Forest Ecology and Management 304 (2013) 171–181

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Factors controlling patterns of deforestation in moist evergreen Afromontane forests of Southwest Ethiopia

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ARTICLE INFO

Article history:
Received 10 January 2013
Received in revised form 4 March 2013
Accepted 1 May 2013

Keywords:
Afromontane
Coffee
Deforestation
Land use change
Logistic regression
Southwest Ethiopia

ABSTRACT

This study aims to contribute to a better understanding of deforestation processes of moist evergreen Afromontane forests by disentangling the role of biophysical and socio-economic factors. Hitherto deforestation patterns between 1957 and 2007 were mapped for 9 villages in the Jimma zone of the Oromia regional state in Southwest Ethiopia on the basis of aerial photographs and high- resolution satellite images. The results show a 19% decline in forest cover since 1957. A spatial analysis of the observed deforestation patterns showed that the way of living and the accessibility to markets has controlled to a large extent the spatial pattern of deforestation during the past 50 years. Forest was lost mainly at remote locations away from the main roads where market integration is difficult. Farmers in these locations are relatively poor and self-subsistent which implies that population increase automatically led to new deforestation. Places very nearby to market places were spared from deforestation because of the presence of off-farm jobs in the towns. Significantly less deforestation was observed in areas that are suitable for the growth of shaded coffee. The areas above 2000 m.a.s.l that are not suited for shaded coffee are typically inhabited by relatively poor households who are living far from roadsides and thus are less integrated to the surrounding major markets. As a result, they depend more on subsistence farming causing more deforestation than other households.

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1. Introduction

Tropical forests worldwide provide the largest biological diversity of plants and animals. It is estimated that they contain at least 50% and almost 75% of the world's animal and plant species respectively (Laurance, 1999; Achard et al., 2002a,b; Frey, 2002). Moreover, they provide many ecosystem services that can be directly related with human well-being at local, regional and global scale levels. Increased deforestation is likely to reduce biodiversity and to result in many other negative impacts on the environment such as soil erosion, nutrient depletion, decrease in the amount of available groundwater, destruction and fragmentation of natural habitats, flooding, increased levels of greenhouse gases, disturbances of the carbon cycle and loss of forest products like pharmaceuticals, timber and fuel (e.g. Angelsen and Kaimowitz, 1999; Laurance, 1999; Achard et al., 2002a,b; Frey, 2002; DeFries et al., 2006; Dessie and Kleman, 2007; Turner et al., 2007).

Despite such crucial benefits, these forests are under continuous pressure from various and adverse human activities and they are being degraded at alarming rate. During the 1980s for example, about 15.4 million ha of tropical forest was lost each year (FAO, 1992) and converted into a mosaic of mature forest fragments, pasture, and degraded habitats (Rudel and Roper, 1997; Laurance, 1999; Verolme et al., 1999). Strategies to slow down and eventually reverse tropical deforestation trends became an important point on the agenda of national and international policy makers.

A global comparison of tropical deforestation rates shows a large spatial variability. Hotspots of tropical deforestation can be found in Southeast Asia, Latin-America and Africa (Achard et al., 2002a,b; Lepers et al., 2005). Recent studies (e.g. Brink and Eva, 2009), however revealed that deforestation rates in many parts of the tropical area are slowing down. In some cases forest transitions, i.e. the transition from a phase of net deforestation to net reforestation have been reported (Mather and Needle, 1998; Mather et al., 1999; Rudel et al., 2005). Table 1 gives an overview of recent studies that describe forest transition in the tropical zone.

Typically forest transitions can be linked with pathways of (1) economic development and migration of the people leading to urban areas, (2) abandonment of arable fields because of land degradation and forest plantation due to forest scarcity and (3) government steered reforestation programmes. Hitherto, however, very few forest transitions have been described in tropical Africa. Possible reasons for this observed delay are an ongoing exponential population growth, a large proportion of people being employed in

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http://dx.doi.org/10.1016/j.foreco.2013.05.001

Table 1
Examples of reported forest transition locations and their respective causes in the tropics.

