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Expansion of *Eucalyptus* Plantation on Fertile Cultivated Lands in the North-Western Highlands of Ethiopia

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Abstract: Converting fertile, cultivated land into *Eucalyptus* plantations has become a common practice in Ethiopia. Integrating geospatial techniques with socio-economic data analysis can be a useful method to evaluate the expansion of *Eucalyptus* and its underlying factors. The objective of this study is to detect the spatio-temporal patterns and main factors contributing to *Eucalyptus* expansion in the Mecha district of Ethiopia. To quantify the spatial extents of *Eucalyptus* plantations, the study employed Landsat images from 1991 to 2021 with supervised image classification in ERDAS Imagine 2015. In addition, 120 households were chosen using random sampling technique to incorporate socioeconomic factors related to *Eucalyptus* expansion. The result shows that, *Eucalyptus* plantations expanded significantly across the study area during the last three decades. *Eucalyptus* plantation covered 908.87 ha, 3719.05 ha, and 26261.9 ha in 1991, 2006, and 2021, respectively. The increment was mostly at the expense of fertile cultivated land use. The main reasons for its expansion are linked with farmer's expectations of a better source of income, apprehension about the detrimental effects on nearby cropland, and its affordable production cost. In conclusion, the study area faces challenges from the uncontrolled expansion of *Eucalyptus* plantations on productive lands. Therefore, careful management and intervention strategies should be established to manage its rapid expansion.

Keywords: *Eucalyptus* plantation; land use and land cover; remote sensing; Ethiopian highlands

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1. Introduction

Land use and land cover change are common phenomena in all parts of the globe, with varying magnitudes. Understanding this crucial scenario, requires attention regarding the ways in which land conditions have shifted and where the changes have taken place. In central Ethiopia, most of the natural ecosystems have shifted to agriculture and human settlement. More recently, the expansion of some exotic tree species such as *Eucalyptus* woodlots has been a major land use/land cover change [1]. The largest area of land is converted to cropland use, which is susceptible to land degradation and ultimately affects the economic, political, and social units of a nation [2,3]. However, in most countries, including Ethiopia, much of the fertile cropland has been converted to exotic plant species such as *Eucalyptus* [4,5]. *Eucalyptus* trees can grow in the tropics, subtropics, and temperate regions, which cover 0.5% of the global forest area [6]. *Eucalyptus* is the most widely planted genus, covering 22.4% of all planted areas in Africa [3,7]. In Ethiopia, the *Eucalyptus* tree was introduced in 1894/95 to supply fuelwood and construction wood to the new and growing capital city, Addis Ababa. During the first decade, *Eucalyptus* was planted and grown in the capital city of Addis Ababa and continued to increase. The next stage, of *Eucalyptus* growing outside Addis Ababa, was started by missionaries in Ghimbi, DebreTabor, and Harar. Later still, especially after the 1950s, *Eucalyptus* growth moved to rural areas from these first nodes, being planted first in urban areas, the homesteads, and eventually on agricultural lands by farmers and urban dwellers [3]. The major species grown are *Eucalyptus* camaldulensis and *Eucalyptus* globules, which are designated as red and white *Eucalyptus*, respectively [8,9]. In the early 1970s, it covered about 42,300 ha of the countries land mass; in 1996, 250,000 ha, and by 2002 it had increased to 506,000 ha [10–12]. The estimated mean annual increment of *Eucalyptus* woodlots in Ethiopia is 10–20 m^3/ha/year [13].

Eucalyptus is often considered to have undesirable ecological qualities such as depletion of soil water, competent nature for nutrients with other native species, unsuitability for soil erosion control, production of allelopathic chemicals that suppress the growth of other plants, and provision of inadequate food and habitat for wildlife [14]. Replacing natural grassland and bushland with fast growing *Eucalyptus* could have significant hydrological implications when there exists a variation in water use between the introduced species and the replaced vegetation [15]. Experiments show that planting *Eucalyptus* causes a significant streamflow reduction when it reaches the third year, and in the ninth year, the stream dried up completely [16]. Several studies have been done on *Eucalyptus*' allelopathic effects. Certain species of *Eucalyptus* emit phenolic acids and volatile oils from their leaves, branches, and roots that are harmful to other plant species [1]. Live plant roots have an extraordinary capacity to produce organic compounds into the rhizosphere that plays crucial roles in interactions with other plant species. Rather than its biological qualities, the primary cause of the detrimental effects is the inadequate management practices used. Nevertheless, *Eucalyptus* tree plantations are becoming common practice among smallholder farmers in Ethiopia. At present, farmers are replacing their plots of land by *Eucalyptus* due to its tolerance of fire, insect and browsing animal damage, and its provision of a high yield per hectare due to its short rotation period [1,17,18]. In the Mecha district, there has been a remarkable expansion of *Eucalyptus* plantations on extensive fertile agricultural land. However, this uncontrolled expansion might be responsible for the reduction in food crop yields [18]. There have been a very limited number of studies conducted focusing on the investigation of spatio-temporal changes in *Eucalyptus* plantations and their interaction with soil fertility and water utilization [19,20]. However, it is difficult to find a study linking spatio-temporal *Eucalyptus* expansion with socioeconomic factors.

Understanding the existing information about land use and land cover changes is fundamental for a better understanding of the relationship between the human and the natural environment. With the emergence of geographic information system (GIS) and remote sensing (RS) technology, spatio-temporal changes have been monitored across a variety of aquatic and terrestrial environments including coastal, agricultural, forested, and urban areas [21]. In the past, scientists used field data and aerial photographs to map land use and land cover changes over smaller areas. However, these methods become very costly and time-consuming when the area of interest has large coverage. In recent decades, remote sensing data with multi-temporal satellite imagery has been widely used to quantify and detect land cover information on large geographic extents over time [22,23]. In addition, land use and land cover data coupled with socio-economic data can be very important for obtaining societal perceptions about questions such as 'why is land use change occurring?' and 'so what?' [24,25]. The integration of socio-economic data and land use and land cover changes improves our understanding of the causes and processes of land use and land cover changes [26]. Therefore, the objective of this study was to evaluate the spatio-temporal expansion of *Eucalyptus* plantations and identify the major factors that affect farmers to cultivate *Eucalyptus* trees on their farmland.

