Impacts of Integrated Watershed Management Interventions on Land Use/Land Cover of Yesir Watershed in Northwestern Ethiopia

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Abstract: Since 2002, numerous sustainable land management (SLM) interventions have been implemented in Ethiopia, such as agroforestry, area closure, forage development, gully rehabilitation, and conservation agriculture. In addition, watershed-based developments contributed comprehensively to a better use of existing natural resources. This study determined the impact of Integrated Watershed Management (IWM) on land use/land cover for the Yesir watershed in Northern Ethiopia. Supervised image classification algorithms were applied to a time series of Landsat 5 (2002) and Landsat 8 (2013 and 2022) images to produce land use/land cover maps. A Geographic Information System was applied to analyze and map changes in land use/land cover for settlements, agricultural land, grazing land, and land covered with other vegetation. In focus group discussions, the time series maps were analyzed and compared with the integrated watershed management practices to analyze their impacts. The results document that integrated watershed management practices have contributed to a significant change in land use/land cover in the study area over the past 20 years. The quantitative analysis of land use/land cover between the years 2002 and 2022 only revealed a downward trend in agricultural land. Considering the value of the Normalized Difference Vegetation Index (NDVI) as a biophysical feature for the increase of green mass, this indicator also documents an improvement in land use/land cover with regard to sustainable land management and consequently poverty alleviation.

Keywords: land use/land cover; maximum likelihood; NDVI; sustainable land management practice; integrated watershed management practice; Yesir watershed

1. Introduction

Land is essential for human survival due to its various economic, social, and ecological roles. It underpins all terrestrial ecosystem services and is crucial for a range of functions [1,2]. Continuous changes in land use/land cover are driven by societal development and environmental factors [3]. Assessing changes in land use/land cover and understanding their trends are crucial for strategic planning and the effective management of natural resources [4]. In order to manage the sustainability of natural resources, investigating land use/land cover modifications is important, as are demarcating and mapping land covers [5].

Professionals usually use the term land cover/land use: land cover refers to the physical and biological cover of the land's surface [6–10], whereas land use refers to how humans utilize and manage land for various purposes, involving the manipulation and alteration of its natural state [11]. On the other hand, land conversion involves changing the land's use as a result of human activities and interventions [6,12]. It includes industrial zone establishment, infrastructure construction, settlement extensions, and fishing [13]. Land use/land cover changes are major threats to natural resources, particularly endangering

wetlands, forests, and various fauna [14]. Major changes in land use/land cover are primarily caused by anthropogenic factors [15]. This often leads to soil erosion and land degradation [16]. Land degradation due to changes in land use/land cover has become a significant global issue [1]. According to [17], land degradation has been exacerbated by overgrazing, intensive agriculture, drought, heavy and unpredictable rainfall, flooding, deforestation, and other factors.

Ethiopia is one of the most natural resource-rich countries in sub-Saharan Africa [18]. Yet, Ethiopia has been experiencing centuries-long resource loss [19]. In accordance with this, refs. [16,20] stated that the loss of land resources and their productivity is Ethiopia's most critical issue, and this problem is expected to worsen in the future due to ongoing population growth. The main causes of land degradation in Ethiopia include low vegetation cover, severe soil erosion, rapid population increase, deforestation, and imbalanced agricultural and livestock production. To tackle some of these pressing challenges, various governmental and non-governmental organizations have initiated Integrated Watershed Management (IWM) programs since the 1970s [20,21]. The goals of rehabilitating degraded lands, preserving soil and water systems, meeting increasing food and fiber demands, and maintaining ecosystem services have led to changes in watershed management practices, including modifications in land use/land cover and vegetation cover [22]. Watershed management is the process of developing and implementing a plan of action that involves manipulating the natural system of a watershed to achieve the intended goals [23]. Since the early 1970s, Ethiopia has used an integrated watershed program as a rural development strategy to implement a variety of activities that aid in poverty alleviation [24]. Since the early 1970s, several watersheds, including Yesir, have received a significant quantity of community labor mobilization, as well as financial support for watershed management interventions, from both government and non-government organizations. Despite prior intervention strategies, SLM Programs, in collaboration with relevant governmental bodies, have worked hard in the study area since 2008 to improve the watershed's natural resources and the community's standard of living. Despite the expanding significance of watershed management, there have not been many studies on how it affects biophysical resource changes [21].

Watershed management's socioeconomic effects have been assessed using farm household assets, health, income, employment opportunities, income diversification, education, and food security [25]. Additionally, biophysical changes in the land use/land cover of the watershed are utilized to evaluate the impact of watershed management practices [26]. Ref. [27] claims that the Sheka watershed's IWM program has improved soil fertility, cattle productivity, and apiculture following watershed treatment, which had a major positive influence on crop yield, water resources, rural livelihoods, and ecosystems. Similar findings were determined in the Yesir sub-watershed, where after watershed management measures, household income increased by 51.4% and assets increased by 37.5%.

Integrated watershed management not only improves vegetation cover but also reduces sheet and rill soil loss rates by about 89% from all land use/land cover classes [28]. Moreover, watershed management practices in the conserved areas have increased vegetation cover (greenness) and reduced the speed of surface runoff and the impact of raindrops. In the Ethiopian highlands, watershed management is focused not only on enhancing and conserving the natural and ecological environment but also on supporting the sustainable development of Ethiopia's agricultural sector and overall economy. However, the effects of these practices on changes in land use, land cover, and vegetation greenness have not been extensively assessed or studied through the use of geospatial technologies.