Reference	Location	Turnover point of forest transition	Main driver
Zhou et al. (2009)	China	2005	Implementation of national scale reforestation programme
Meyfroidt and Lambin (2008)	Vietnam	1990	Economic development and forest plantations
Sánchez-Cuervo et al. (2012)	Colombia	2001	Land abandonment because of internal conflict, economic development
Bae et al. (2012)	South Korea	1955	Implementation of national scale reforestation programme, economic development
Rudel et al. (2002)	Ecuador	1987	Outmigration, expansion of market oriented agricultures
Grau et al. (2003)	Puerto Rico	1940	Economic development and urban growth
Rudel et al. (2005)	India	1990s	Implementation of national scale reforestation programme due to scarcity in forest products

self-subsistence farming and the slow adoption of modern farming technology that could result in higher crop yields (Teka et al., 2013).

Despite the fact that some review papers (Geist and Lambin, 2001) provided a wide overview of factors controlling deforestation processes, such overviews appeared to be insufficient for the development of successful land use policies that could stop deforestation. The main reason for this must be sought in the complex nature of society–environment interactions which are often very site-specific. Since the tropical area is very diverse both from biophysical and socio-economic perspectives, a uniform policy scheme has little chance to be successful. Most studies on tropical deforestation in Africa focus on the tropical lowlands in western and central Africa. However, relatively little is known regarding the society-environment interactions that lead to deforestation of the moist evergreen Afromontane forests in the East-African highlands.

This study aims to contribute to a better understanding of the deforestation processes of the moist evergreen Afromontane forests by disentangling the role of biophysical and socio-economic factors for a study site in the Jimma area of the Oromia regional state in Southwest Ethiopia. The study site is located in a relatively remote location near the waterdivide between the Blue Nile and the Omo-Gibe River basins where ongoing deforestation is causing problems at a national scale level. The local deforestation has been linked with processes of sediment delivery to the main river (Broothaerts et al., 2012), which seriously hamper the functioning of newly installed hydropower plants that are considered to be of vital importance for the economic development of Ethiopia. Moreover, the recent deforestation is perceived as a source of potential conflicts between various land users (Wood, 1993). Shifting cultivators that are driven by poverty get in conflict with forest farmers that collect natural coffee, spices and honey from the natural forests (Wood, 1993).

The main hypothesis of this research paper is that deforestation dynamics and the corresponding patterns in the rural areas of Southwest Ethiopia which are characterized by poor people living from self-subsistence farming are quite different from tropical forest-rich places such as the Amazon or the Congo basins, where deforestation mainly occurs along roads (Mertens and Lambin, 1997; Soares-Filho et al., 2004; Wilkie et al., 2000; Southworth et al., 2011). In order to reveal the spatial logic behind deforestation in the moist evergreen Afromontane forests of Southwest Ethiopia both socio-economic variables describing the various ways of living and biophysical variables were collected and mapped.

In order to better understand the driving factors of deforestation and its related environmental and socio-economic problems, the following specific objectives were considered: (1) to determine and quantify forest cover changes occurred during 1957–2007; (2) to identify and analyze the most significant explanatory variables that lead to forest conversion in Southwest Ethiopia; (3) to establish a predictive deforestation model that takes into account biophysical and socio-economic factors.

2. Materials and methods

2.1. Study area

The selected study area is located near the waterdivide between the Blue Nile River and Omo-Gibe River basins in Southwestern Ethiopia (Fig. 1). It consists of seven villages and two local towns: Yebu and Bilida which are important market places. The total area of the study site, which extends between 7°37′53″N–7°53′00″ N and 36°41′01″E–36°50′44″E, is 184.6 km^2. The study area belongs to the socio-economic sphere of influence of the city of Jimma, with a population of 120,960 inhabitants (CSA, 2007) and located at a distance of 360 km southwest of Addis Ababa, the capital of Ethiopia.

The topography of the study area is dominated by undulating hills dissected by many small tributaries that drain northward to the Blue Nile basin or southward to the Omo-Gibe basin. The overall elevation ranges from 1700 m.a.s.l in the eastern part of the study area to 2400 m.a.s.l in the western part. The climate is characterized by two distinct seasons: a wet season from April till mid September and a dry season from November till January (Legesse et al., 2003). On average, the area receives annual rainfall of ca. 1550 mm with an increasing trend towards the north. The mean monthly air temperature varies between 13° C and 25° C (Personal communication with Mana District Agriculture and Rural Development Office, 2009). Dystric nitisols dominate the area whilst considerable proportion of chromic vertisols, eutric nitisols, eutric fluvisols and dystric fluvisols are also present (BPED, 2000). According to Central Statistics Agency of Ethiopia (CSA, 2007), the study area has a total population of 58,544 resulting in an average density of 317 in h/km^2 which is an increase of 55% since 1984.