2. Materials and Methods

2.1. Description of Study Area

The Mecha district is geographically located between 11°10′ and 11°25′N latitude and 37°02′ and 37°17′E longitude (Figure 1). It is located 525 km northwest of Addis Ababa and 38 km west of Bahir Dar, the capital of the Amhara regional state. The mean monthly minimum and maximum temperatures range from 6.9 °C in January to 13.8 °C in May, respectively. The area's average annual rainfall is 1270 mm. The Mecha district comprises

12% temperate, 64% alpine, and 24% subalpine climatic zones. The soil type in the Mecha district is characterized by 93% Nitisols, 3% black soil, and 4% gray soil. Nitisols have deep porous and stable soil structure, which allows for deep rooting and creates an ideal environment for the production of food crops such as maize and finger millet, as well as trees such as *Eucalyptus* [27]. The Mecha district has a total population of 292,080, with 147,611 males and 144,469 females; 22,677, or 7.76%, are urban inhabitants. Its population density is 197.13 persons per square kilometer [28].

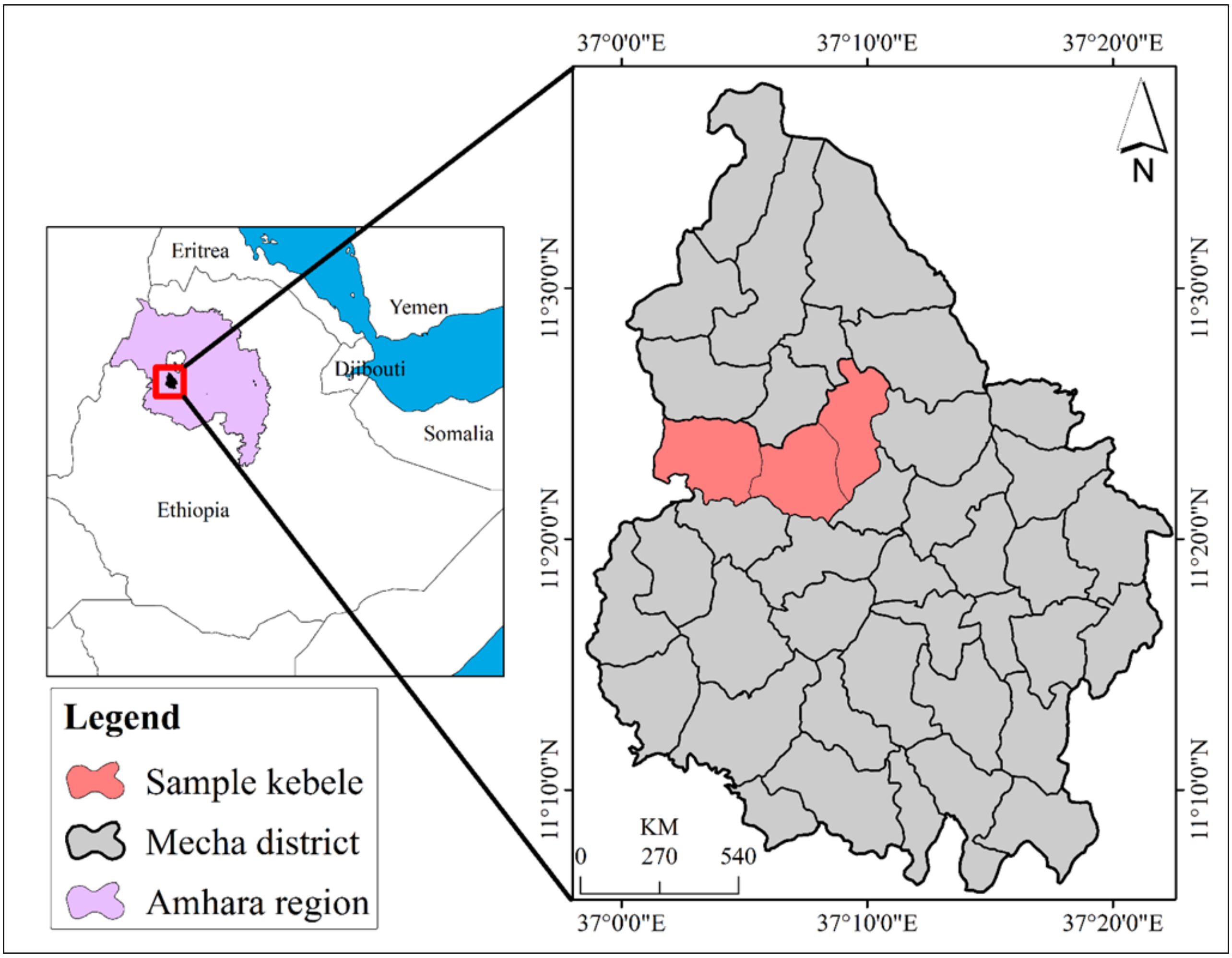

Figure 1. Location map of the study area, Mecha district.

2.1.1. Image Data Sources

Landsat satellite images were acquired from United States Geological Survey in 1991, 2006, and 2021 from http://glovis.usgs.gov accessed on 20 January 2020 (Table 1). The study area coverage delimited on single scene, only path 170/row 52 of Land sat images. These images were acquired during the clear sky season (January–February) to reduce atmospheric and radiometric errors. The images were extracted to "Tiff" formats for preprocessing and actual image analysis.

Table 1. Types of satellite image.

Satellite Data	Date	Spatial Resolution	Source
Landsat 5 MSS	1 February 1991	30 m	Global Land Cover Facility (GLCF)
Land sat 7 TM	8 February 2006	30 m	Global Land Cover Facility (GLCF)
Landsat 7 ETM+	12 February 2021	30 m	Global Land Cover Facility (GLCF)

2.1.2. Field Observation

Observation is the conscious noticing and detailed examination of the behavior in a naturalistic setting [29]. So, in this study an intensive field visit was made to closely observe the status of *Eucalyptus* expansion, which was useful in substantiating the responses obtained by interview; and in validating image classification results. This was made by taking pictures from *Eucalyptus* plantation fields. In addition, a Global Positioning System (GPS) was used for spatial ground truth point collection, which was used for classification accuracy assessment (Figure 2).

Figure 2. *Eucalyptus* woodlots encroaching on cultivated fields (**a**) and GPS point data collection (**b**).

