Asian Journal of Research and Review in Agriculture

Volume 6, Issue 1, Page 40-48, 2024; Article no.AJRRA.1525

Spatiotemporal Vegetation Cover Change Analysis Using GIS and Remote Sensing Technologies: The Case of Ganta-Afeshum District, Tigray Region, Northern Ethiopia

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.globalpresshub.com/review-history/1525

Original Research Article

Received: 08/01/2024
Accepted: 12/03/2024
Published: 18/03/2024

ABSTRACT

Biodiversity conservation through enclosure distribution to landless youth plays its own role as a means of environmental conservation, maintaining biodiversity, and as a job opportunity option for youths in the Tigray region. But its impact on vegetation cover change dynamics has not been studied yet at the distributed sites. This study aims to investigate historical and existing spatiotemporal vegetation cover dynamics before and after enclosure distribution to landless youths in some selected kebeles of Ganta-Afeshum. To do so, satellite images of Landsat 5 and Landsat 8 OLI for the years 1992 and 2020 were downloaded, respectively, and satellite image pre-processing activities were done before proceeding to the processing stage. Using Erdas Imagine and ArcGIS Pro software's Normalized Difference Vegetation Index (NDVI), the selected kebeles of Mugulat, Sasun, Hagereselam, and Whudet sites were computed to analyze the vegetation status of each kebele both in 1992 (before distribution) and 2020 (after distribution). Vegetation cover dynamics and change analysis from 1992 to 2020 for these kebeles were also analyzed, quantified, and

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mapped. The result showed that the NDVI values of Mugulat kebele ranged from 0.006 to 0.442 with a mean of 0.121 in 1992 and from 0.008 to 0.390 with a mean value of 0.142 in 2020. The NDVI values of Hagreselam range from 0.013 to 0.306 with a mean of 0.112 in 1992 and 0.008 to 0.317 with a mean value of 0.132 in 2020. In the Sasun kebele, the NDVI value ranges from 0.024 to 0.387 with a mean value of 0.153 in 1992 and from 0.005 to 0.420 with a mean value of 0.156 in 2020. And NDVI values of Wuhdet kebele range from 0.021 to 0.359 with a mean value of 0.110 in 1992, and NDVI ranges from 0.004 to 0.312 with a mean value of 0.127 in the year 2020. Generally, there is an increasing vegetation trend in both Mugulat and Hagreselam kebeles, while there is a decreasing vegetation coverage in both Sasun and Whudet kebeles. Generally, there is an increasing vegetation trend in both Mugulat and Hagreselam kebeles, while there is a decreasing vegetation coverage in both Sasun and Whudet kebeles. GIS and Remote sensing technologies are the most widely applied methods for monitoring, modelling, mapping and measuring natural resources for wise utilization and future planning. This finding serves as a base line of information for policymakers, researchers, and peasant association experts to conduct detailed investigations on vegetation cover analysis and to set future plans for conservation of biodiversity through enclosure distribution to landless youths in the region and is used as a means of biodiversity conservation, job creation and income generation for the landless youths.

Keywords: NDVI; remote sensing; kebeles; vegetation dynamics; change detection; GIS.

1. INTRODUCTION

Different plantation activities and soil and water conservation practices were made to restore the degraded lands of the Tigray region through different governmental, non-governmental, and local communities over the last three decades, which have had a successful restoration history. Most of the interventions in soil and water conservation practices, sustainable land management strategies, afforestation, and re-afforestation programs were implemented in the period from 1991 to 2020 to restore degraded land, conserve natural resources, and maintain biodiversity through an integrated watershed management approach in Tigray [1].

The vegetation is the main component of terrestrial ecosystems on the earth, playing a crucial role in energy exchange and balancing water and biological cycles on the terrestrial surface. It connects the atmosphere, hydrosphere, and biosphere and is vital for reducing greenhouse gases, regulating carbon balance, and maintaining climate stability both at the local and global scale. Vegetation dynamics are especially sensitive to climate change and environmental degradation and, in recent years, have been regarded as the key element in the global changes of terrestrial ecosystems. Because of its wide coverage, remote sensing data has become a common and important data source in the fields of vegetation cover dynamics and vegetation health monitoring. Currently, the normalized difference vegetation index (NDVI) is widely used as a method of vegetation change analysis and refers to the quantitative values of vegetation status through a combination of different spectral remote sensing data. It has been the most widely applied indicator used to represent vegetation status, health, and coverage, among other vegetation indices [2,3,4,5].

It is the most recent remote sensing product and the most popular index used for vegetation condition, vegetation health monitoring, and vegetation cover assessment, calculated with any multispectral sensor with a visible and a near-IR band [6,7].

The NDVI is an effective and efficient index used to analyze large-scale vegetation coverage, vegetation health, phenological changes, and vegetation dynamics. Aboveground vegetation coverage plays a great role in reducing wind erosion, reducing greenhouse gases, preventing the occurrence and large-scale development of sand and dust storms, and minimizing their impact. By utilizing the ratio of band intensities, NDVI mitigates various sources of noise caused by cloud shadows, topographic and solar angle variations, and atmospheric conditions present in the visible red and infrared bands [8,5,9].

The NDVI is an index of plant photosynthetic activity. It is a commonly used and easily calculated satellite image-based proxy for vegetation productivity. The NDVI is a simple numerical indicator that is related to photosynthetically active radiation (PAR) and basically measures the capability of leaves and gives a measure of the vegetative cover on the land surface over wide areas. This index shows a positive correlation with photosynthetic activity, vegetation cover, biomass, and the Leaf Area

Index (LAI). It is computed by subtracting the red reflectance values from the near-infrared and dividing it by the sum of the near-infrared and red bands. The function used is as follows:

1.1 NDVI = (NIR-RED) / (NIR+RED)

Where NIR represents the spectral reflectance in the near infrared band while RED represents the red band. NDVI values range from -1 to 1. A very low value of NDVI corresponds to barren areas of rock, sand, snow, cloud, etc. Moderate values represent shrubs and grasslands, while high values indicate temperate and tropical rainforests. Bare soil is represented with NDVI values that are closest to 0, and water bodies are represented with negative NDVI values [10,11,12].

This research aims to implement the NDVI method to analyze spatio-temporal vegetation cover change dynamics in some selected enclosures sites of Ganta-Afeshum district, Tigray region.

1.2 Objectives

The main/general objective of this research was to analyze spatiotemporal vegetation cover change dynamics before and after enclosures distributed to landless youths between 1992 and 2020 in four selected kebeles of Ganta-afeshum district, Tigray Region, Northern Ethiopia.

2. MATERIALS AND METHODS

2.1 Location of Study Area

This study conducted in the selected kebeles of Ganata-afeshum district, Tigray Region (Fig. 1). Geographically, it founds on 14.09º to 14.37ºN latitudes and 39.21º to 39.55º E longitudes with elevation ranges from 1840 m to 3216m with mean of 2440 m a.s.l. It receives annual rainfall ranges from 553 to 646 mm with mean of 588 mm and temperature ranges from 13.05ºC to 20.07ºc with mean of 16.3ºc. According to the FAO soil textural classification, it has three textural classification of loam soil, sandy loam soil and loamy sand soil, dominantly covered by sandy loam soil and based on the elevation-based agroecology classification, it has three classes, weyna dega, dega, and wurch with dominant class of Dega zone.

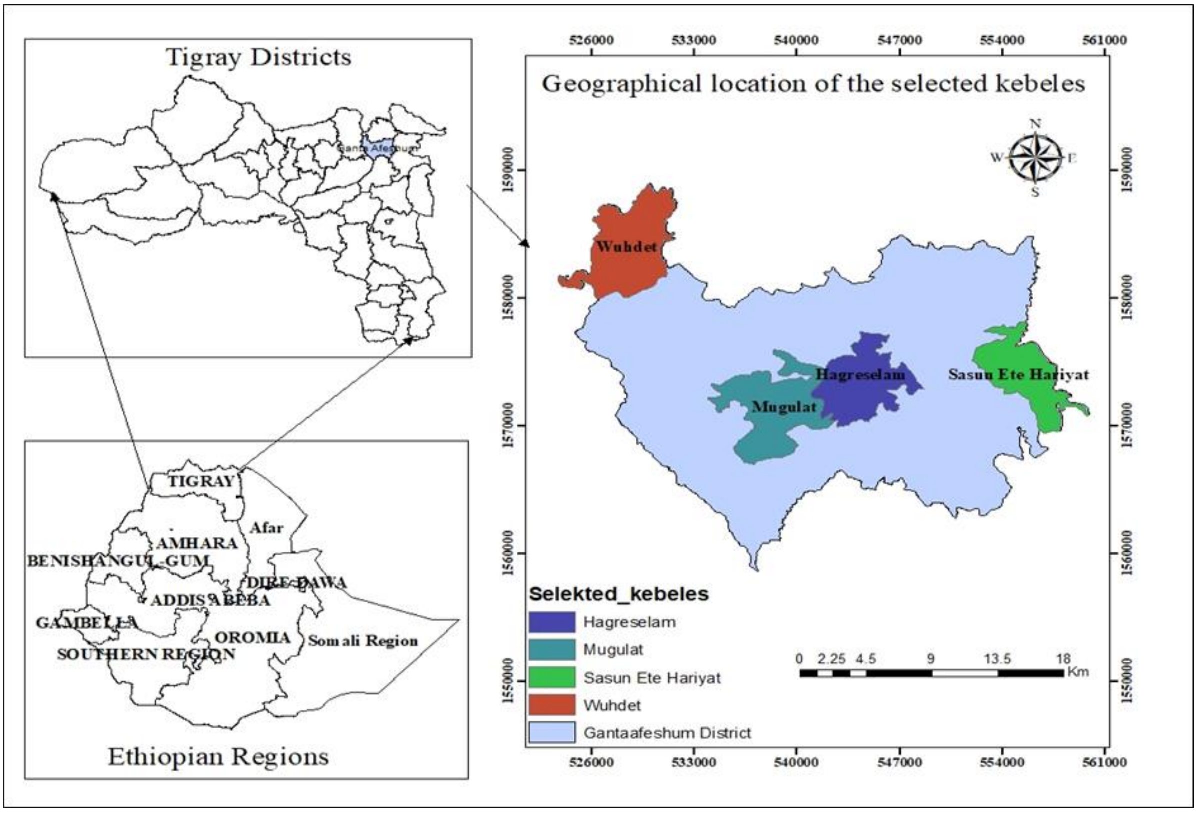

Fig. 1. Geographical locations of the selected kebeles of Ganta-afeshum district

A sample enumeration performed by the CSA in 2001 interviewed 20,704 farmers in this woreda, who held an average of 0.37 hectares of land. Of the 7,710 hectares of private land surveyed, 83.38% was under cultivation, 2.67% pasture, 5.15% fallow, 1.95% in woodland, and 6.86% was devoted to other uses. For the land under cultivation in this woreda, 64% was planted in cereals, 8.9% in pulses, 0.61% in oilseeds, and 13 hectares in vegetables. The total area planted in fruit trees was 646 hectares, while 78 were planted in gesho. 72.00% of the farmers both raised crops and livestock, while 25.63% only grew crops and 2.37% only raised livestock. Land tenure in this woreda is distributed amongst 94.88% owning their land, 3.39% renting, and 1.74% holding their land under other forms of tenure (https://en.wikipedia.org/wiki/Ganta-Afeshum).

2.2 Research Methodology

This study uses Normalized Difference Vegetation Index (NDVI) method to analyze the spatiotemporal vegetation cover change dynamics of the selected kebeles (Hagrselam, Mugulat, Sasun, and Wuhdet) of Ganta-afeshum districts before and after the enclosure's distribution to landless youths between 1992 and 2020. To do this, Satellite images of Landsat 5 and Landsat 8 OLI product with path/row of 169/50, resolution 30*30 meter and with projection WGS-UTM-Zone-37N was downloaded from www.earthexplorer.usgs.gov to compute NDVI values of each selected kebeles. After the satellite images were downloaded, some satellite image pre-processing activities like band composite and reflectance adjustment/removing were done using Erdas Imagine and ArcGIS Pro software's. After performing pre-processing stage, NDVI analysis/computation, NDVI values masking by the selected kebeles, classification using natural breaks used to understand NDVI values change dynamics as low class, moderate class, and high-class values, mapping and area calculation was done using Arc GIS environment version 10.8. The NDVI index is computed by subtracting the red reflectance values from the near-infrared and dividing it by the sum of the near-infrared and red bands. The function used is as follows:

NDVI = (NIR-RED) / (NIR+RED)

Where NIR represents the spectral reflectance in the near infrared band while RED represents the red band. NDVI values range from -1 to 1.

Band combination of 4 (NIR) and 3 (RED) used to compute the NDVI values of selected kebeles using the satellite image of the year 1992 and band 5 (NIR) and 4 (RED) used to compute NDVI using Landsat 8OLI. Area of each NDVI class values was compute using the counts of each class times by the resolution of the raster files and parentage was also computed by classifying area of each class to the total area of the study and times 100. In this case, the NDVI files have a spatial resolution of 30*30 meter.

Lastly but not least, classified NDVI values of each kebeles for the years of 1992 and 2020 was prepared and mapped to understand its spatio-temporal dynamics both in time and in space. Each classified NDVI values were also computed its areal coverage in three NDVI class breaks/values of as low class, Moderate-class and High-class values of each kebele in 1992 and 2020.

2.3 Materials and Software's Used

In this research, the main materials and software's used were

- Landsat 5, acquired at December 14, 1992 and Landsat 8, acquired at December 27, 2020 for calculation of NDVI values
- GPS tool to identify coordinate of the study area and to identify path/row
- Erdas Imagine for computing Band stacking/composite and NDVI calculation
- ArcGIS Pro for Satellite image pre-processing analysis, like Reflectance removing
- ArcGIS 10.8 Environment for NDVI classification, Area calculation and Mapping
- Ms-Office 2019 for reporting and presentation of results
- Laptop computer to perform all these mentioned activities

3. RESULTS AND DISCUSSION

The Normalized Difference Vegetation Index (NDVI) is an effective quantitative remote sensing monitoring index used to analyze large-scale vegetation coverage, phenological changes, and vegetation dynamics. In general, in the Ganta-afeshum district, there is a decreasing trend in spatiotemporal vegetation coverage/trend from 1992 to 2020 due to different reasons. Based on the satellite images of 1992 and 2020, the NDVI analysis of each kebele was analyzed as follows:

3.1 Spatiotemporal Vegetation Cover Change Dynamics of SASUN Kebele in 1992 and 2020

The result showed that, Spatial distribution of NDVI value of Sasun kebele ranges from 0.024 to 0.387 with mean value of 0.153 in 1992 and NDVI value ranges from 0.005 to 0.420 with mean value of 0.156 in the year 2020. Based on the NDVI class values (Fig. 2, Table 1), there is shifting of 4% in the low-class value from 1992 to 2020, which means the vegetation coverage was decreasing in 4%, but increasing in 2% within the high class from 1992 to 2020. In the moderate class there is changing in -6% which means there is decreasing trend from 1992 to 2020. Generally, there is declining/decreasing of vegetation coverage in the sasun kebele from 1992 to 2020.

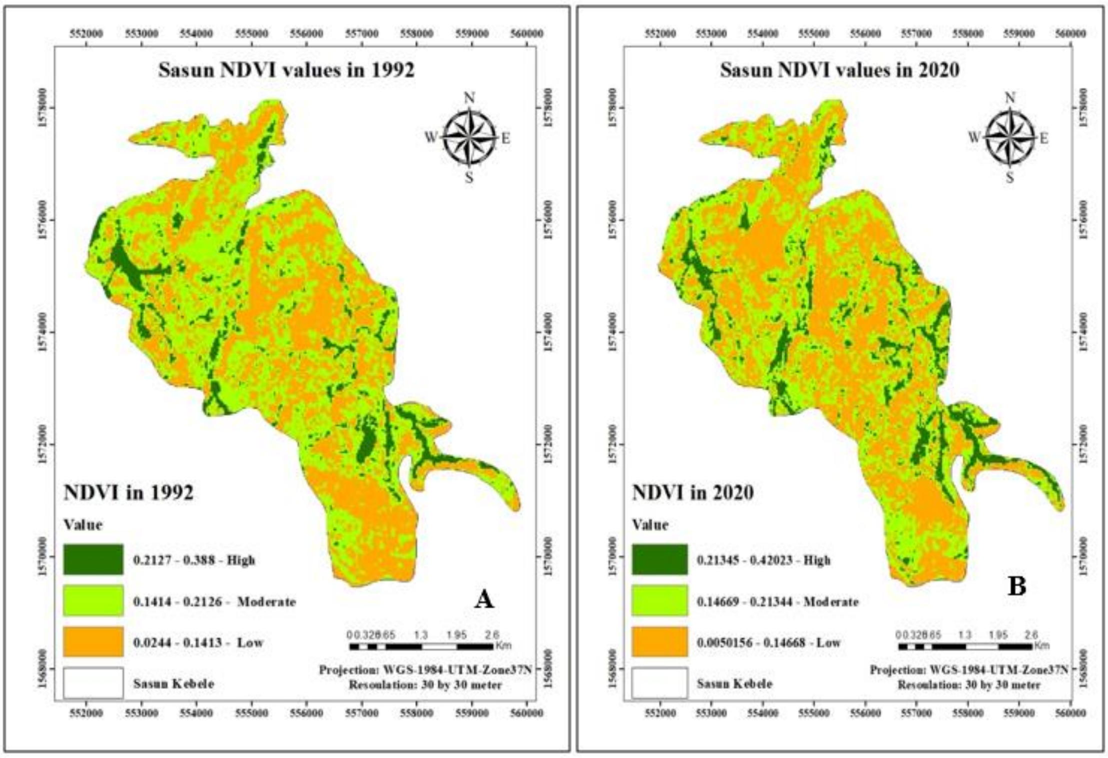

Fig. 2. Spatiotemporal distribution NDVI class values of Sasun kebele in 1992(A) and 2020(B)

Table 1. NDVI class values and their areal coverage of Sasun Kebele in 1992 and 2020

ID	NDVI_1992	Area(ha)	Area (%)	NDVI_2020	Area(ha)	Area(%)	Change (1992 - 2020)
1	Low class	1155.33	44	Low class	1270.98	48	**+4**
2	Moderate class	1243.62	47	Moderate class	1089.81	41	**-6**
3	High class	240.21	9	High class	278.37	11	**+2**

Table 2. NDVI class values and their areal coverage of Mugulat Kebele in 1992 and 2020

ID	NDVI_1992	Area(ha)	Area (%)	NDVI_2020	Area(ha)	Area (%)	Change (1992 - 2020)
1	Low class	1599	44	Low class	1306.89	36	**-8**
2	Moderate class	1721	47	Moderate class	1780.29	49	**+2**
3	High class	339	9	High class	571.41	16	**+7**

3.2 Spatiotemporal Vegetation Cover Change Dynamics of Mugulat Kebele in 1992 and 2020

The result showed that, Spatial distribution of NDVI value of Mugulat kebele ranges from 0.006 to 0.442 with mean value of 0.121 in 1992 and NDVI value ranges from 0.008 to 0.390 with mean value of 0.142 in the year 2020. Based on the NDVI class values (Fig. 3, Table 2), there is shifting of -8% in the low-class value from 1992 to 2020, which means the vegetation coverage was increasing in 8% from 1992 to 2020. And also, there is positive change trend on the moderate class values with +2% and high-class values with +7% from the year 1992 to 2020, which means that there is increasing vegetation coverage from the year 1992 to 2020. Generally, there is an increasing vegetation coverage trend was observed in the Mugulat kebele from the year 1992 to 2020 both in time and space due to internal and external drivers of the community.

3.3 Spatiotemporal Vegetation Cover Change Dynamics of Hagreselam Kebele in 1992 and 2020

The result showed that, Spatial distribution of NDVI value of Hagreselam kebele ranges from 0.013 to 0.306 with mean value of 0.112 in 1992 and NDVI value ranges from 0.008 to 0.317 with mean value of 0.132 in the year 2020. Based on the NDVI class values (Fig. 4, Table 3), there is shifting of -12% in the low-class value from 1992 to 2020, which means the vegetation coverage was increasing in 12% from 1992 to 2020, and also, there is an increasing value with +2% within the Moderate class from the years of 1992 to 2020, and an increasing value of +10% in the High-class values from 1992 to 2020 in the Hagreselam kebele. In general, there is dramatic positive increment/change in vegetation coverage was observed in the Hagreselam kebele between the years of 1992 to 2020.

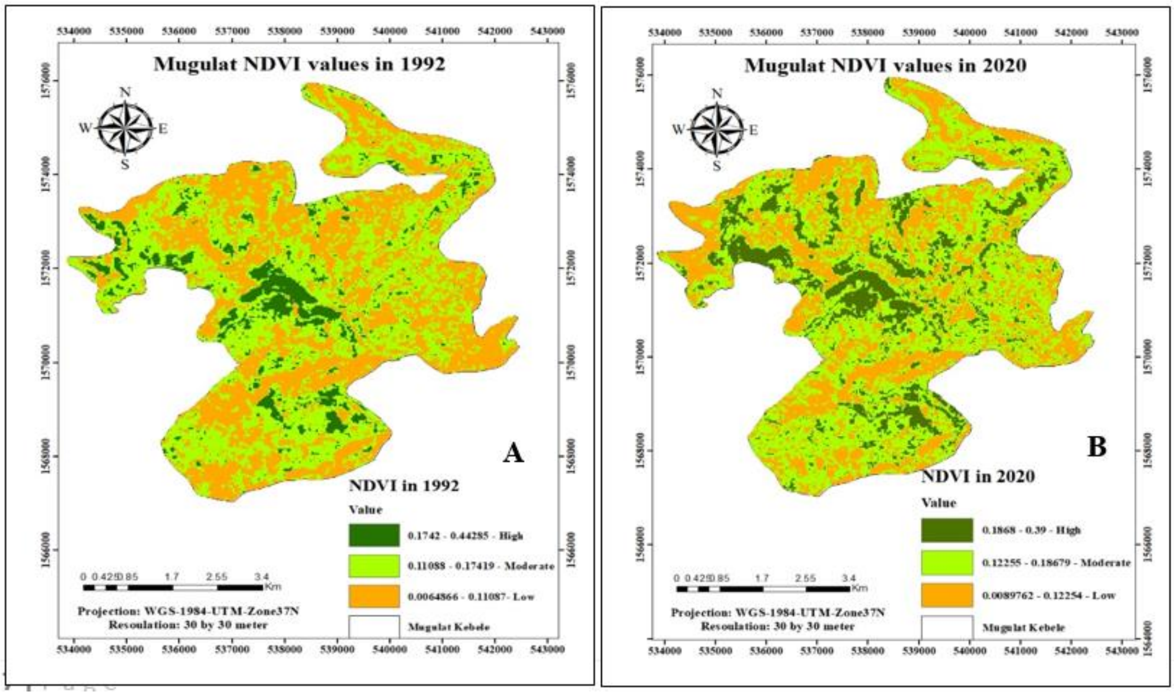

Fig. 3. Spatiotemporal distribution NDVI class values of Mugulat kebele in 1992(A) and 2020(B)

Table 3. NDVI class values and their areal coverage of Hagreselam Kebele in 1992 and 2020

ID	NDVI_1992	Area(ha)	Area (%)	NDVI_2020	Area(ha)	Area (%)	Change in % (1992 - 2020)
1	Low class	1405.53	48	Low class	1046	36	-12
2	Moderate class	1200.87	41	Moderate class	1271	43	+2
3	High class	337.41	11	High class	626	21	+10

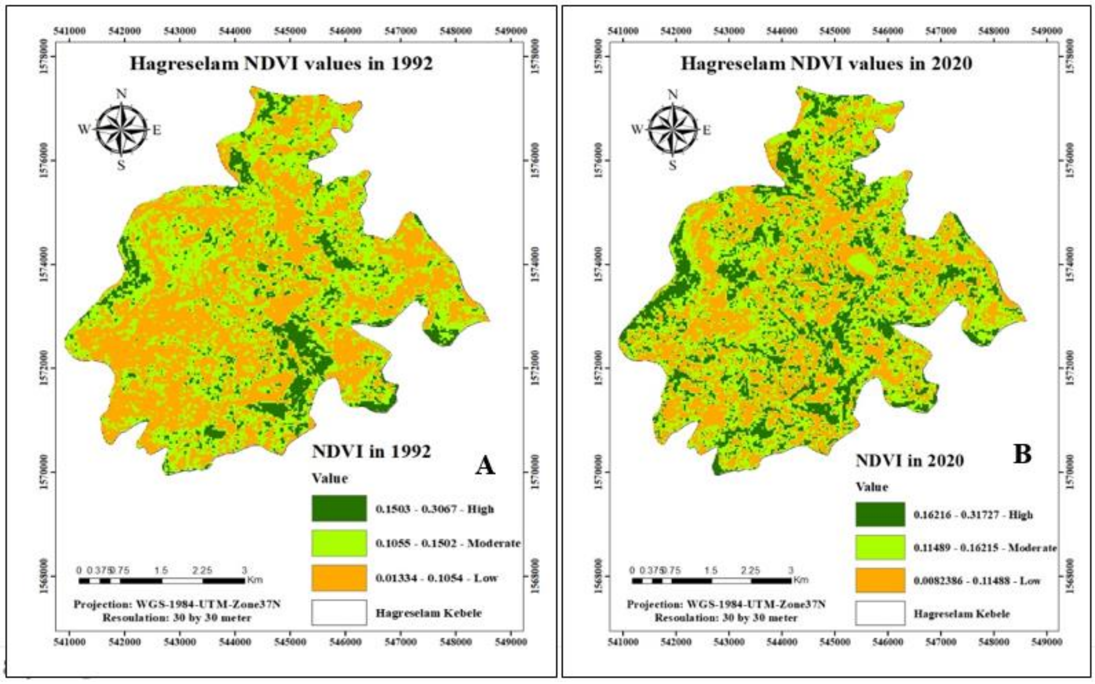

Fig. 4. Spatiotemporal distribution NDVI class values of Hagreselam kebele in 1992(A) and 2020(B)

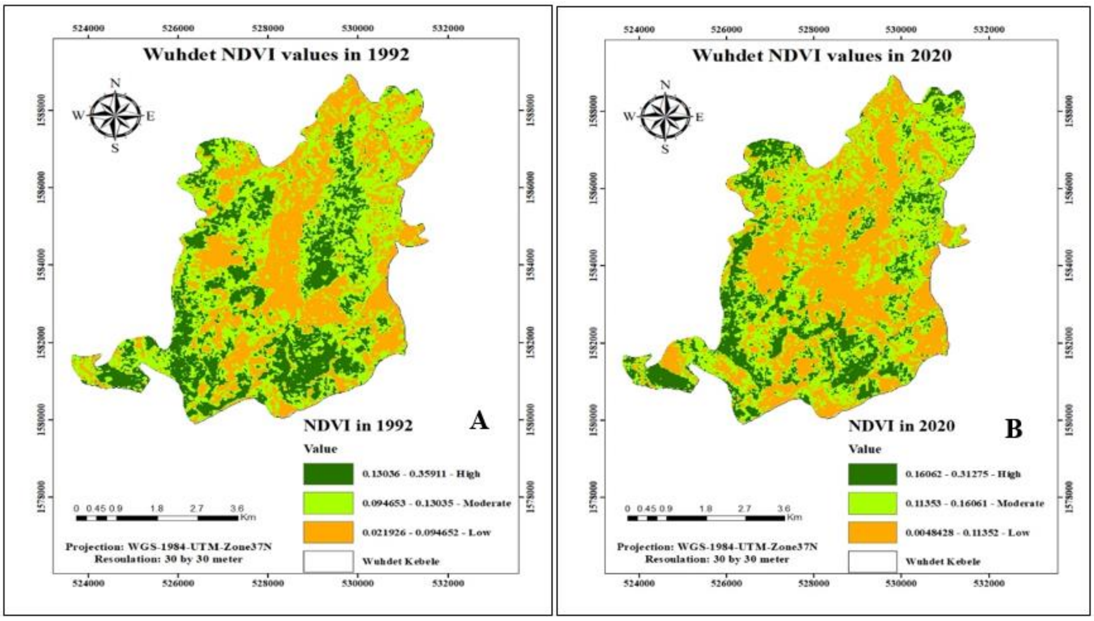

Fig. 5. Spatiotemporal distribution NDVI class values of Wuhdet kebele in 1992(A) and 2020(B)

Table 4. NDVI class values and their areal coverage of Wuhdet Kebele in 1992 and 2020

ID	NDVI_1992	Area(ha)	Area (%)	NDVI_2020	Area(ha)	Area (%)	Change in % (1992 - 2020)
1	Low class	1243	33	Low class	1524	41	+7
2	Moderate class	1588	42	Moderate class	1489	40	-2
3	High class	911	24	High class	730	19	-5

3.4 Spatiotemporal Vegetation Cover Change Dynamics of Wuhdet Kebele in 1992 and 2020

The result showed that, Spatial distribution of NDVI value of Wuhdet kebele ranges from 0.021 to 0.359 with mean value of 0.110 in 1992 and NDVI value ranges from 0.004 to 0.312 with mean value of 0.127 in the year 2020. Based on the NDVI class values (Fig. 5, Table 4), there is shifting of +7% in the low-class value from 1992 to 2020, which means the vegetation coverage was decreasing in 7% from 1992 to 2020, and also, there is negative shifting of vegetation cover in -2% in the moderate class values from 1992 to 2020. There is also dramatic negative shift on the high-class value of -5% from 1992 to 2020 in the Wuhdet kebele. Based on the vegetation coverage change detection/trend, there is a decreasing vegetation coverage between the years of 1992 to 2020 in the Wuhdet kebele.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

Remote sensing data has become a common, effective and vitally important data source in the field of vegetation dynamics analysis, modelling and quantification used to monitor spatiotemporal vegetation coverage, vegetation health, and change dynamics in a given area.

GIS and Remote Sensing technologies are the best and widely accepted decision-making tools for monitoring, modelling, mapping, and quantification of natural resources for wise utilization, proper planning and preparing monitoring strategic conservation plans in a given area.

Spectral band combination of 4 and 3 were used to compute NDVI values of the year 1992 and band combination of 5 and also used to drive NDVI values of the kebeles for the year 2020.

The recent technologies of GIS and Remote Sensing plays a great role in quantification, mapping and change detection analysis of vegetation cover in a given area for monitoring the status and to identify the driving factors for vegetation cover change in a given area.

According, the investigation of spatiotemporal vegetation dynamics of the selected kebeles using the NDVI index, there is dramatic positive increment on vegetation coverage from 1992 to 2020 in both kebele Mugulat and Hagreselam kebeles, whereas there is a negative shift/decrease in vegetation coverage from 1992 to 2020 in both Sasun and Wuhdet kebeles.

Distribution of enclosures to landless youth's is important as a means of biodiversity conservation, Income generation, and Job creation in a given area and helps in preparing strategic plan for wise utilization and conservation of forest resources in sustainable manner.

4.2 Recommendations

- GIS and Remote Sensing technologies are best decision-making tools for monitoring, mapping, modelling and quantification of natural resources from point location to large scale areas, therefore in such investigation, they are effective and efficient methods that should be considered to save time, cost and effort.
- This finding used as a baseline information to conduct detail and large-scale investigation on vegetation cover change analysis by researchers, regional experts, policy makers in the region.
- The main determinant factors for vegetation cover shifting should be identified and monitored to sustain the vegetation cover in a good condition.
- The NDVI values of each kebele computed should be verified through ground truth data.
- This method Should be scaled up in a region wise to monitor the vegetation cover change through different human made and anthropogenic activities.

ACKNOWLEDGEMENTS

We would like to thank the Tigray Agricultural Research Institute, the staff, and volunteers who contributed a lot to implement this research work within the Tigray region.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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