Agriculture is the main income source for 86% of the population. Agriculture is characterized by mixed farming systems run by smallholders whereby local households grow cereals and enset (*Ensete ventricosum*) and keep livestock of cattle, goat and sheep. Common cereal crops are maize (*Zea mays*), teff (*Eragrotis tef*), sorghum (*Sorghum bicolor*), and barley (*Hordeum vulgare*). Cereals and livestock products are mainly meant for self consumption. In order to acquire an additional income many households are engaged in beekeeping and the growth of cash crops such as coffee (*Coffea arabica*) and Khat (*Catha edulis*) and various fruits and vegetables. Farmers sell their products on local markets in Yebu, Bilda and the city of Jimma. The long occupational history of the area has resulted in a fragmented landscape with patches of open fields and grazing land alternated with patches of primary and secondary forests.

2.2. Forest cover mapping

The forest cover in 1957 and 1975 was mapped by visual interpretation of aerial photographs at a scale of 1:50,000 provided by the Ethiopian Mapping Agency (EMA). An additional forest cover

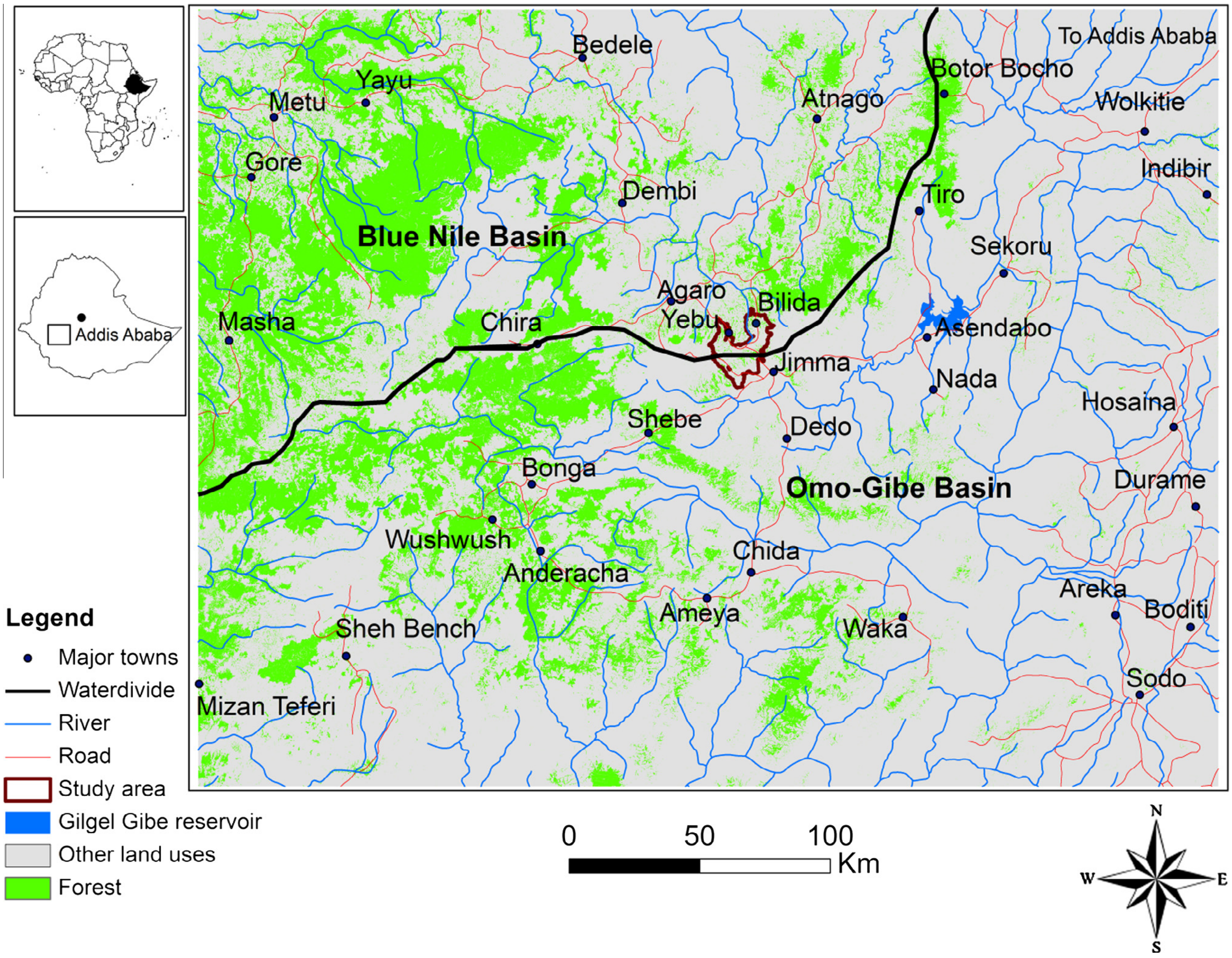

Fig. 1. Location of study area in Southwest Ethiopia.

map was produced for 2007 by visual interpretation of Quickbird satellite images with a spatial resolution of 0.6 m × 0.6 m provided by Digital Globe (2010). Because of cloud cover, images from two dates (7/12/07 and 25/12/07) were stitched together. The aerial photographs and satellite images were co-registered geometrically on the same geographic coordinate system, UTM WGS 84, Zone 37 via ground control points (GCPs) collected in the field using a handheld GPS. Additional GCPs for inaccessible areas were collected from topographic maps of 1980 at a scale of 1:50,000 and from Google Earth™.

In agreement with the definition of the Food and Agricultural Organization of the United Nations (FAO, 2006), a land unit was considered to be forested if it is larger than 0.5 ha and has a tree canopy cover of more than 10%. All the forests in the study area consist of evergreen tree species thus the mapping process was not biased by possible effects of seasonality. Therefore, forests were identified visually on the basis of their texture and color (typically dark-gray on panchromatic imagery). Boundaries of the forest polygons were digitized using ArcGIS software. Next, the forest cover maps of 1957, 1975 and 2007 were overlaid to produce deforestation and afforestation maps.