2.1.3. Image Classification Scheme

The major land use and land cover classes found in the study area were identified as forest, *Eucalyptus* plantations, grazing land, built-up areas of crop (cultivated) land, and waterbody (Table 2). These land uses were identified by modifying the Anderson land use and land cover classification system based on the prior knowledge of the researcher [30]. *Eucalyptus* plantations were discriminated from other forests using recode function and integration of google earth in ERDAS Imagine menu. Moreover, intensive field observation took place across the study area which was predominantly covered by *Eucalyptus*.

Table 2. Characteristics of identified land cover classes in the study area.

Class Name	Description
Forest	Land use/land cover, which is covered by natural and artificial forests excluding *Eucalyptus*.
Eucalyptus	Areas covered with growth mainly *Eucalyptus* and other mixed crops
Grazing Land	Areas used for grazing, as well as bare lands (or rocks) with little or no grass cover, bushes, or shrubs.
Built-up areas	Residential areas including educational, health, and socio-economic facilities, and shops; especially urban areas.
Cropland	Areas used for crop cultivation, especially cereal crops (Teff, Wheat, Barley, etc.) and different scattered settlements.
Waterbody	Lakes and rivers, and waterlogged and swampy areas throughout the year.

2.2. Methods of Data Analysis

2.2.1. Image Preprocessing

In remote sensing, preprocessing functions involve the operations required prior to the main data analysis and consist of processes aimed at geometric correction, radiometric correction, and atmospheric corrections to improve the ability to interpret the image components qualitatively and quantitatively for further analysis. Thus, preprocessing is mandatory in most of the document layout analysis and classification operations. The preprocessing may itself be broken into smaller tasks such as line removal, skew estimation and correction, base-line detection (upper and lower), smoothing, and so on. Several methods have been proposed in the literature for estimating the above parameters [31,32]. In this study, the major preprocessing techniques used were layer stacking and sub-setting using ERDAS Imagine 2015. Hence, layer stacking was made to generate single multi-band false color composite images while sub-setting was applied for clipping out the images to the borders of study area (Figure 3).

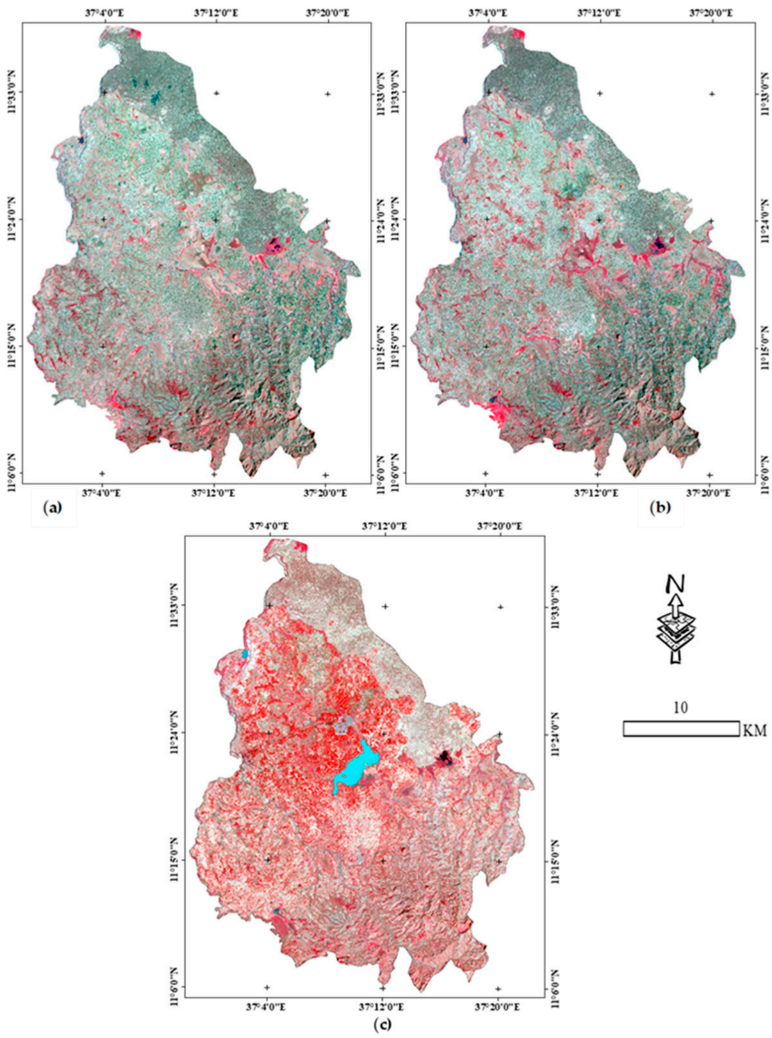

Figure 3. Landsat image False Color Composite of the study area (**a**) 1991, (**b**) 2006 and (**c**) 2021.

2.2.2. Image Classification

Image classification is defined as the process of categorizing all pixels in an image or raw remotely sensed satellite data to obtain a given set of labels or land cover themes. There are several approaches and methods that are associated with satellite image classification. However, most widely used satellite image classification methods are unsupervised and supervised techniques [32]. For this study, we employed supervised image classification using the maximum-likelihood parametric decision rule. This technique is better because it automatically classifies all pixels in an image into predefined classes/ themes. This classification approach is achieved using training samples of spectral signatures with the help of visual interpretation.

2.2.3. Change Detection

Change detection is the process of identifying occurrences of targeted changes in a scene, at a given instant time, with the same scene acquired at an earlier instant time. This task consists in finding relevant transitions of one land use into another land use [33,34]. Accordingly, this study made change detection analysis to determine quantities of conversions of different land cover to *Eucalyptus* during the reference years. Thus, land use change towards *Eucalyptus* plantation was evaluated at three interval periods: 1st period

(1991–2006), 2nd period (2006–2021), and 3rd period (1989–2021). ERDAS Imagine 2015 was used to provide information about area of conversion in raster tab thematic icon matrix union.

2.2.4. Accuracy Assessment

Land cover maps derived from remote sensing imagery always contain some sort of error due to several factors ranging from classification technique to method of satellite data [35]. The study employed producers' accuracy, users' accuracy, overall accuracy, and kappa statistics to validate classification ERDAS Imagine 2015. User's accuracy represents the probability that a given pixel appears on the ground as it is assigned, while producer's accuracy represents the percentage of a given class that is correctly identified. Whereas, the Kappa coefficient is a measure of agreement between the classified pixel value and the reality [36]. The Kappa statistics were calculated using Equation (1).

$$K = \left(\frac{ND - p}{N2 - p}\right) \times 100 \quad (1)$$

where; K = Kappa statics, N = total classified pixels, D = the sum of correctly classified pixels (diagonals), P = total sum of the product of correctly classified pixels with classified total.

To make validation of classified images, a total number of ground truth sample points of 284, 259, and 243 were used for the 1991, 2006, and 2021 images, respectively. In the case of the 1991 and 2006 images, the sample points were collected with supported from local area elders, through asking, "What was there at that time". For the 2021 classified image, validation was carried out with the support of Google Earth pro software. The test sample points were examined according to each assigned class value to investigate how the results reflected the reality on the ground.

2.2.5. Socio-Economic Sampling Procedure and Sample Size

The study applied a multistage sampling procedure. First, the kebele (lower level of administration) of the study area was stratified into two groups: those who have a large area of *Eucalyptus* and those with insignificant *Eucalyptus* cover based on the classification results of the 2021 satellite image. Secondly, three kebeles were chosen out of 39 kebeles that have significant *Eucalyptus* tree cover. The sample kebeles selected were Kudmi, Inamrt, and Ambomesk, with *Eucalyptus* plantation coverage of 154.86 ha, 1373.42 ha, and 952.61 ha, respectively. According to information gathered from the district administration office, the three kebeles are home to 3893 (N) households. Out of these, 88% (P) are households with *Eucalyptus* plantations, while 12% (Q) are households without *Eucalyptus* plantations. Therefore, using the Cochran [37] approach as given in Equation (2), 120 households were chosen randomly from the lists of households at the kebele administration.

$$N = \frac{NZ^2PQ}{d^2(N-1) + Z^2PQ} \quad (2)$$

where: n = sample size of housing units (household head); P = household who have agricultural land use; Q = household who have not agricultural land use = 1 − P; N = Total number of housing units; Z = Standardized normal variable and its value that corresponds to 95 % confidence interval equals 1.96; d = Allowable error (0.05).

Figure 4 shows the general framework of the study including input data, techniques and methods employed during the study period.

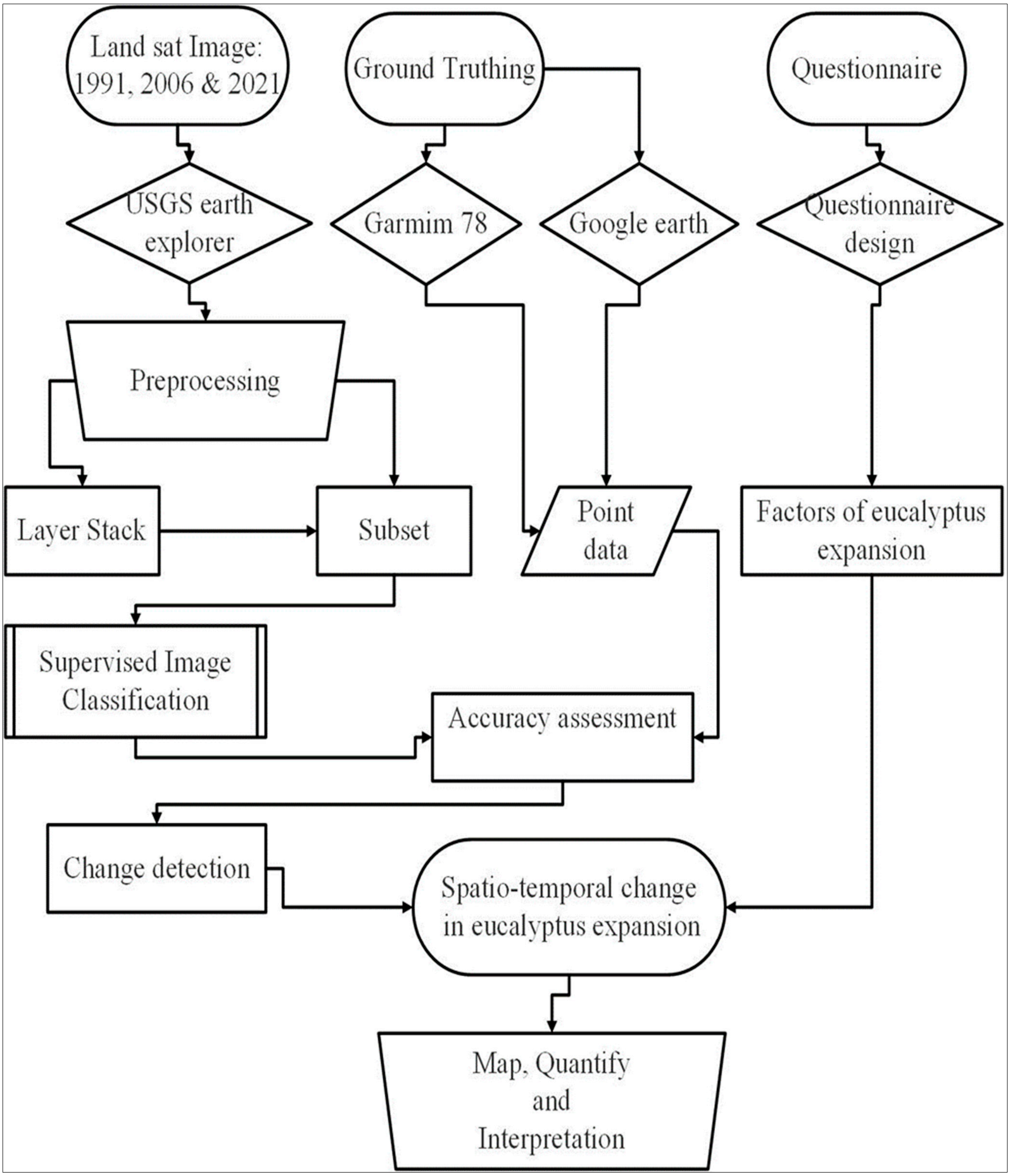

Figure 4. Methodological Flowchart implemented for the study.

3. Results

3.1. Accuracy Assessment Results

Table 3 illustrates the total reference point, total classified point number of correctly classified points, producer and user accuracies, and the Kappa statistics. The overall accuracies for all classified images were above the threshold i.e., >85% [38]. Overall accuracy of classified image was 95.42%, 98.07%, and 96.3% during 1991, 2006, and 2021, respectively. The user's accuracy results range from 91.67–100%, 96.3–100%, and 93.75–100% in 1991, 2006, and 2021, respectively (Table 3). The producer's accuracy varies from 86.1–100%, 93.3–100%, and 93.3–100% during 1991, 2006, and 2021, respectively (Table 3). This disclosed that only the lowest values of class were misclassified due to spectral property similarities among other land cover classes. Moreover, the Kappa coefficient achieved 0.95, 0.98, and 0.96 in 1991, 2006, and 2021, respectively, which indicates an agreement of the classified image with real land cover.

Table 3. Accuracy assessment for 1991, 2006, and 2021 classified image.

	Classified Data	Reference Totals	Classified Totals	Number Correct	Producers Accuracy (%)	Users Accuracy (%)
1991	Forest	46	42	42	91.3	100
	Eucalyptus	48	48	44	91.67	91.67
	Grazing land	54	59	54	100	91.53
	Built-up area	36	31	31	86.1	100
	Cultivated land	54	58	54	100	93.1
	Waterbody	46	46	46	100	100
	Total	284	284	271		
2006	Forest	33	33	32	96.97	96.97
	Eucalyptus	48	48	47	97.92	97.92
	Grazing land	47	48	47	100	97.92
	Built-up area	48	48	48	100	100
	Cultivated land	53	54	52	98.11	96.3
	Waterbody	30	28	28	93.3	100
	Total	259	259	254		
2021	Forest	45	42	42	93.3	100
	Eucalyptus	48	51	48	100	94.12
	Grazing land	48	49	46	95.83	93.88
	Built-up area	34	33	33	97.06	100
	Cultivated land	46	48	45	97.83	93.75
	Waterbody	22	20	20	90.91	100
	Total	243	243	234		

3.2. Land Use and Land Cover Changes (1991–2021)

Based on image classification result *Eucalyptus* plantation covered about 908.87 ha (0.6%) in 1991; 3719.05 ha (2.5%) in 2006, and 26,261.9 ha (17.6%) in 2021 respectively (Table 4). Similarly, built-up and water body increased from 72.86 ha (0.1%) to 1570.84 ha (1.1%), and 450.05 ha (0.3%) to 2051.3 ha (1.4%) between 1991 and 2021, respectively. However, cultivated land coverage declined from 87,613.6 ha (58.6%) to 68,561.52 ha (45.9%) between 1991 and 2021 (Table 4). In addition, grazing land and forestland showed a decreasing trend which covered 50,237.32 ha (33.6%), 49,161.2 ha (32.9%), and 40,927.52 ha (27.4%) in 1991, 2006, and 2021, respectively (Table 4).

Table 4. Area of land use classes in ha in 1991, 2006, and 2021.

Land Use Class	1991		2006		2021	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest	10,158.47	6.8	10,670.9	7.1	10,068.1	6.7
Eucalyptus	908.87	0.6	3719.05	2.5	26,261.9	17.6
Grazing land	50,237.32	33.6	49,161.20	32.9	40,927.52	27.4
Built-up area	72.86	0.1	126.94	0.1	1570.84	1.1
Cultivated land	87,613.6	58.6	85,644.96	57.3	68,561.52	45.9
Water body	450.05	0.3	118.13	0.1	2051.3	1.4
Total	149,441.2	100	149,441.2	100	149,441.2	100

3.3. Driving Factor of Eucalyptus Expansion

There are different factors responsible for the expansion of *Eucalyptus* plantations; the major ones are the desirable price of the tree over food crops, fear for crop yield reduction due to adjacent *Eucalyptus* plantations, and low production cost (Table 5). In the study area, around 45.8 % of respondent farmers choose to plant *Eucalyptus* on their plots, hoping to generates better income (Table 5). While, 27.5% of the respondents replied that farmers were forced to change their land to *Eucalyptus* due to the fear of its negative impacts from nearby croplands covered with the plant (Table 5). The remaining 18.3% of the respondent specified that farmers had planted *Eucalyptus* due to its low cost of production, and short growing and harvest time (Table 5). The majority of the respondents (97.5%) replied that cropland which the most commonly converted land use to *Eucalyptus* (Table 5).

Table 5. Driving factors for expansions of *Eucalyptus* plantation.

	Number of Respondents	Percent
Drivers for the expansions of *Eucalyptus* farming		
An increasing price of wood products in the market	9	7.5
Yields better income than other land use products	55	45.8
Low Production Cost	22	18.3
Guarantee for their ownership of land	1	0.8
Fear for adjacent crop yield reduction	33	27.5
Land use mostly converted to *Eucalyptus*		
Crop land	117	97.5
Residential area	3	2.5
Grazing land	0	0
Total	120	100

4. Discussion

Expansion of Eucalyptus Plantation

Image classification result presented that there was dramatic expansion of *Eucalyptus* plantation in the Mecha district during the last three decades, as indicated in Table 4. This expansion was due to transformation and/or modification from other land use and land cover types to *Eucalyptus* largely cultivated land use (Figure 5).

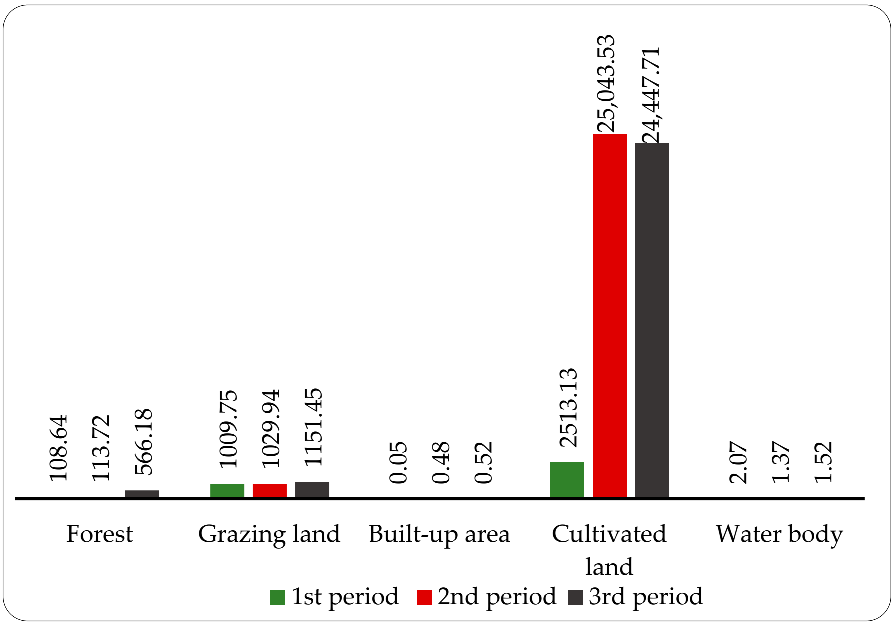

Figure 5. Land use transitions towards *Eucalyptus* plantation for the three periods.

Change detection results revealed that there was significant conversion of different land uses into *Eucalyptus* plantation. The highest share of conversion was primarily at the expense of extensive fertile cultivated land (Figures 5 and 6). *Eucalyptus* expanded on 2513.13 ha, 25,043.53 ha, and 24,447.71 ha cultivated land during the 1st period, the 2nd period, and the 3rd period, respectively (Figure 5 and Table 6). In the first period (1991–2006), expansion was limited to agricultural land closer to the homestead, and later productive croplands altered into *Eucalyptus* woodlots (Figure 2). This result agrees with the study reported by Biru et al. [39] in Koga watershed, which states that there is a rising trend in forest cover that is associated with the quick growth of *Eucalyptus* plantations. Another investigation in Southern Ethiopia described how growing *Eucalyptus* at a farm level in the form of woodlot has become common practice among rural households in Southern Ethiopia [40]. The finding is also in agreement with the report of Jenbere et al. [5]; for example, in south central parts of Ethiopia Arsi-Negele district, *Eucalyptus* plantation is rapidly expanding in fertile agricultural land. Accordingly, the rate of *Eucalyptus* plantation is the most dominant species and has been planted over 95 countries in the world [41]. Lal [42] identified that in India, forest and farmlands, community lands and road/rail/canal strips have been transformed to large-scale *Eucalyptus* plantations to satisfy fuel shortage. A study in China also indicates that China were ranked first in the world in the mid-1990s in terms of expansion of *Eucalyptus* plantations, due to the short logging/rotation period for production of timber [43]. The same report has been published by Merino et al. [44] in southern Europe, stating that forest plantations are dominated by fast growing species such as *Eucalyptus* which can grow on acidic soils. The major reason for its expansion is that people are highly dependent on the multi-functionality of the tree. Unless masonry construction is used, the only tree source used for house construction is *Eucalyptus*. Even the masonry buildings are consuming a large volume of *Eucalyptus* to support the construction. Dessie et al. [45] indicated that 92% of the construction industry was covered by *Eucalyptus*. This makes the tree worth more income from the sale of the tree. A study in central Ethiopia indicated that *Eucalyptus* covers 75% of the firewood sold in the market and about 25% of the income source for livelihood [46]. From its very nature, the tree has a very wide adaptation to the different agro-ecological zones in the country, and is fast growing, resulting in rapid plantation of *Eucalyptus* by smallholders. More surprisingly, unlike other tree species *Eucalyptus* is non-palatable by livestock. Plantation efforts were made every year with a government-sponsored campaign; however, the success rate is marginal.

Table 6. The spatial conversions of different land use towards *Eucalyptus* (1991–2021).

Land Use Classes	***Eucalyptus* Plantation (ha)**		
	1st Period	**2nd Period**	**3rd Period**
Forest	108.64	113.72	566.18
Eucalyptus	85.41	72.86	94.52
Grazing land	1009.75	1029.94	1151.45
Built-up area	0.05	0.48	0.52
Cultivated land	2513.13	25,043.53	24,447.71
Water body	2.07	1.37	1.52
Total	3719.05	26,261.90	26,261.90

Moreover, about 1009.75 ha, 1029.94 ha, and 1151.45 ha of grazing land use was transformed to *Eucalyptus* in the first, second, and the third periods, respectively. This finding corresponds with Lemenh et al. [46] which indicated that there was substantial expansion of *Eucalyptus* plantation on grazing and bushland areas in different parts of Ethiopia. The finding is also supported by reports of Jaleta et al. [1] who presented that there was an increase in *Eucalyptus* coverage in central Ethiopia at the expense of grassland and bush land, driven by the demand for fuel wood and construction materials, the rising of the market, and profit gained from the wood products. A similar report, presented that in Uruguay commercial *Eucalyptus* plantations have increased during the last decade due to conversion of natural grazed pastures [47]. Figure 5 and Table 6, indicates that 108.64 ha, 113.72 ha, and 566.18 ha of forest land was also converted into *Eucalyptus* plantation in the first, second, and the third period, respectively. The results are also congruent with the findings of Bayle [17], which show that the expansion of *Eucalyptus* plantation because of the depletion of natural forests by other land uses such as farming practice leads to the shortage of fuel wood; and its ability to grow in areas where other forest species cannot persist. Yet, the transformation of built-up areas and waterbodies into *Eucalyptus* plantation were not significate during the study period.

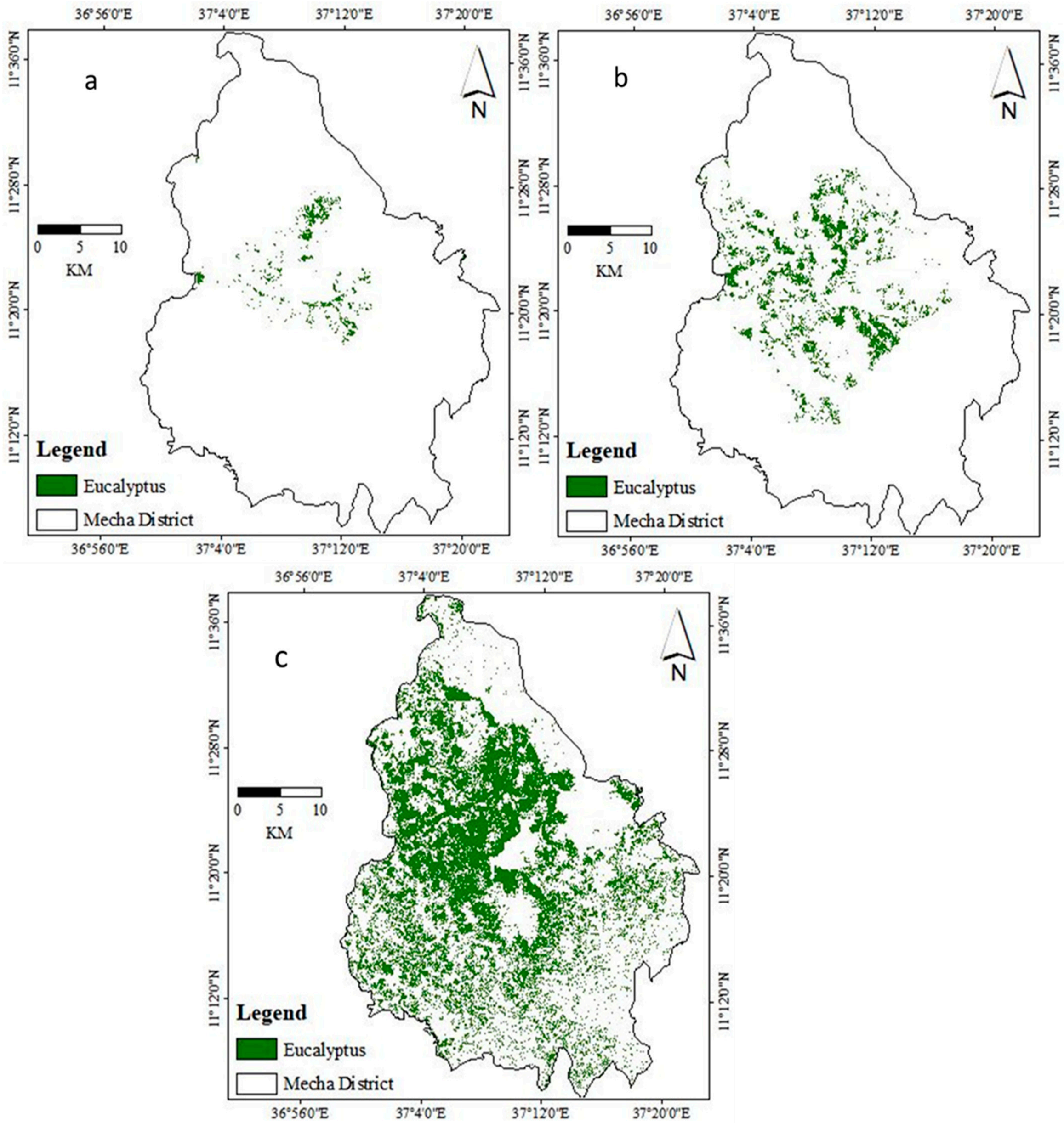

Figure 6. Spatial coverage of *Eucalyptus* plantation in the study area (**a**) 1991 (**b**) 2006 and (**c**) 2021.

The result of remote sensing data proved that there was rapid expansion of *Eucalyptus* plantation during the past three decades in the Mecha district. The major factors for expansion of *Eucalyptus* plantation are the desirable price of the tree over food crops, fear for crop yield reduction due to adjacent *Eucalyptus* plantation, and low production cost (Table 5). Around 45.8% of respondent farmers prefer planting *Eucalyptus* on their plots, hoping to generates better income (Table 5). This finding agrees with the study by Zerga [48] indicating that recently *Eucalyptus* is becoming an immediate source of money for various expenses for farmers. Similarly, a study in the Tigray region Ethiopia, indicated that the main factors influencing household or community decisions to invest in *Eucalyptus* tree growing is due to its low-cost requirement and a high yield, especially where it is planted on croplands [49]. Furthermore, Desta et al. [50] also indicated that farmers planted *Eucalyptus* expecting a better return, although, its price is becoming marginal as compared to crops and livestock. Besides, 27.5% of the respondents reacted that farmers were forced to change their land to *Eucalyptus* due to the fear of its negative impacts from nearby croplands covered with the plant (Table 5). This was investigated by Chanie et al. [18], who indicated that the production of crops where *Eucalyptus* is planted in the adjacent cropland as a *Eucalyptus* plantation creates high competition for nutrients, shadow effects, and competition for water. Another experimental investigation supported the finding that finger millet and maize yield suffered as a result of *Eucalyptus* over-competition with crops cultivated in the nearby croplands [27]. The other 18.3% of the respondents indicated that farmers planted *Eucalyptus* because it requires low cost of production and needs a short growing and harvest time, as indicated (Table 6). The same report has been published by [44] in southern Europe, stating that, forest plantations are dominated by fast growing species such as Eucalyptus, which can grow on acidic soils. It is also supported by a study done in China which shows that *Eucalyptus* coverage increased because of its fastest growing and high-yielding qualities, as well as its high tolerance to infertile soil [43]. A total of 97.5% of the respondents agreed that cropland is mostly subject to conversion into *Eucalyptus* plantation. The result corresponds with the classified image outcome, which shows that the principal change was observed from cultivated land use (Table 6 and Figure 7). Thus, the results imply that large hectares of fertile cropland is converted into *Eucalyptus* plantation. This is supported by the same study in the North-Western highlands of Ethiopia by Tesfaw et al. [51].

Despite the multi-level benefits and rapid expansion of *Eucalyptus* plantations, there are still opposing opinions among practitioners and policymakers on the advantages and disadvantages of planting *Eucalyptus* [50–54]. With the existing conflicting ideas from various perspectives, an idea that brings both sides together is critical. According to Gil et al. [54], *Eucalyptus* has negative impacts when it is planted to replace existing natural forests and is then poorly managed. In contrast, it would have a positive impact if planted in degraded areas under good management. Currently, raising *Eucalyptus* seedlings from government nursery sites is not encouraging. However, most farmers understand the merits and demerits of *Eucalyptus*. Most of the time, farmers need short-term benefits from plantations and other development interventions. As a result, farmers prefer to raise *Eucalyptus* seedlings on their own plots of land and sell them in the local market [55,56]. The primary source of household income in most households is the sale of *Eucalyptus* seedlings and wood lots. It is possible to say that, there is no smallholder farmer who does not have a *Eucalyptus* tree in the study district, even in Ethiopia. In addition, planting *Eucalyptus* is considered an employment opportunity for unemployed youth and women. There is a current argument that degraded areas are home to unemployed and landless youths. These lands are mostly communal and can be used as a means to create job opportunities for income generation [57]. Low-income countries, such as Ethiopia, should encourage *Eucalyptus* plantations since it is the backbone of smallholder farmers' livelihoods, and should develop legislation to encourage the adoption of fast-growing tree species such as *Eucalyptus* that meet the growing demand for firewood, construction materials, and timber to prevent further degradation of natural forests. Furthermore, *Eucalyptus* could contribute to rural development and poverty reduction [49]. Sustainable land resource management can be achieved through sound land use planning. With a rapidly growing population, land is a serious and sensitive economic sector for rural and peri-urban areas. Ethiopia as a nation has a land use planning policy under proclamation number 456/2005. However, the implementation of the policy is hampered by the lack of integration among stakeholders, follow-up capacity, rule enforcement, and regulatory mechanisms. Implementing institutions at all levels are expected to require the capacity to develop regulations and reinforce existing rules. In addition, regulating the expansion of exotic species should also be monitored along with the land use policy. For example, *Eucalyptus* is a widely planted tree species that would be managed properly to harmonize its impact from different perspectives. In order to reduce the challenges and enhance its productivity, strict regulations should be maintained. Such decisions shall be supported by research results reported by different scholars. The rate of *Eucalyptus* plantation and its expansion from fertile cropland, according to this study, is an unregulated practice. In order to enhance the implementing partner organizations and decision-makers' skills and capacities, research outputs are fundamental. Thus, the results of this study can support decision-makers, land planners, and local governments to apply appropriate land management policies and strategies. In particular, such site-specific information enables the local government to understand the issue and needs critical action. Moreover, it is crucial to start action on selecting the appropriate land use through communication among stakeholders including the landowners. It is obvious that fertile croplands will be preserved because they are critical land uses for combating food insecurity, whereas perennial tree crops such as *Eucalyptus* shall be grown in degraded areas to maintain ecosystem services and restore degraded areas.

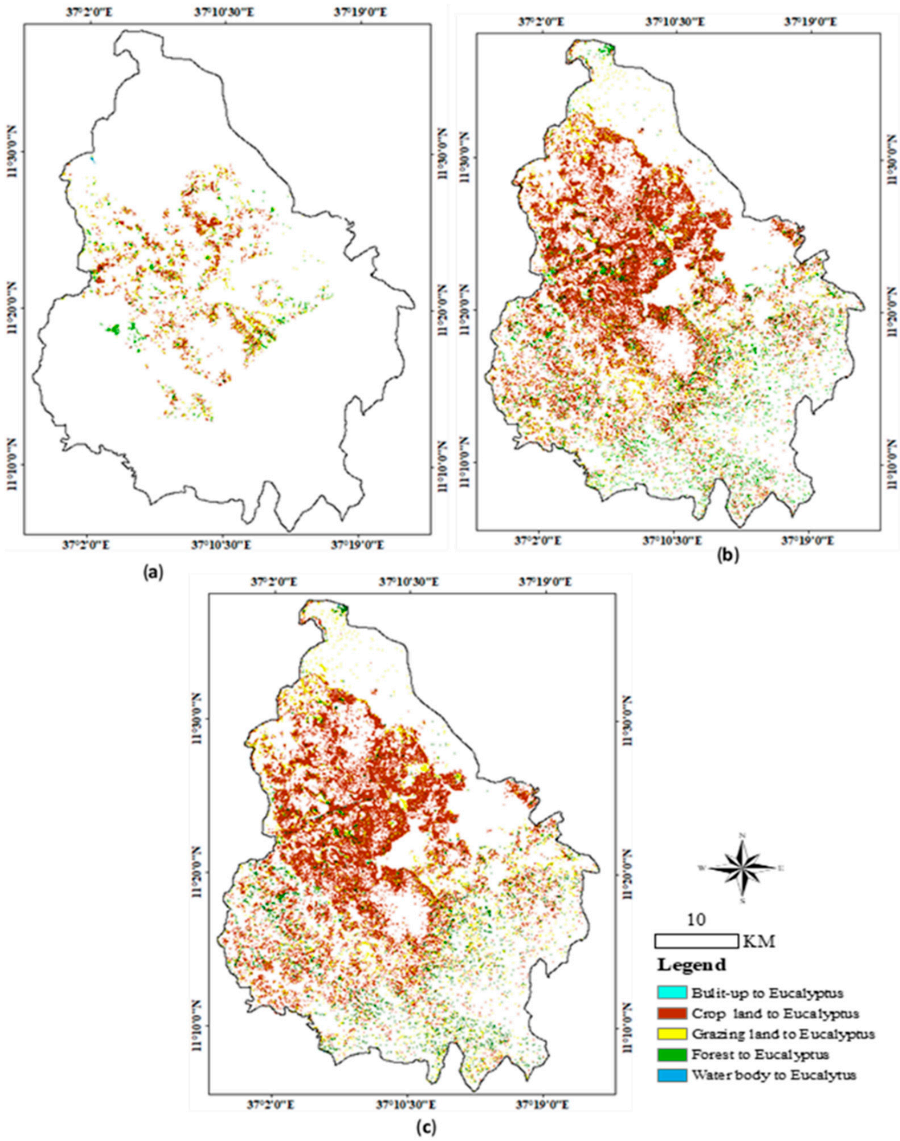

Figure 7. The conversion trends of different land use towards *Eucalyptus*: (**a**) 1991–2006, (**b**) 2006–2021 and (**c**) 1991–2021.

5. Conclusions

In the study district, *Eucalyptus* tree plantation is the most common practice referred to by farmers. The study revealed that *Eucalyptus* plantation coverage increased rapidly over the last three decades. It increased from 908.87 ha to 26,261.9 ha (17.6%) between 1991 and 2021, which is around twenty-nine times the earlier year. This increment was mainly at the expense of 24,447.71 ha of cultivated land followed by 1151.45 ha of grazing and 566.18 ha of forest land use during 1991–2021. The observed expansion was due to various factors such as fear of its negative impact on the productivity of adjacent cropland and affordable cost of production as compared to other land uses. There are varies opinions on the advantages and disadvantages of planting *Eucalyptus*. However, the advantages of planting *Eucalyptus* outweigh the benefits a smallholder gains from other land uses. Many agree on planting the tree in degraded areas with proper management methods. Otherwise, it seems challenging to discourage the practice without putting in place an alternative means of livelihood support. Hence, further investigation into the impacts of *Eucalyptus*, especially the interaction between Eucalyptus and soil, water, nutrients, and others through experimentation is required, to reach a reasonable utilization of the resource among policy makers and user communities. Beyond doubt, the results of this study can support decision-makers, land planners, and the local government in applying appropriate land management policies and strategies.

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