Although development activities in the Yesir watershed have been ongoing for the last 14 years, no scientific research has been conducted to assess the watershed's biophysical changes. The aim of this study is to assess whether and how the comprehensive interventions have a positive impact on the biophysical characteristics of the watershed. The need for this study is underlined by the fact that Ethiopia's economy is largely based on agriculture and driven by its natural resources. Investigations have to be conducted to

evaluate the efforts of sustainable land management intervention by applying satellite image trend analysis [22,29]. The authors applied GIS and remote sensing techniques to assess the long-term impact of integrated watershed management practices on land use/land cover and landscape greenness in the Yesir watershed.

2. Materials and Methods

2.1. Study Area

The research was carried out in the Yesir micro-watershed (Figure 1), situated in the Amhara region of Ethiopia. The study area lies 149 km west of Bahir Dar and 410 km northwest of Addis Abeba. Geographically, it is located between latitudes $10°36'4.45''$ and $10°47'54.66''$ N and longitudes $37°2'27.98''$ and $37°8'5.8''$ E, with an elevation between 1785 and 2640 m above sea level (m.a.s.l). The watershed has a total area of 11,169 hectares and consists of 22 small catchment areas. Most of this area is very productive for agriculture, with numerous irrigable land and surface water resources. Politically, there are nine administrative kebeles (municipalities) in the watershed, with 5177 households. The watershed has an annual mean precipitation of 1269 mm, with a lowest and highest temperature of 15 °C and 18 °C [30]. Eutric Vertisols and Haplic Alisols, which cover 1281 ha and 9888 ha, respectively, are the two main soil types found in the watershed. Watershed management was haphazardly introduced in the early 1990s, with no pertinent development strategies in place at the time. Watershed management was implemented using SLM practices in 2008. A total of 19 community watersheds were established. Since then, all available watershed management strategies have been implemented in practice [31].

2.2. Methods of Data Collection and Analysis

2.2.1. Data Sources

The study employed time series spatial data to examine land use/land cover before and after the implementation of IWM in the study area. Satellite images from the Landsat 5 Thematic Mapper™ from 2002 and Landsat 8 Operational Land Images (OLI) from 2013 and 2022 were used to produce the land use/land cover maps. The year 2002 was selected to be a reference year before the watershed intervention. 2013 was assumed as the optimal time to evaluate the first impacts of the watershed intervention launched in 2008. 2022 was selected to obtain the current status of the impact of watershed implementation on land use/land cover.

The multi-temporal Landsat satellite images of the study area were freely downloaded from the United States Geological Survey (USGS) Earth Explorer portal for all three time periods (https://earthexplorer.usgs.gov/) (accessed on 10 January 2023). Datasets taken in the dry season (January to February) were selected to obtain cloud-free images, as well as to record land surface reflectance values that were not influenced by agricultural practice [32]. Specifications of the datasets used for the investigations are summarized in Table 1.

Table 1. Explanation of Landsat images and sources used for this study.

Landsat Series	Acquisition Date	Sensor	Bands Used	Path/Row	Spatial Resolution (m)	Cloud Cover (%)
Landsat 5	2002-01-15	TM	1,2,3,4,5,7	170/053	30 × 30	0
Landsat 8	2013-01-29	OLI	2,3,4,5,7	170/053	30 × 30	0
Landsat 8	2022-02-23	OLI	2,3,4,5,7	170/053	30 × 30	0

2.2.2. Data Collection

The classification scheme (that is, agricultural land, grazing land, settlement, and vegetation) for the study area was developed based on the researchers' prior knowledge of the study area and a brief reconnaissance with additional information from the Burie Zurie District Agricultural Office (Table 2).
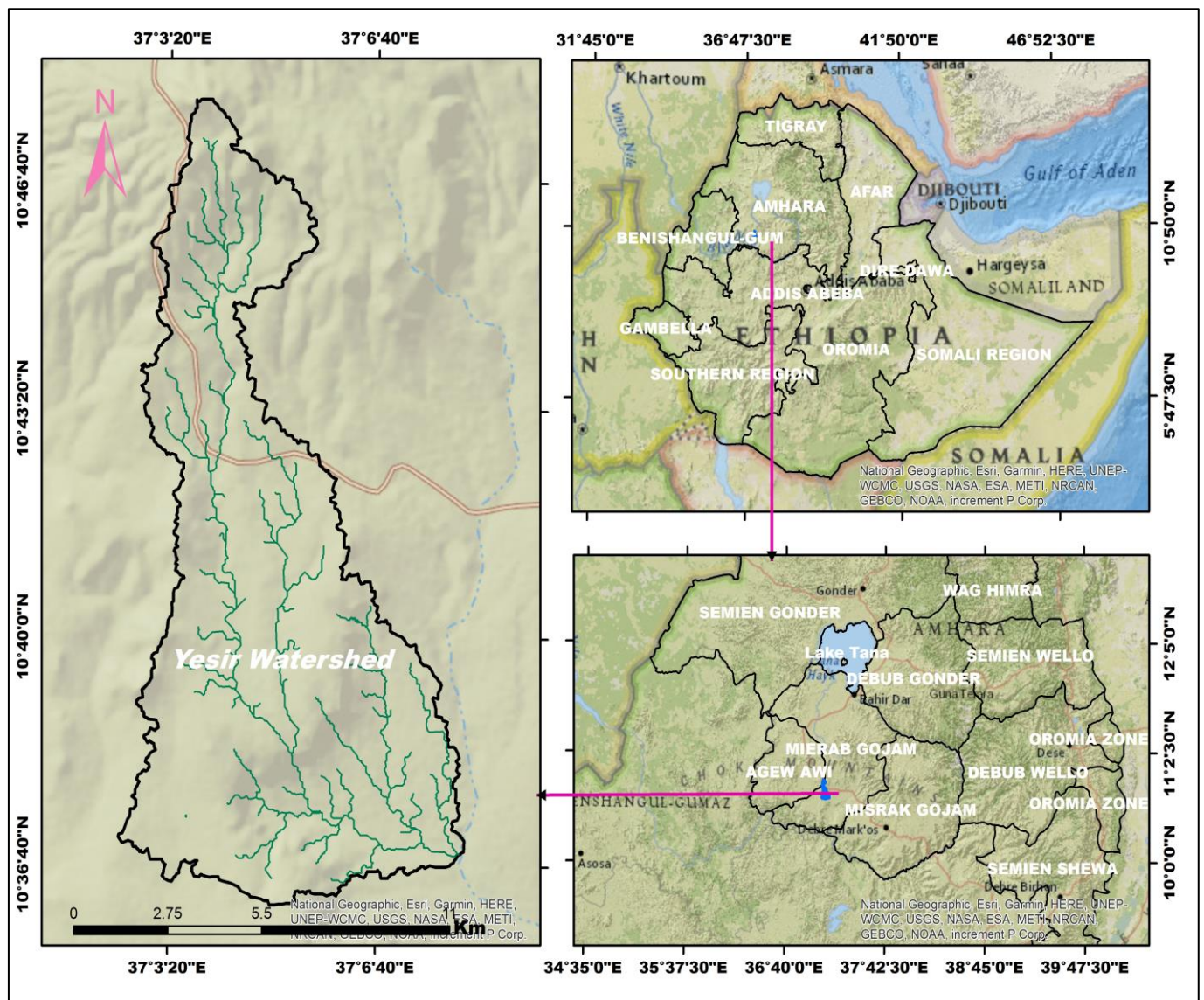
Figure 1. Map of study area.

Table 2. Land use/land cover classification scheme and description of land use/land cover types applied in the study.

No.	Land Use/Cover Type	Brief Description of Each Land Use/Cover Type
1	Agricultural Land	Rain-fed agricultural land, both small- and large-scale, is cultivated at least once per year. This category includes areas currently covered by crops, land prepared for crop production, and fallow plots.
2	Grazing land	Land covered with natural grass or dominated by grass, including communal grazing areas and bare land that becomes grass-covered seasonally.
3	Settlement	These areas primarily consist of scattered rural settlements and rural institutions, such as schools and clinics.
4	Vegetation	Trees, shrubs, semi-natural vegetation, and deciduous forest.

In this classification, water was not considered a land cover classification type because of the limited extent of water bodies in the area. The existence of just a few rivers and streams suggests that water constitutes a tiny percentage of the landscape, which may not justify its classification as a separate category. Moreover, if these rivers and streams are

seasonal or subject to drying up, they may not always be recognizable as water features in satellite images. Additionally, if the satellite imagery was captured during a dry season, the water levels in these rivers and streams might have been too low to be detected.

Representative training sites for image classification and validation (accuracy assessment) were collected for each land use/land cover class.

For 2022, ground reference point data were collected for training and validation purposes using a hand-held GNSS (Garmin 72 instrument) and high-spatial-resolution Google Earth imagery. Ground truth assessments were conducted in the months of January and February (according to the date of image acquisition). The sample locations were selected based on their accessibility or convenience. To ensure representative sampling, a total of 505 samples were collected using the random sampling technique for the land use/land cover classification of 2022 as training samples, of which 80% (404 Ground Truth Points (GTPs)) were used for image classification and 20% (101 GTPs) for validation.

A visual interpretation of the Google Earth time lapse using pure pixels of 30 m × 30 m for each land use/land cover type was used to collect reference data for 2002 and 2013. A total of 400 GTPs were collected for 2002 and 2013, of which 80% (320 GTPs) were used for image classification and 20% (80 GTPs) for validation. As reference data, historical black and white aerial photos were combined with raw satellite imaging data via visual interpretation to collect sample points for classifying Landsat images from 2002 and 2013. Along with training data collection, transect walks were used to conduct site observations, which were used to refine training sites and verify classified images. Considering the time lag between the acquisition date of satellite images and the assessment of reference data (Google Earth data and field survey), the reliability of reference data was verified in group discussions and interviews with farmers. In addition, Focus Group Discussions (FGDs) and Key Informant Interviews (KIIs) were carried out to complement the quantitative changes in land use/land cover analysis.

Representative FGD participants from three community watersheds (Chenetally, Debelekant, and Zagra) were purposely selected from the upper, middle, and downstream sections of the Yesir watershed. Consequently, the impacts of watershed intervention were examined using information gathered through 46 key informant interviews. In total, nine group discussions (three in each kebele) were conducted, involving government officials, local communities, and non-governmental organizations active in the study area, with each discussion group comprising 11 to 13 participants. The study also included seven FGDs, each consisting of five participants from both genders. Each FGD session lasted two hours. Secondary data sources, including official reports, published research, and public statistics, were also utilized to document the dynamics of land use and land cover in the study area.

The key informants from each community watershed were selected considering their age (60 and above), their living in the study area for more than 30 years, their readiness to participate in the interview, and their involvement as either a watershed committee member and/or as a kebele leader. Because of their expertise in watershed intervention and their knowledge of the dynamics of land use/cover during the investigation period, mainly government representatives, regional experts from the Burie Zuria District Agricultural, Environmental Protection Office, and land administration officers participated in KIIs.

2.2.3. Data Processing and Analysis

Image pre-processing techniques were applied to correct image distortions, remove noise, and improve image data interpretability. In particular, appropriate band selections, atmospheric and geometric corrections, sub-setting productions, layer stacking, and image enhancements were applied [33–35]. L5 TM images were registered to their corresponding Landsat 8 OLI image using automated image-to-image registration approaches and a set of ground truth points (GTPs) to combine time series image data sets to enable change detection at the pixel level.

Image classification is considered an important process to recognize the geographical features in digital remotely sensed images [21,36]. In this study, land use/land cover

classifications for the three years (2002, 2013, and 2022) were carried out by applying supervised pixel-based classification with a maximum likelihood classifier (MLC). Training pixels were used to identify pixels based on the known features of each land use/land cover type [37–39]. The MCL determines the likelihood that a given pixel belongs to a specific class, which assumes that the statistics for each class in each band are normally distributed [38,40].

To enhance classification accuracy and minimize errors, post-classification enhancement was applied. Smoothing algorithms were used by moving a window over the classified dataset to identify the most common class within the window. To prevent over-smoothing in the classification image, the filter window was restricted to a size of 7 pixels by 7 pixels [41].

Land use/land cover maps generated from remotely sensed data have inherent errors. These inaccuracies arise from various factors, including the classification techniques used and the methods by which satellite data are captured [42]. To assess the accuracy of the classified land use/land cover map, ground verification was performed. To perform an accuracy assessment, a set of points was generated directly from the ground and a Google Earth map (high-spatial resolution), and the positions of these points were compared to the classified land use/land cover maps [43]. In order to assess the dependability of the information extracted from classification, it is crucial to assess the accuracy of the classified images [44]. The classification's accuracy was evaluated using randomly selected reference sample points. Overall accuracies, kappa coefficients, user and producer accuracies, and an error matrix of the land use/land cover classification were calculated, and an error matrix of the land use/land cover classification was generated [45]. The accuracy of the classification results was tested using reference data for validation.

Land use/land cover classifications were used to determine the change in land use/land cover classes during the investigation period. Using cross-tabulation [46–48], changes in areas between the different classes were determined and mapped for three periods, namely for changes between the years 2002 and 2013, between 2013 and 2022, and between 2002 and 2022. Annual land use/land cover change has been assessed [15,49] and percentage changes for each land use/land cover type over time were calculated [47,50–53]. The study area's total change and net changes, as well as specific class gains and losses, were evaluated [48,54].

2.2.4. Normalized Difference Vegetation Index (NDVI)

Various vegetation indices were developed based on the reflectance pattern of vegetation to explain the healthiness, vegetation cover, and biomass condition of vegetation.

In this study, NDVI values of the different dates were applied to classify land use/land cover and its changes during the investigation period. The NDVI is the most commonly used index for monitoring forest vegetation biomass [55] and one of the most important means for vegetation monitoring studies [56] as green plants absorb photosynthetically active radiation (PAR) in the electromagnetic spectrum (EMS), which they use as a source of energy in the photosynthesis process while reflecting energy in near-infrared (NIR) wavelengths [57]. Hence, live green plants appear relatively dark in visible wavelengths (red) and relatively bright in near-infrared wavelengths. These interactions of solar radiation with live green plants are the basis for calculating the NDVI [58].

The NDVI is calculated as follows:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

where, NDVI = normalized difference vegetation index, NIR = reflection from the near-infrared wavelength region, RED = reflection from the red wavelength region.

In terms of vegetation, NDVI values range from 0 to +1. Due to their relatively high reflectance in the NIR range and low reflectance in the red range, healthy vegetation yields have high positive NDVI values. For this study, NDVI values according to [21] were

classified into three categories: "no plant cover" (degraded land, bare soil, and barren areas of soil and rock), "weak plants" (grassland and shrub land), and "healthy plants" (natural forest trees).
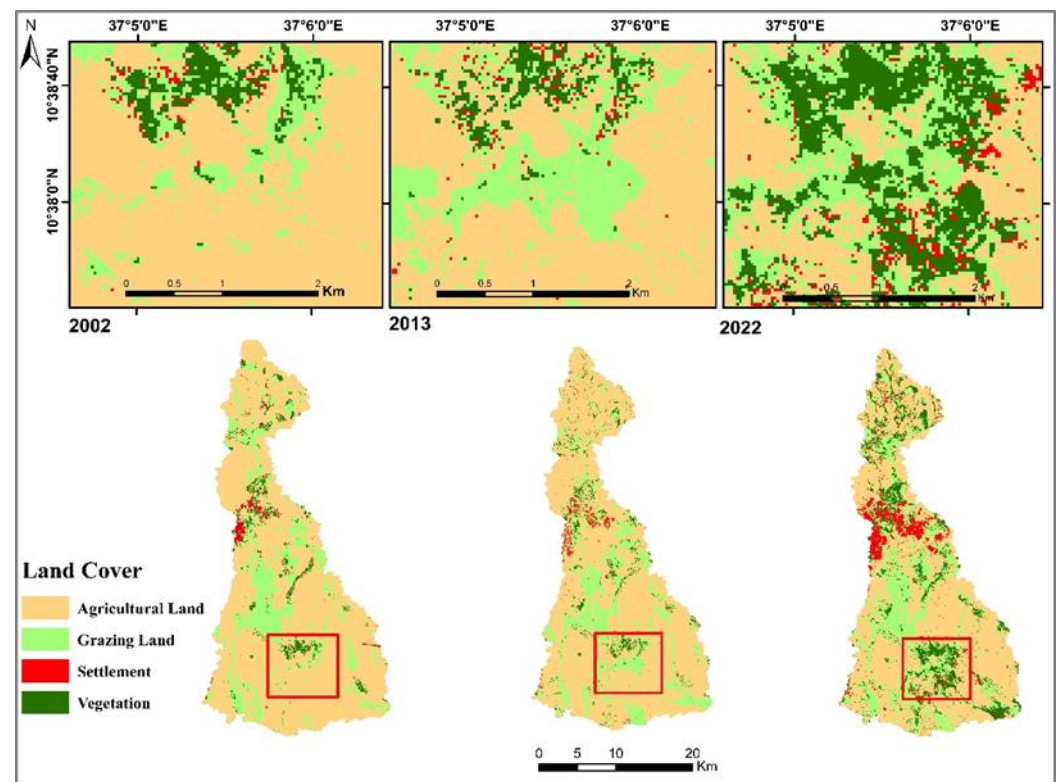
3. Results

3.1. Land Use/Land Cover Classification

Table 3 documents quantitative results regarding land use/land cover in the respective years (2002, 2013, and 2022).

Table 3. Total area of land use/land cover in the years 2002, 2013, and 2022.

Land Use/Land Cover Type	Area across the Study Periods					
	2002		2013		2022	
	(ha)	(%)	(ha)	(%)	(ha)	(%)
Agriculture	8403.84	75.2	8286.39	74.2	6549.39	58.5
Grazing Land	2232.27	20.0	2310.21	20.7	2788.56	25.0
Settlement	199.17	1.8	211.23	1.9	725.76	6.5
Vegetation	333.72	3.0	361.17	3.2	1105.29	10.0
Total	11,169.00	100.0	11,169.00	100.0	11,169.00	100.0

The results of the classification, as well as the land use/cover maps of the Yesir watershed for the years 2002, 2013, and 2022, are presented in Figure 2.

Figure 2. Land use/cover maps of the Yesir watershed for 2002, 2013, and 2022.

During 14 years of watershed development intervention (2002–2022), the gross changes in area coverage varied from one land use/land cover type to another. Grazing land, vegetation, and settlement experienced significant increases, while agricultural land experienced a reduction in the study area. The land use/land cover map of 2002 documents an agricultural land coverage of about 75.2% of the total area of the watershed. It decreased rapidly

and became 58.5% of the watershed area in 2022. In 2002, vegetation covered about 3.0% of the total area of the watershed, but by 2022, it had increased to 10%. Grazing land in 2002 covered 2232.27 hectares, which is 20.0% of the total area. However, it increased to 2788.56 hectares in 2022, which is 25.0% of the area. In 2022, settlement covered 725.76 hectares of land, a share of 6.5% of the total watershed area. In 2002, only 199.17 hectares were covered by settlements, which is 1.8% of the total coverage of the watershed (Table 3).

3.2. Accuracy of Land Use/Cover Maps

The accuracy of satellite image classification was assessed. Table 4 documents the results of the accuracy assessment for the supervised land use/land cover classification.

Table 4. Accuracy assessment (%) of land use/land cover maps (2002, 2013, and 2022).

Land Use/Land Cover Type	2002		2013		2022	
	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy	User's Accuracy	Producer's Accuracy
Agriculture	95	97	91	99	92	91
Grazing	88	76	89	78	83	82
Settlement	96	96	97	93	92	96
Vegetation	96	84	96	71	93	96
Overall accuracy	94%		92%		90%	
Kappa statistics	0.88		0.84%		0.85	

For 2002, an overall accuracy of 94% was achieved. For 2013, the accuracy was 92%, and for 2022, an overall accuracy of 90% was achieved. The kappa coefficients for 2002, 2013, and 2022 are 0.88, 0.84, and 0.85, respectively. It can be said that the achieved accuracies of the land use/land cover maps meet the requirements for subsequent analysis of land use/land cover changes.

3.3. Land Use/Cover Changes

Table 5 presents an analysis of changes in land use and land cover in the Yesir watershed over three time frames: from 2002 to 2013, from 2013 to 2022, and throughout the entire period from 2002 to 2022. The data indicate substantial transformations in land use and cover within the study area over these years.

Table 5. Land use/land cover changes determined in the Yesir watershed for the periods 2002 to 2013, 2013 to 2022, and 2002 to 2022 (in percent, in hectares, and the annual rate of change).

Land Use/Land Cover Type	Change (%)			Net Change (ha)			Rate of Change (ha/year)		
	2002–2013	2013–2022	2002–2022	2002–2013	2013–2022	2002–2022	2002–2013	2013–2022	2002–2022
Agricultural land	−1.4	−21.0	−22.1	−117.5	−1737.0	−1854.5	−10.7	−193.0	−92.7
Grazing land	3.5	20.7	24.9	77.9	478.4	556.3	7.1	53.2	27.8
Settlement	6.1	245.0	265.9	12.1	517.5	526.6	1.1	57.5	26.3
Vegetation	8.2	206.0	231.2	27.5	744.1	771.6	2.5	82.7	38.6

During the period from 2002 to 2013, the area coverage of grazing land, settlement, and vegetation increased by 77.9 ha (3.5%), 12.1 ha (6.1%), and 27.5 ha (8.2%), respectively. On the other hand, agricultural land decreased by 117.5 ha (1.4%). Similarly, grazing land increased by 478.4 ha (20.7%), settlement increased by 517.5 ha (245%), and vegetation increased by 744.1 ha (206%) between 2013 and 2022. At the same time, agricultural land decreased by 1737 ha (21.0%).

The analysis highlights that, between 2002 and 2013, increases in the grazing land, settlement, and vegetation classes correspond to annual rates of 7.1 ha/year, 1.1 ha/year, and 2.5 ha/year, respectively. Agricultural land decreased by 10.7 ha/year.

The same trends could be observed between 2013 and 2022. Grazing land, settlement, and vegetation persistently increased at a rate of 53.2 ha/year, 57.5 ha/year, and 82.7 ha/year, respectively. However, agricultural land decreased by 193 ha/year (Table 5).

Between 2002 and 2022, the detection of land use/cover change revealed that grazing land, settlement, and vegetation increased at rates of 27.81, 26.33, and 38.58 ha/year, respectively. Contrary to this, the share of agricultural land diminished at a rate of 92.72 ha/year.

3.4. Land Use/Cover Change Detection Matrix

According to [59], the change tracks between land use/land cover types is an important aspect (i.e., which land use/land cover type is changed to another type of land use/land cover class). The land use/land cover change detection matrix depicts the direction of change as well as types of land use/land cover that remained constant at the end of the period. Each period's change matrix was examined to better understand the source and destination of major land use/land cover changes. According to the study's findings, approximately 71.9% of the area covered by agriculture in 2002 remained the same in 2022. By 2022, the remaining 28.1% had switched to other land use/land cover types (see Table 6). Other land use/land cover types were converted to agricultural land at a rate of about 6.3%, compared to 28.1% lost to other land use/land cover types. In contrast, only about 58.9% of the area that was covered with grazing land in 2002 was still covered in 2022. In 2022, the remaining 41.1% was converted to other land use/land cover types. When compared to the amount of grazing land lost to other land use/land cover types, the area converted from other land use/land cover types to grazing land accounted for 66.2% of the total. In addition, 47.9% and 69.8% of total settlement and vegetation in 2002 remained unchanged in 2022 (Table 6), while the remaining majority of these land use/land cover types changed to other land use/land cover types.

Table 6. Matrix of changes in land use/cover types between 2002 and 2022 in the Yesir Watershed.

Land Use/Land Cover Changes in ha from LULC (Line) to LULC (Column)	Agricultural Land	Grazing Land	Settlement	Vegetation	Total 2002
Agricultural land	6082.2	1344.2	494.1	531.6	**8452.1**
Grazing land	502.6	1295.7	94.1	305.7	**2198.2**
Settlement	19.8	42.8	92.3	37.6	**192.5**
Vegetation	10.2	69.3	19.1	227.7	**326.2**
Total (2022)	**6614.9**	**2752.0**	**699.6**	**1102.6**	**11,169.0**

3.5. NDVI Comparison of 2002, 2013, and 2022

Table 7 documents an increase in the average NDVI value for the whole study area for the investigation period from 2002 to 2022. This is also an indicator of an increase in biomass, indicating that ILM has a positive impact on sustainable land management.

Table 7. NDVI value of the whole study area calculated from Landsat images (2002, 2013, and 2022).
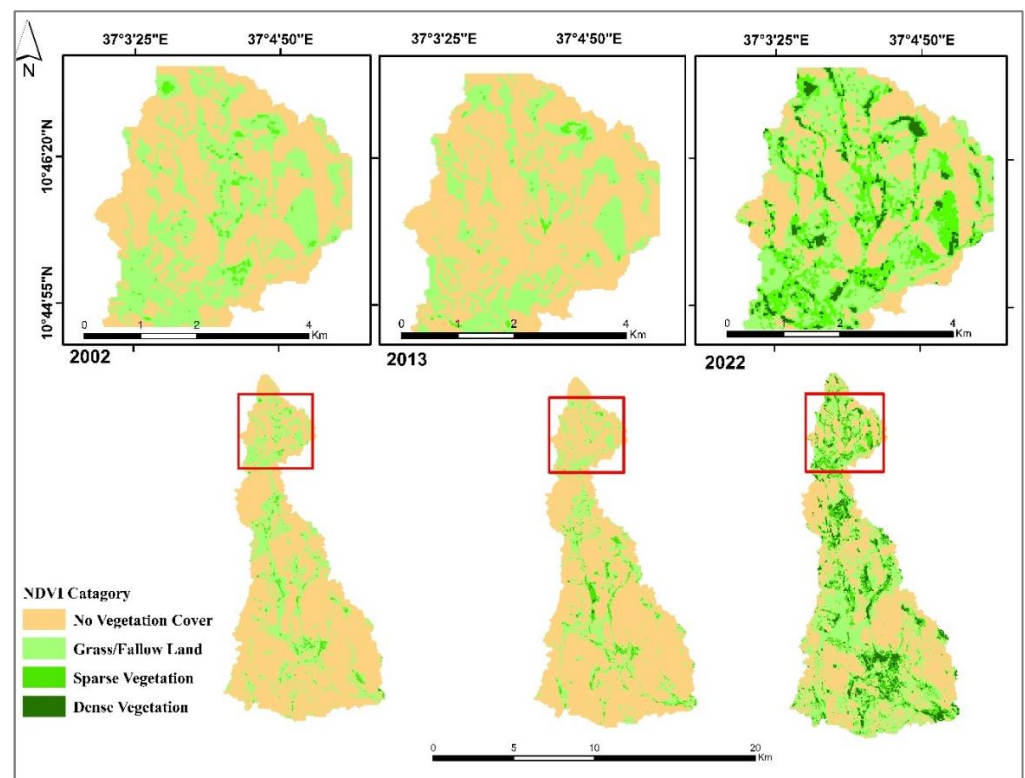
No.	NDVI Value	2002	2013	2022
1	Maximum	0.6177	0.4495	0.6697
2	Minimum	−0.0567	−0.0319	−0.0287
3	Mean	0.1695	0.1515	0.2318
4	Standard Deviation	0.0977	0.0646	0.0836

According to the literature cited in the Methodology section, the NDVI values were categorized into four basic categories (see Table 8), which correspond approximately to the land use/cover classes: no vegetation, grass/fallow land, weak plant cover, and healthy plant cover (see Table 8).