Forest degradation due to fuel wood collection could result in a gradual transition from forest to non-forest (although also clear-cut deforestation occurs) which is not visualized in the binary maps that were produced in this study. In theory it could be possible to map and analyze time series of continuous forest cover percentages. However, the available data do not allow assessing such percentages. Therefore, we opted to work with a binary classification: forest - non-forest following the FAO-definition with a procedure that was calibrated by means of ground truth data.

2.3. Collection of explanatory data

The observed forest cover change patterns were linked with explanatory variables that describe the socio-economic or biophysical characteristics of the land units. Table 2 gives an overview of all the variables that were taken into account. For all variables raster maps with a resolution of 90 m × 90 m were produced.

The socio-economic variables that were collected relate to the way of living of local households and the possibilities they have to generate an income through farming or non-farming jobs. Therefore, an extensive field survey was carried out from August till November, 2009 in which 163 households in the study area were interviewed. The households were selected using stratified random sampling techniques whereby hamlets with contrasting characteristics with respect to their biophysical and socio-economic settings and accessibility were selected in advance. Next transect walks were carried out to select households without considering population density. The transects were walked in both hamlets with high as well as low population densities. In each of the hamlets households were asked for their consent orally to participate in an interview which took 45 min on average.

Table 2
Description of biophysical and socio-economic variables influencing deforestation in Southwest Ethiopia during 1957–2007.

Variables	Acronym	Unit	Source
Biophysical			
Elevation	EL	m.a.s.l	SRTM-90 m (NASA)
Slope gradient	SG	%	SRTM-90 m (NASA)
Soil type (categorical)	ST	Categorical with five classes	FAO-Unesco (1974)
Socio-economic			
Distance from asphalt road	D-AR	km	Ethio-GIS (2004)
Distance from gravel road	D-GR	km	UTM topographic maps, 1:50,000 (EMA, 1980)
Distance from nearest market place	D-NM	km	Own processing
Population density	POPD	Population number/km^2	CSA (1984, 1994, 2007)
Household type	HT	Categorical with 3 classes	Cluster analysis based on field surveys

The objective of these interviews was to get a deeper insight in the livelihood of the households with an emphasis on the household economy and its implications for the land use. By means of semi-structured interview (SSI) techniques information was collected from each household on the composition of their total income whereby a distinction was made between incomes from farming on an own farm, farming as laborers and off-farm jobs.

Secondly, for each household an overview of their different expenditures was reconstructed. Expenditures were grouped into the following classes: food consumption, other household consumption, rent, and inputs for agriculture practices (i.e. fertilizers, seeds, labor, animal fodder, tools). This allowed to define different categories of typical livelihoods in the study area to which all the interviewed households could be attributed. Based on the location of the different livelihoods in the study area which was registered with a handheld GPS, a livelihood map was developed that depicts the livelihood pattern by grouping dominant livelihoods.

Moreover, additional GIS-layers were developed that describe market accessibility. The distance factors (distance from roads and local towns) were considered to be proxies for accessibility to market places. The software IDIRISI Andes was used to calculate Euclidean distances. Gravel roads were digitized from topographic maps at a scale of 1:50,000, while the location of asphalted roads was extracted from Ethio-GIS (2004) database.

The economic activities in the study area are oriented towards either to the town of Yebu and Bilida which can be considered as local market places or to the city of Jimma, which can be considered as a regional market place. The variable distance from town is therefore the distance to the most nearby market place.

Population density (persons/km^2) was derived for each village based on available census data provided by the Central Statistics Agency of Ethiopia (CSA) for the years 1984, 1994, and 2007.

Biophysical variables are related to the potential for agricultural production of different crops. Slope gradient and soil type can typically be linked with suitability for agricultural land. Elevation is potentially an important variable in the study area because it controls the possibilities for shade coffee production. Above 2000 m.a.s.l, the productivity of the coffee shrubs is considered to be too low for economic exploitation. The elevation and slope data were extracted from digital elevation model (DEM) obtained from Shuttle Radar Topography Mission (SRTM-90 m resolution). A raster soil map of the study area was produced by rasterisation of the digital soil map which was originally produced by FAO-Unesco (1974) at a scale of 1:5,000,000 and later on provided digitally by Ethio-GIS (2004).

2.4. Statistical analysis of the controlling factors of deforestation

In order to link the collected variables with the observed patterns of forest cover change binary logistic regression models were developed for the periods 1957–1975, 1975–2007, and 1957–2007 following a procedure described by Linkie et al. (2010), Arkehi, 2011 and Mon et al. (2012). In order to calibrate the models 3376 and 3329 sample points were selected at random from the forest polygons of the 1957 and 1975 maps respectively. Next, for each of these sample points it was evaluated whether they were still under forest (code 0) or deforested (code 1) in 1975 and 2007 respectively. In addition, the corresponding value of all explanatory variables for each of the sample points was extracted (Table 3). The compiled database allowed to parameterize an equation of the following form (Eq. (1)):

$$\begin{aligned}\mathrm{Logit}\rho = \ln\left(\frac{\rho}{1-\rho}\right) &= \alpha + b(\mathrm{EL}) * (\mathrm{EL}) + b(\mathrm{SG}) * (\mathrm{SG}) + b(\mathrm{ST}) * (\mathrm{ST}) + b(\mathrm{D} \\ &\quad - \mathrm{AR}) * (\mathrm{D} - \mathrm{AR}) + b(\mathrm{D} - \mathrm{GR}) * (\mathrm{D} - \mathrm{GR}) + b(\mathrm{D} \\ &\quad - \mathrm{NM}) * (\mathrm{D} - \mathrm{NM}) + b(\mathrm{POPD}) * +(\mathrm{POPD}) + b(\mathrm{HT}) \\ &\quad * (\mathrm{HT}) \end{aligned} \tag{1}$$

where EL refers to elevation, SG – slope gradient, ST – soil type, D-AR – distance from asphalt road, D-GR – distance from gravel road, D-NM – distance from nearest market place, POPD – population density and HT – household type.

Categorical variables (such as soil type and household type) were coded with dummy variables (Hosmer and Lemeshow, 2000). Parameterization of the equation was carried out using SAS Enterprise Guide 4.2 statistical software. The standard error on each of the parameterized coefficients was assessed which allowed to retain only the variables that were significant at a 95% level. The overall statistical significance of the final models was assessed using Wald Chi^2 statistics and percentage of correctly predicted observations.

3. Results

3.1. Forest cover mapping

Fig. 2 shows the compiled forest cover maps for 1957, 1975 and 2007. Over the studied time span the forest cover percentage in the study area decreased from 32.6% in 1957 over 28.1% in 1975 to 26.4% in 2007. These numbers correspond with a net yearly deforestation rate of 0.38% for the period 1957–2007. The maps show that the net yearly deforestation rate is decreasing over time. In the period 1957–1975 the net yearly deforestation rate was 0.76% and dropped to 0.19% in the period 1975–2007.

Fig. 3 shows the deforestation and afforestation patterns between 1957 and 1975 and between 1975 and 2007. The maps show that afforestation became an important factor after 1975 and is responsible for the overall slowing down of the net deforestation.

Table 3
Significant predictors of deforestation in the study area for the periods 1957–2007, 1957–1975, and 1975–2007. (EL – elevation; SG – slope gradient; ST – soil type; D-AR – distance from asphalt road; D-GR – distance from gravel road; D-NM – distance from nearest market place; POPD – population density; HT – household type).

Parameter	Categories	1957–2007		1957–1975		1975–2007	
		Coeff.	*P*-value	Coeff.	*P*-value	Coeff.	*P*-value
Intercept		−13.6	<.0001	−21.1	<.0001	−5.66	<.0001
EL		0.0052	<.0001	0.0085	<.0001	NS	NS
D-AR		0.28	<.0001	0.00019	<.0001	0.00036	<.0001
D-GR		0.16	0.025	0.00048	<.0001	−0.0005	0.0013
D-NM		NS	NS	NS	NS	0.00018	0.004
HT	Non-farmers	−1.26	<.0001	−1.26	<.0001	−1.17	0.0074
HT	Poor-farmers	0.07	0.563	0.49	0.0171	−0.54	0.0329
SG		−0.13	<.0001	−0.14	0.0002	NS	NS

NS = Non-significant.

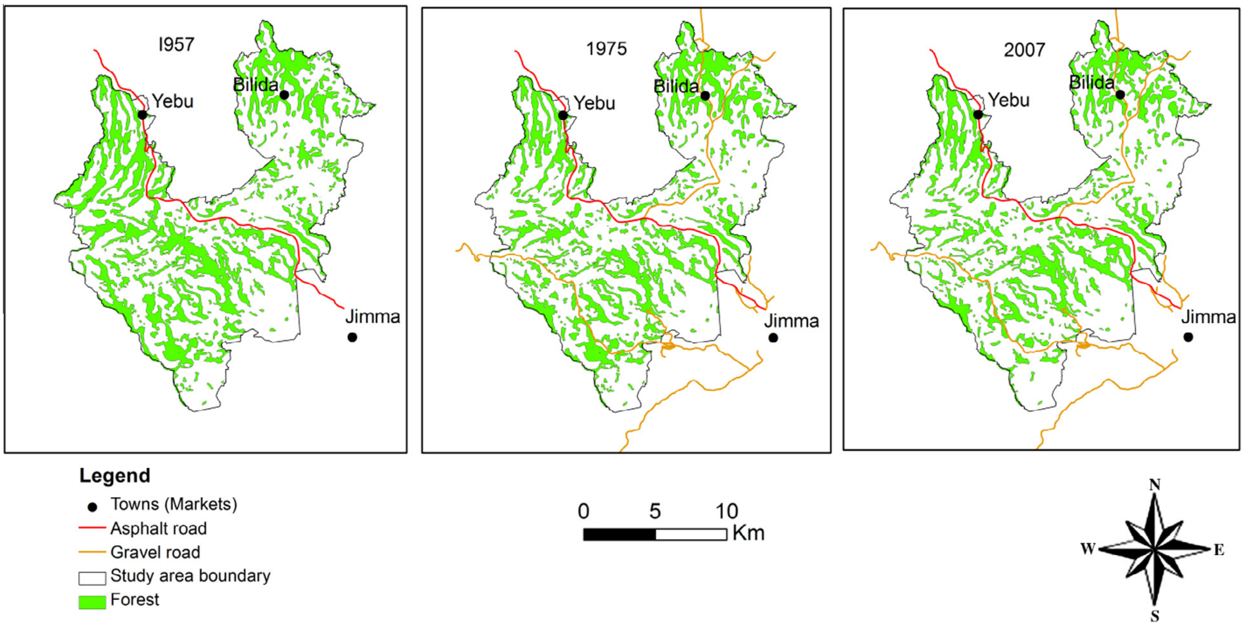

Fig. 2. