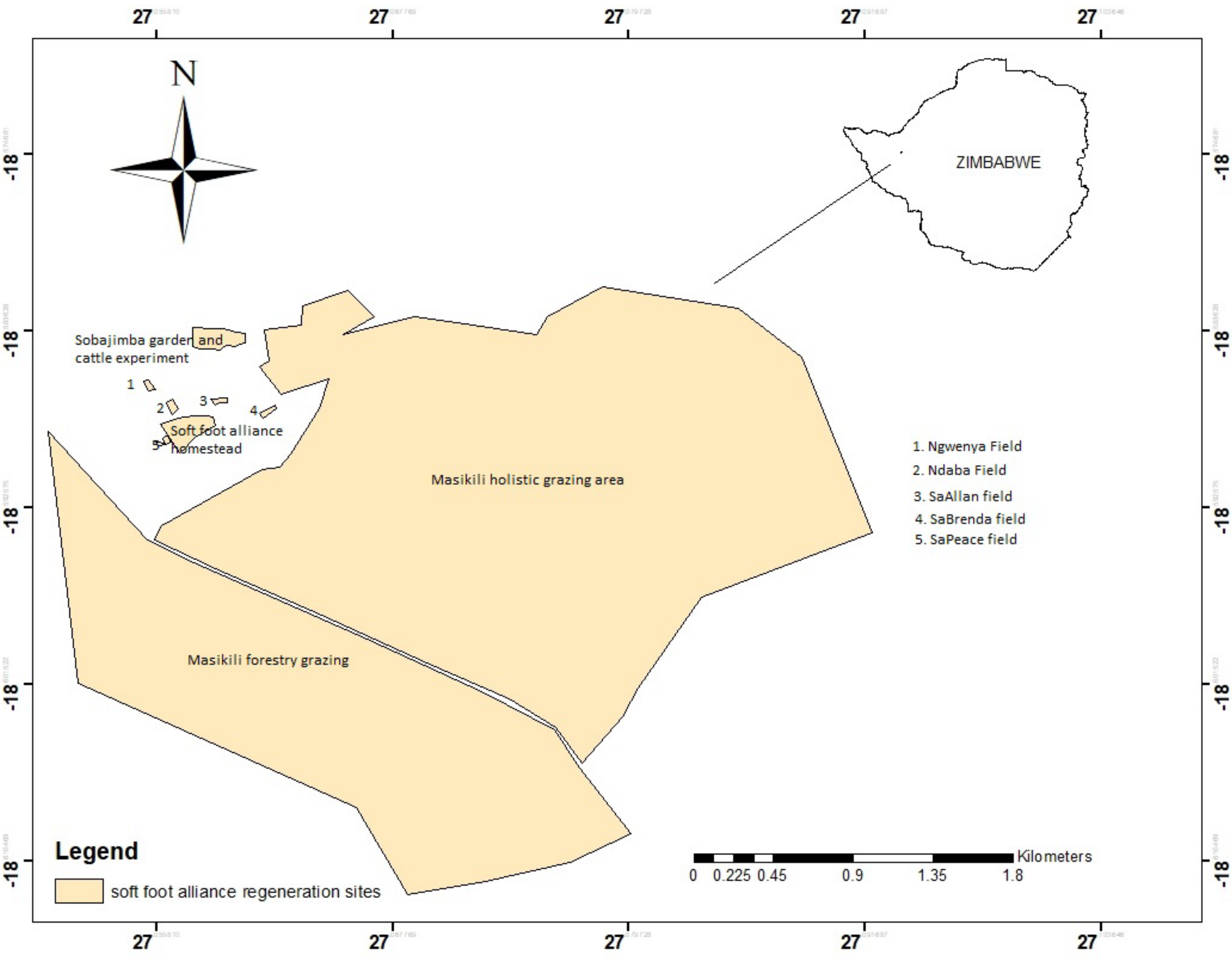


Figure 1 : Study Area

### 2.1. Soft Foot Alliance homestead

Figure 1 shows the homestead and headquarters of the Soft Foot Alliance. The Soft Foot Alliance uses the participatory approach where the inhabitants live in the communities in which they work. The Soft Foot Alliance took up residence in this area in November 2014. An achievement of note is that since the inhabitants have started using rocket stoves, there has been no cutting of trees for firewood in the study area.

### 2.2. Rocket Stoves

Fuel-efficient rocket-stoves are used for cooking purposes: −the inhabitants use only fallen sticks or twigs. A rocket stove is a stove that uses pieces of wood of a small diameter. It consists of a combustion chamber, where the fuel burns, and a vertical chimney. Part of what makes rocket stoves so efficient is that their vertical chimneys are insulated, meaning that almost all the heat moves upward; hence, they burn at very high temperatures. The vertical chimney is tall enough to ensure that the fuel fully combusts before the flames reach up to the cooking surface. Significantly, a rocket stove produces no smoke, which means that these stoves benefit the atmosphere and the lungs of the people using them (Barker and Meadows, 2015).

### 2.3. Allan Savory's holistic grazing plan

There is a mobile goat paddock system used at the Soft Foot Alliance homestead. It follows Allan Savory's holistic grazing plan. Eight acres of land have been mapped into paddocks and the movement of the goats on the farm is planned to the effect that they are in any one place for only two to three days. The plan allows for a 90-day recovery plan for the vegetation. In fact, for 90 days in the wet season, the animals will not return to any one spot. During the dormant season, the plan is for the goats to be in one place for only two or three days; this allows the villagers to mulch the soil and to prepare it to receive the rain when it comes. In addition, as the land is sloping, contour swales are dug in the fields to harvest the rainwater flowing across the land surface. Since no fertilizers or pesticides are used, there is also the practice of composting urine /excrements, which are applied to the fields. Tree branches are cut off for the goats but this is done in such a way that the operation can be repeated over the year. The branches, when dried, are used to fuel the rocket stoves. The Soft Foot Alliance has created a database to monitor the species diversity in the surrounding environment and has also promoted the habit of not killing any animals, including snakes.

### 2.4. Sobajimba Garden and cattle experiment

This experiment involves the community regeneration demonstration area. Included in it is the Sobajimba Garden, which was started in August 2018. Initially, it was a rocky area of land with a barren soil along the slopes and a hard-capped soil on the valley floor, with a large gully running through it. The garden has been terraced, with contour swales, which were initially dug to harvest the rainwater and prevent soil erosion. The garden generates compost as a substitute for artificial fertilizers since no fertilizers nor pesticides are used. The garden is fenced off to keep livestock out. There is an abundance of planted fruit trees , as well as perennial plants, such as pigeon peas, etc. A rainwater pond has been dug to attract natural predators, such as dragonflies, etc. to the area. No trees have been chopped down since August 2018.

The flat lands around the gully have been subjected to a cattle-impact experiment where we fenced off the area and subjected it to high-density cattle grazing for hours and days. Their hoof-action broke the soil cap and their manure fertilized the land. The grass was allowed to grow and the animals were then allowed to feed on the grass before the paddock was closed up to allow the land to rest. This demonstrates how livestock can be used as a means to allow the land to recover. The gully itself has several gabions that have been built by the community to slow down the rush of water during flash floods to subsequently allow for the release of the load of soil and to harvest the rainwater.

### 2.5. Masikili holistic grazing area

The grazing areas are on the communal lands of our local villages. The communal lands are on the top northern side of the road and the forestland on the southern side. The Soft Foot Alliance has been working over some years to encourage the community to divide these areas into paddocks and to plan the grazing along the same lines as was done with the goats at the Soft Foot Alliance homestead. This project has been followed only to any real extent over the last six months or so, with some − efforts before that, being since 2016. It is a large area where people cut trees for bricks, building purposes, etc. as well as for fodder for their animals. There are wild animals too. They include lions, occasionally, elephants, regularly, and the other ungulates, such as kudu and giraffe.

### 2.6. Ngwenya field

This area is a field where a mobile cattle boma (kraal) is placed for a couple of weeks and the animals are brought home after a day out grazing. Their manure and urine fertilize the field, while they are protected against predators at night. Here, we are looking for any indications of increased soil fertility and crop yields as compared to the other areas of the field.

### 2.7. Materials and Method

The Normalized Difference Vegetation Index (NDVI) data derived from Landsat satellites was used to assess the impact of the forest regeneration activities. Not only is NDVI a good indicator used to estimate forest carbon and biomass (Baniya *et al.*, 2018); the indices have been used widely to map forests and to monitor the extent of carbon sequestration whereby the carbon in the atmosphere is taken up by terrestrial ecosystems (Erasmi *et al.*, 2021). To understand the extent of forest regeneration, land-cover maps were also used in the study. A land-cover map is one showing the spatial distribution of the various thematic areas constituting the study area. These thematic areas could include built-up areas, forests, and cropland, to name a few (Foody, 2002). Figure 2 summarises the methodology behind the research.

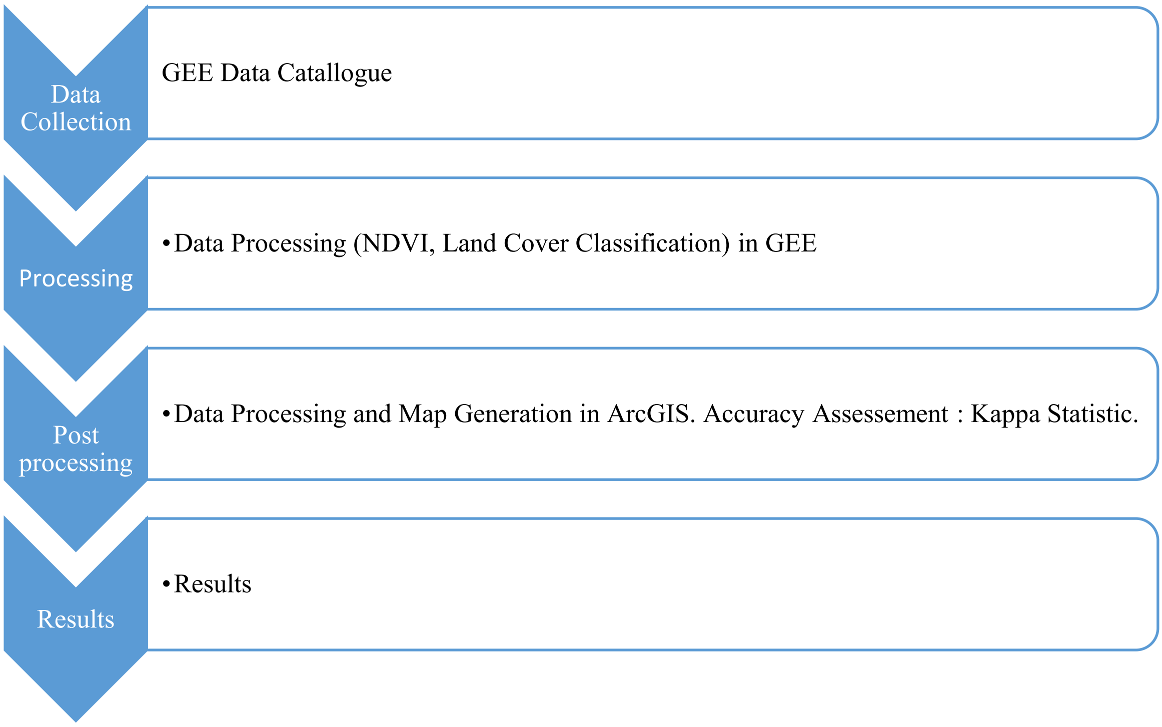


Figure 2: Flow chart of the methodology

## 2.8. Data Collection

Ten-metre resolution data were acquired from the Sentinel 2 satellite for the study area for the dates, 2018-01-01 to 2018-12-31, 2019-01-01 to 2019-12-31, 2020-01-01 to 2020-12-31 and 2021-01-01 to 2021-12-31. Considering that Sentinel 2 involves optical satellite imagery with a high temporal and spatial resolution (Drusch *et al.*, 2012), a cloud-filtering algorithm was run and the resultant images were combined into a single image by considering the median of all the images acquired.

## 2.9. Vegetation Indices

The Normalized Difference Vegetation Index (NDVI data) was used to characterise the vegetation and to consider the extent to which it is used for monitoring the vegetation.

NDVI is given by the formula : $NDVI = \frac{NIR-RED}{NIR+RED}$

where, NIR is the near infrared band and RED is the red band, with the data catalogue of the NDVI derived from Google Earth Engine (GEE)

GEE is a cloud-computing platform for earth-wide geospatial analysis that brings Google's massive computational capabilities to process various geographical phenomena, including deforestation, drought, disaster, disease, food security, water management, climate monitoring and environmental protection (Gorelick *et al.*, 2017). Satellite imagery was acquired from the Sentinel 2 satellite launched by the European Space Agency, which is a wide-swathe, high-resolution, multi-spectral imaging mission supporting Copernicus Land Monitoring studies, including the monitoring of vegetation, soil and water cover, as well as observations of inland waterways and coastal areas (Main-Knorn *et al.*, 2017).

### 2.10. Landcover, Classification and Classifier training

Once the imagery had been acquired, training points were taken for the different land classes in the study area. These were mainly - Bushland, Grassland, Forest, Water, Bare, Cropland, Plantation, Built up and Rock –a thousand points in total. The following figure shows the GEE dashboard used in the research,

The 'ee.Classifier.smileCart' classification algorithm - CART was used. The CART algorithm involves the identification and construction of binary decision trees using a sample of training data for which the correct classification is known (Onojeghuo *et al.*, 2021). The CART decision tree is a binary recursive partitioning algorithm with the ability to process both continuous and nominal attributes as targets and predictors (Onojeghuo *et al.*, 2021). The main advantage of the decision tree algorithms in land cover classification over machine learning classifiers is their ability to deal with complicated dataset distributions (Onojeghuo *et al.*, 2021).

### 2.11. Validation

A confusion matrix was used and an overall validation accuracy of 0.66 was achieved, with a Kappa statistic of 0.60 for the 'ee.Classifier.smileCart' classification algorithm. Amongst other methods, the accuracy of a classifier is normally estimated with the help of a confusion matrix, as it is a useful tool for analyzing how well the classifier can recognize rows of different classes (Patro and Ranjan Patra, 2014).

## 3. Results

### 3.1. NDVI

In 2018 (figure 3), there were high NDVI values in the southern region of the study area and low NDVI values in the northern region of the study area. In 2019, high NDVI values were observed in both the southern and central regions of the study area. In both 2020 and 2021, higher values of NDVI were observed in the southern parts of the study area. Figure 3 shows the spatial distribution of the NDVI for the years 2018, 2019, 2020 and 2021.

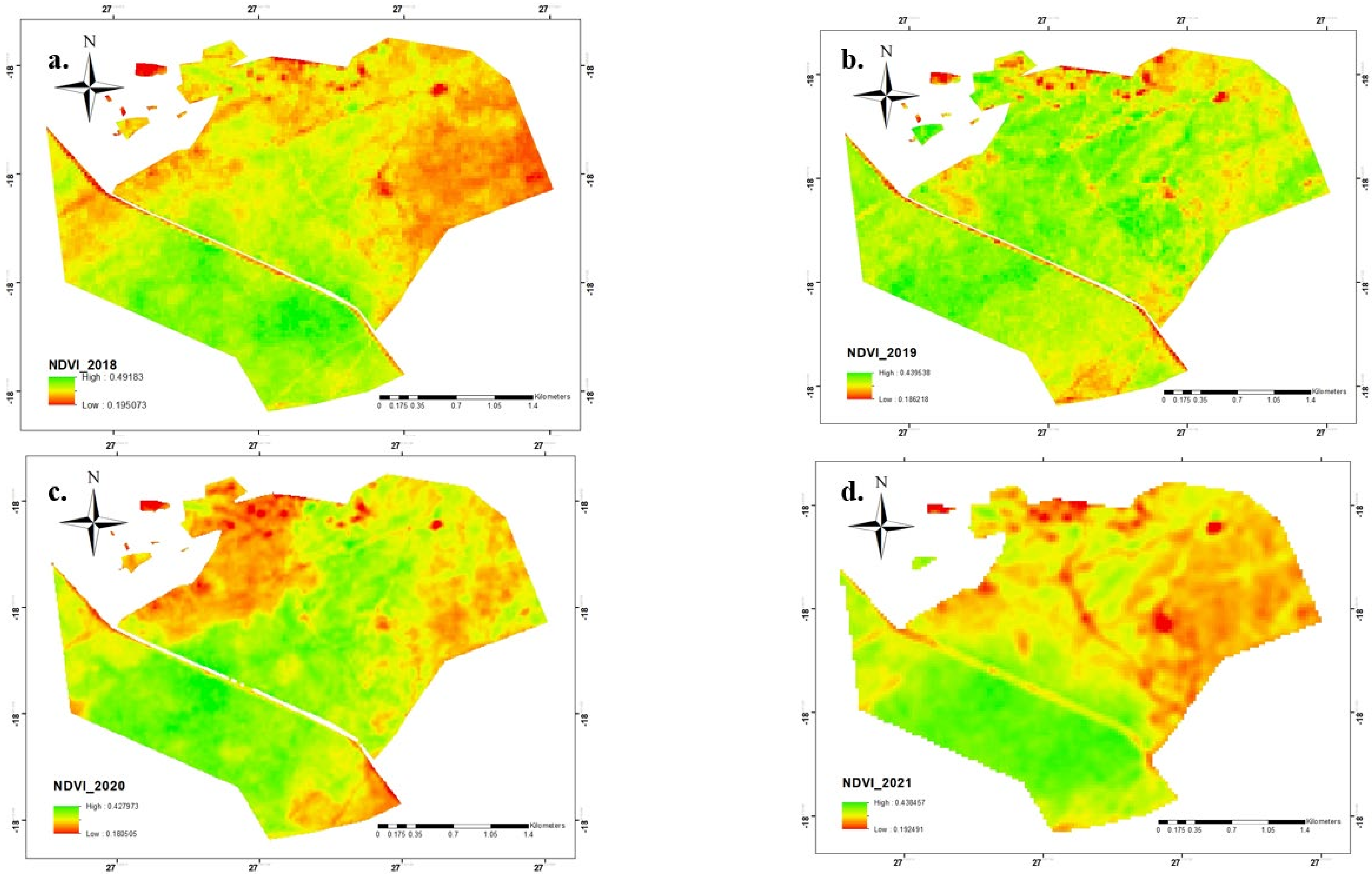


Figure 3 : NDVI for (a) 2018, (b) 2019, (c) 2020, and (d) 2021

Figure 4 shows the variations of the NDVI over the years 2018-2021. There was a slight decrease in NDVI from 0.349 in 2018 to 0.346 in 2019; in 2020, there was a further decrease to 0.304; and in 2021 an increase in NDVI to 0.345. Figure 4 shows the variation of NDVI for the years 2018-2021.

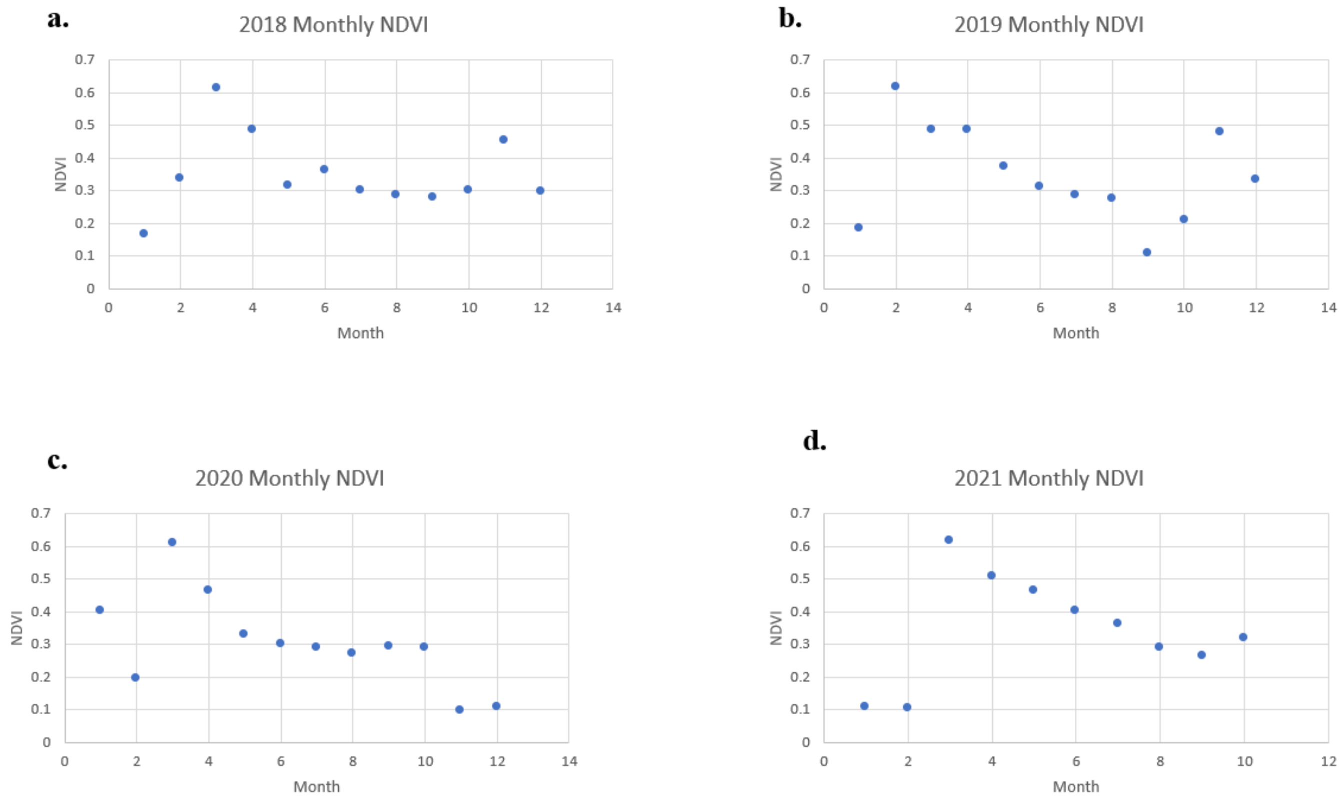


Figure 4 : Monthly NDVI for (a) 2018, (b) 2019, (c) 2020, and (d) 2021

## 3.2. Land cover

Figure 5 shows the variation in land cover from 2018 – 2022. As shown in Tables 1 , 2 , 3 , 4 and 5, most of the land cover in 2018 was forest. Forest cover declined in 2019 and 2020, and slightly increased in 2021 and 2022.

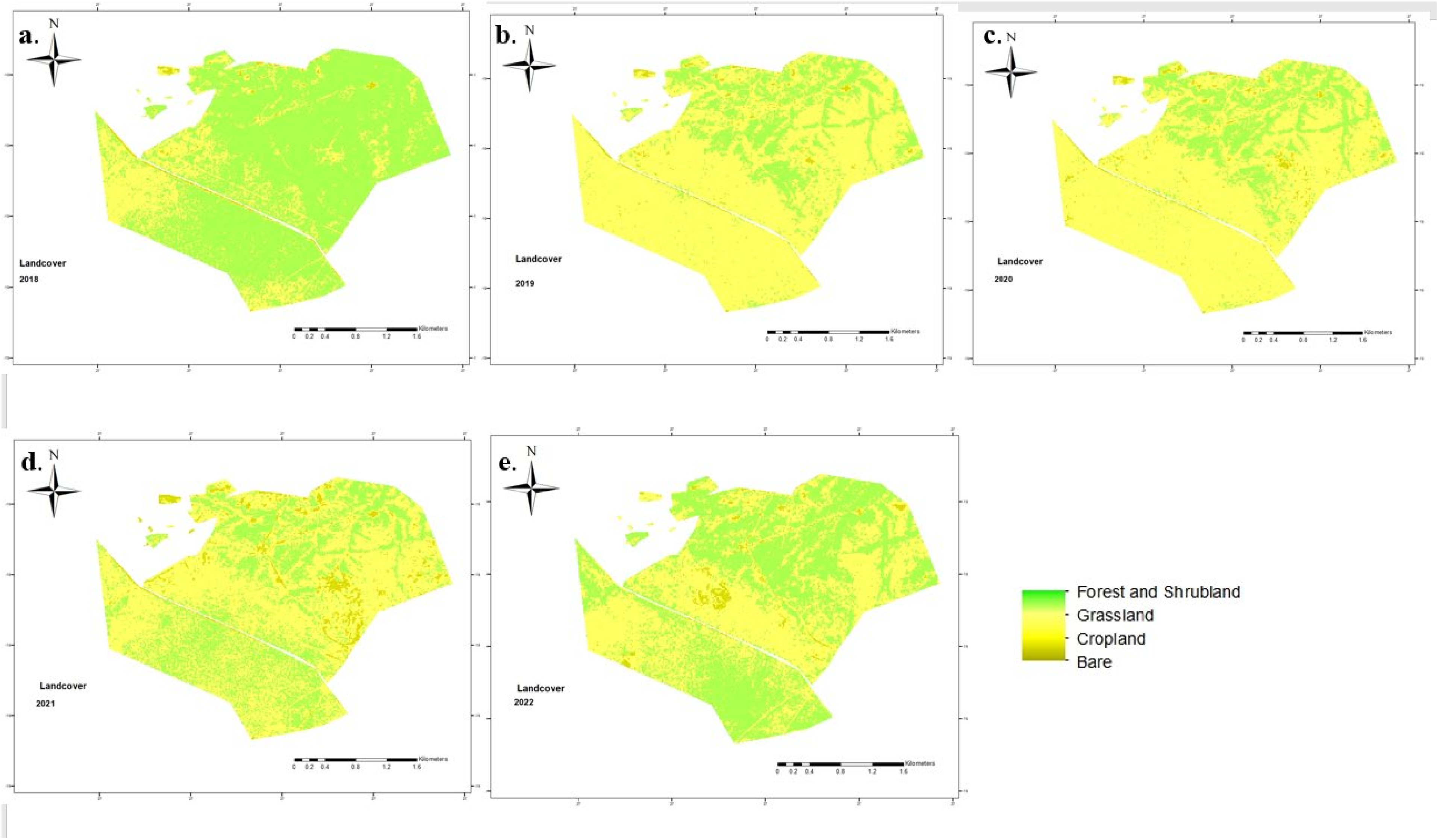


Figure 5 : Spatial distribution of landcover in the study area for (a) 2018, (b) 2019, (c) 2020, (d) 2021, and (e) 2022.

LULC changes (Figure 6) show a decline in the forest and shrubland class from 2018(74.7%)-2020(19.8%), followed by an increase in the same class from the years 2021(30.1%)-2022(46%).

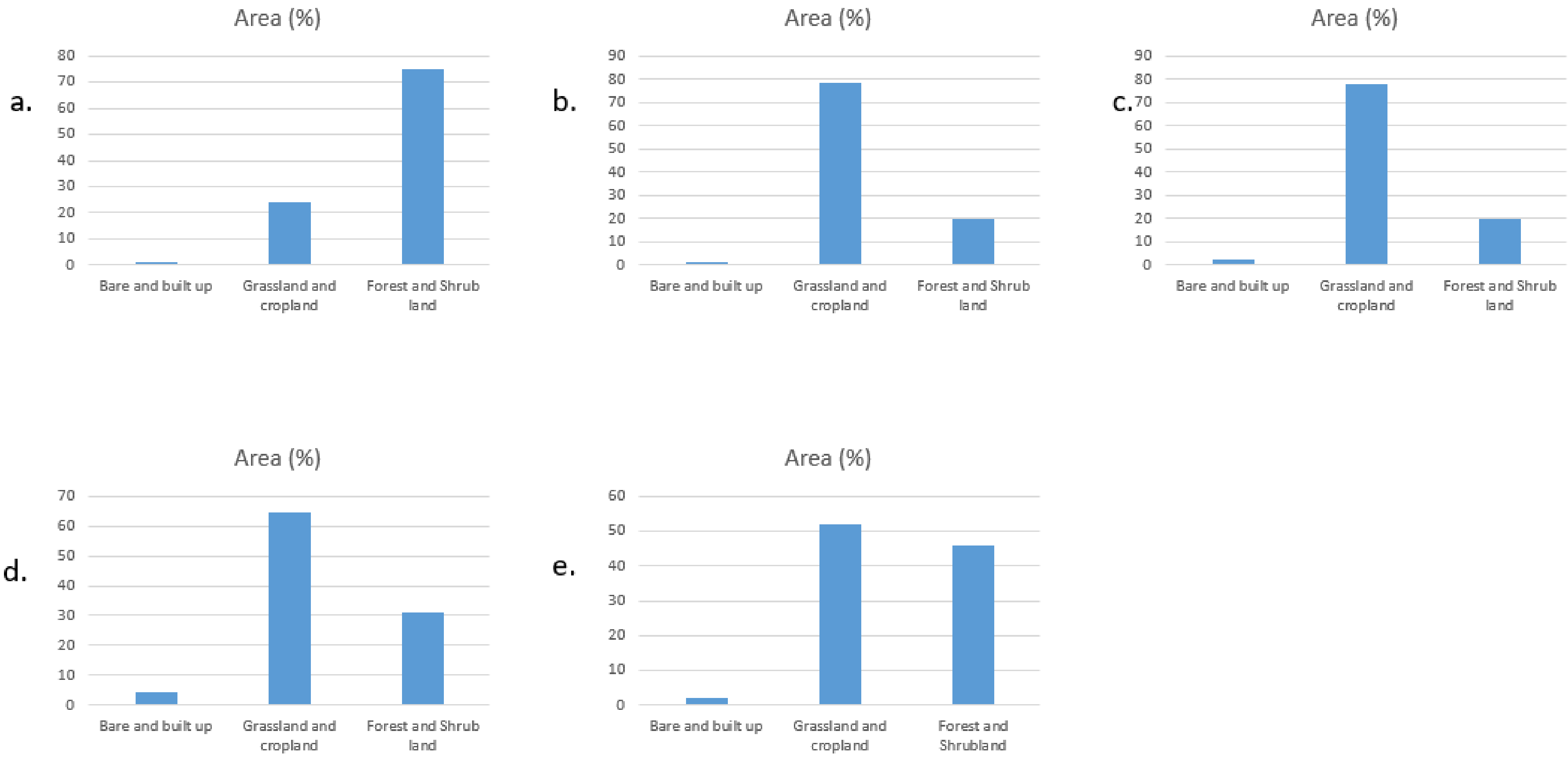


Figure 6 : LULC changes for the years (a) 2018, (b) 2019, (c) 2020, (d)2021 and (e)2022

## 4. Discussion

There has been an evident increase in vegetation cover considering the increase in the land cover class of forest from 30% in 2021 to 46% in 2022. This implies that the activities being implemented by the Soft Foot Alliance have had positive impacts on the environment, specifically in the rejuvenation of the vegetation. The activities include the holistic grazing methods employed, the use of swales, the mulching of fields, the cultivation of cover crops, the use of gabions, erosional reconstruction works and the use of rocket stoves to minimise the reliance of inhabitants on firewood.

A study in Kenya, argues that grazing is a vital ecosystem management tool that can assist in improving rangeland productivity(Lalampaa *et al.*, 2016). However, the effectiveness of grazing is dependent on controlling the timing and frequency of grazing, and generates the same conclusion that holistic grazing improves the sustainable utilization of grazing resources, and enhances livestock production(Lalampaa *et al.*, 2016). In fact, recent studies have produced similar results, showing that holistic grazing can actually increase productivity in rangelands, reverse climate change and double the stocking rate (Hawkins, 2017). Hence, the authors have argued a similar outcome of improvement in the vegetation cover in areas where holistic grazing is being practised. Furthermore, this has helped in the improvement of carbon sequestration considering that land vegetation plays a pivotal role in reducing greenhouse gases and reducing atmospheric $CO_2$ concentrations (Zhang *et al.*, 2023). Furthermore, studies have shown that soil water content (SWC) is also a factor that contributes to vegetation growth and vegetation cover(Rujner *et al.*, 2018).

In other studies, the methods of using grass swales, the mulching of fields, cover crops and gabions, as adopted by the Soft Foot Alliance, have indicated their efficiency in improving the SWC(Rujner *et al.*, 2018). In some cases, the surface water run-off volume has been reduced significantly by as much as 82% (Rujner *et al.*, 2018). Mulching fields have been considered as a suitable technique in improving the organic carbon content of soils (Pang *et al.*, 2023). This in turn improves the soil fertility and maintains the sustainability of crop and vegetation production in semiarid regions (Pang *et al.*, 2023) such as the Hwange National Park. Studies in Ethiopia have also shown that the reliance on firewood as a source of energy for cooking has resulted in excessive forest clearing and the exploitation of the existing forests for fuel (Kebede, Chimdi and Nair, 2015). Thus, the intervention of using rocket stoves should translate into less reliance on firewood and translate into an increase in the vegetation cover over time. Considering that all these activities have the effect of increasing the vegetation biomass over time, the researcher has used remote sensing metrics, that have also been used in other studies, and has also included NDVI and LULC.

Considering that NDVI values close to 1 indicate the presence of healthy vegetation and NDVI values close to 0 indicate the absence of vegetation (Kinyanjui, 2011), similar results were also obtained in the NDVI analysis. NDVI changed from 0.349 in 2018 to 0.346 in 2019; in 2020, NDVI was 0.304; and in 2021, NDVI increased to 0.345. This was a result of the 2018-2019 drought (Frischen *et al.*, 2020) in the period, 2018-2020, that saw a decline in the forest land cover class and NDVI and the subsequent increase in NDVI in 2021 because of the various activities being carried out by the Soft Foot Alliance. This increase in NDVI also translates into an increase in forest carbon sequestration, in the moisture content of the soil and in the forest biomass, as substantiated by results in other studies where correlations are shown between NDVI, carbon sequestration, soil water moisture content and biomass, respectively (Wani *et al.*, 2021).

Figure 7 shows the cattle plot before and after the Soft Foot Alliance activities. This evident increase in the NDVI concurs with other research that shows that the increase in NDVI corresponds with an increase in vegetation cover(Kinyanjui, 2011).

Figure 7: Cattle plot before and cattle plot after the rejuvenation activities

The LULC showed a decline in the forest and shrubland class from 2018 (74.7%) -2020 (19.8%), followed by an increase in the same class from the years 2021(30.1%) -2022 (46%). This is also as a result of the 2018-2019 drought (Frischen *et al.*, 2020). More so, various studies have shown a correlation between drought and the reduction of both forests, shrubland and grassland in relation to drought (Kinyanjui, 2011).

## 5. Conclusion

Clearly evident are the positive results on the activities of the Soft Foot Alliance Trust in the rejuvenation of vegetation in Hwange. For the project objectives to be better assessed and mapped with improved precision by using remote sensing to analyse the changes in carbon, soil moisture and vegetation, it might be necessary for the project to cover more ground in terms of the spatial resolution level. This should be seen in the context that some satellites have a spatial resolution of up to three kilometres (3km); for example, the Soil Moisture Active Passive Sensor - SMAP (Ojha *et al.*, 2021). This would be besides the obvious benefits accruing to the ecosystem, should the project be conducted on a larger scale – preferably at a resolution of 50km$^2$ or more. To quantify the carbon stock of the study area, other methods should be used for remote sensing, for example, −, an aerial survey employing a LiDAR sensor that has been used successfully in numerous other studies.

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