Table 8. Area coverage of NDVI classified values.

No	Category	NDVI Value	Area					
			2002		**2013**		**2022**	
			(ha)	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**
1	No vegetation	<0.2	8371.2	75.0	8731.6	78.0	5044.5	45.2
2	Grass/fallow land	0.2–0.3	2596.7	23.0	2059.1	18.5	4076.3	36.5
3	Weak plant cover	0.3–0.4	199.7	2.0	365.3	3.3	1375.1	12.3
4	Healthy plant cover	>0.41	1.4	0.0	13.0	0.2	673.1	6.0

In addition, NDVI values were mapped for the study area (Figure 3).

Figure 3. NDVI maps of the Yesir watershed for 2002, 2013, and 2022.

The 2022 NDVI map (Figure 3, right) and Table 8 document a decrease of 45.16% or 3,326.67 hectares in the first category (no vegetation), which is according to agricultural land in the land use/land cover category (agricultural land). Similar trends can be observed for the other classes. Incredibly, grassland/fallow land increased by almost double, from 2597 hectares in 2002 to 4076 hectares in 2022. The categories of weak and healthy plant cover have also increased from 200 hectares to 2048 hectares within the period of 2002 to 2022.

Table 8 and the map of 2002 (Figure 3, left) document that 75% of the watershed is categorized as areas with no vegetation. Grass/fallow land use/land cover corresponds to 23% of the total area, and the summation of weak and healthy plants covers another 2%.

4. Discussion

4.1. Land Use/Cover Change

The land use/land cover of the Yesir watershed experienced significant spatiotemporal change during the study period (2002–2022) (Table 5; Figure 2). A high proportion of land use/cover changed to vegetation (771.6 ha), grazing land (556 ha), and settlement (527 ha).

On the contrary, agricultural land (1855 ha) showed a declining trend. The focus group discussants confirmed that in the watershed, households changed their agricultural land to plant vegetation and for settlement purposes.

The most important land use/cover type used to assess the impact of integrated watershed intervention is vegetation land. In the Yesir watershed, a continuous increase in vegetation could be observed. Hence, over the 20 years of time between 2002 and 2022, the vegetation coverage almost tripled from 3.0% to 10% (Table 3). Local resident responses from a socioeconomic survey and focus group discussions confirmed that major Sustainable Land Management Practices (SLMPs), such as agroforestry, the reforestation of degraded land, biological soil and water conservation measures, and gully rehabilitation, have a significant impact on increasing vegetation cover. This finding is consistent with [55], who found that a participatory watershed management intervention enhanced the watershed's plant cover.

Grazing land is the second largest land use/land cover in the Yesir watershed. In 2002, grazing land covered 2232 hectares, which is approximately 20% of the whole study area. Similar figures were assessed for the years 2013 and 2022, with results of 2310 hectares and 2789 hectares, respectively. The area of the grassland category of the NDVI classification increased from 2597 hectares in 2002 to 4078 hectares in 2022. This is in line with the findings of [55], which found that farm bunds, rehabilitated gullies, and area closures on degraded lands have been potential sources of fodder biomass, and that the increase in grassland was caused by improved grassland management, area closure, and other natural resource management interventions. In the focus group discussions of the current study, participants confirmed that fodder production and management are among the most important sustainable land management practices. Soil conservation structure, backyard improved forage development, and rehabilitation practices have a significant impact on the expansion of grassland in the Yesir watershed.

Settlement areas showed significant growth during the study periods in the Yesir watershed (Table 5). Currently, in 2022, settlements cover 729 hectares of land. In total, the size of settlement areas increased from 1.8% to 6.5% in the study area. This corresponds to the exponential growth of the human population, which hastens the spread of settlement areas. FGD participants confirmed that the expansion of villages is directly related to population growth. Ref. [32], who conducted a study similar to the current one, stated that housing for a growing population as well as the need for public facilities, such as schools and clinics, is contributing to the growth of settlement areas. In the northwest highlands of Ethiopia, a study conducted by [60] found that, between 1973 and 2011, the area under cultivation and settlement increased from 4492 to 11177 hectares. Many studies carried out in different regions of Ethiopia provide evidence about the ongoing and rapid growth of built-up areas in both rural villages and rural towns as a result of population growth [61–65].

Based on the classified map, agricultural land coverage occupied the largest share of land use/land cover type in the study area. It comprised 8404 hectares (75.2%) of the total watershed in 2002; however, until 2013, the coverage slightly decreased by 118 hectares. Currently, in 2022, the share of this land use/land cover shrank significantly by 16.7% to 6549 hectares (Table 5 and Figure 2). FGDs and KIIs stated that the decrement of agricultural land is the result of population growth and the related growing demand for settlements in the watershed, as well as afforestation activities carried out in the study area. Studies on the Somodo watershed in southwestern Ethiopia also concluded that the impact of watershed management decreased the area of cultivated land due to the expansion of afforestation and agroforestry practices [49]. Unlike the findings of this study, ref. [21] pointed out that in a watershed in western Ethiopia, cultivated land increased by 42% to attain the ultimate objective of the watershed development program, increasing agricultural production by converting bushland to cultivated areas.

In general, the watershed management development approach aims to increase agricultural production. In the Yesir watershed, this was achieved, as stated by the farmers, FGDs, and KIIs, not by expanding the cropland but by afforestation.

4.2. Vegetation Greenness

The NDVI values were classified into the four basic categories: no plant cover, grass and fallow land, weak plant cover, and healthy plant cover (see Table 8). Basic land use/cover features, such as cultivated and bare land, represent no vegetation cover; open grazing land, backyard pasture development, and conservation agriculture land (CA) are grouped under grass/fallow land. Bushland, dense agroforestry practices, and biological soil and water conservation measures were categorized under weak vegetation cover, whereas natural forest areas, woodlots, and communal land plantations are categorized as healthy vegetation cover.

The NDVI analysis demonstrates a significant impact of the watershed management intervention practice on the biophysical changes of the watershed. As the data prove, after the intervention, bare land decreased from 75.3% to 45.2% whereas both grass/fallow land and vegetated land increased from 23.0% to 36.5%. In addition, ref. [66] determined that watershed rehabilitation measures increased the greenness of the watershed.

The findings of the analysis of land use/cover changes provide assurance that the Yesir watershed management intervention has a pronounced impact on mainly green and dray soil cover, which is in line with SLM intervention studies on the Wutame micro-watershed in the Omo Gibe basin, confirming a significant increase in vegetation cover due to watershed management [21].

4.3. Impact of Integrated Watershed Management

The practice of IWM is to restore ecological balance by utilizing, conserving, and developing degraded natural resources such as soil, vegetative cover, and water. Hence, evaluating the impact of SLMPs is crucial. To assess the biophysical changes in the watershed, a comparison of the main land use/cover types before and after the implementation of the watershed development program was conducted [21,67].

The impacts of watershed interventions on land use/cover change have been assessed by remote sensing image analysis approaches, extensive field observations, and focus group discussions (FGDs). All investigations identify that watershed management has a significant impact. Fourteen years after the implementation of IWM practices in the Yesir watershed, a significant change in land use/cover could be observed. Participants of FDGs proved that soil and water conservation structures, mainly soil bunds, micro water-harvesting structures, and gully rehabilitation practices, played a significant role in changing bare land to cropland. In line with this study, ref. [55] stated that IWM brought intense dynamics to land use/land cover. Following the implementation of soil and water conservation measures, the bare land was transformed into products that were alternately covered by crops and fodders throughout the year. In addition, ref. [68] supports the farmers' perception, as they describe the impact of soil and water conservation measures as justifiable to change marginal land to productive land. Soil and water conservation measures have not changed the soil's productive capacity, which has a significant impact on the soil cover due to the moisture content of the soil [69].

Natural resource management strategies, such as agroforestry, area closure, agronomic measures, afforestation, and natural forest conservation practices, resulted in a change in vegetation cover in the study area. Participants in the FGDs and KIIs indicated that farmers in the upper parts of the watershed contribute significantly to vegetation growth through agroforestry practices and hedgerow planting. The increase in vegetation cover in the watershed reduced the depth of groundwater that could be managed and used for irrigation. Studies from [55] on the Aba-Gerima micro-watershed coincide with this analysis. Downstream of the Yesir watershed, the protection of natural forests and fruit tree (orchards) plantations contributed to the greening of the watershed. In addition, as

stated by participants of the FGD and key informants, pastureland development practices and improved animal husbandry contributed significantly to the health of the watershed cover. These findings are confirmed by [19].

Increased soil moisture availability due to increased crop production reduced soil erosion, sedimentation, and flooding problems in the lower parts of the watershed. Stabilization of gullies and riverbanks, rehabilitation of degraded lands, and an overall improved ecological balance are all visible and confirmed by interviews conducted in the current study. Investigations conducted in Northern Ethiopia [70–73] also reported the effectiveness of sustained catchment-level conservation efforts in controlling soil erosion and improving hydrology and land productivity.

5. Conclusions

This study aimed to investigate the impact of IWM measures on land use/land cover change. Significant changes in land use/land cover could be recorded during the observation period, and the change tracks of different land use/land cover classes could be determined and quantified. The results of satellite image analysis were evaluated. The change in land use/land cover is monitored using classifications of a time series of satellite images. Satellite images with increased spatial and temporal resolution are now available.

For the current study, the assessment of the land use/land cover changes was carried out using supervised classification, applying a maximum likelihood approach, and by a simple analysis of NDVI values. Both methods based on Landsat satellite images with a ground resolution distance of 30 m led to reliable results for the given task.

It can be stated that satellite image-processing techniques are essential for assessing the efforts of the government and other stakeholders in evaluating the impacts of IWM on biophysical changes. Time series of satellite images enable permanent monitoring of watershed development programs and aim to ensure the sustainability of the measures. Remote sensing and GIS applications also enable the determination of the impact of IWM interventions.

Significant changes observed after the implementation of IWM include reduced soil erosion and increased soil moisture availability, rehabilitation of degraded land, and improved ecological balance. IWM intervention has reversed ecological changes caused by the destruction of natural vegetation and soil erosion as a result of land mismanagement.

While the IWM intervention studies show encouraging results in terms of vegetation cover, to be sustainable, it is essential to maintain a high level of farmer participation. The authors highly recommend the up-scaling of such interventions in similar agro-ecologies.

The current study is based on Landsat satellite images. In the last decade, worldwide satellite images have become available with improved spatial and temporal resolutions. In the future, this will enable monitoring of long-term processes with increased spatial accuracy.

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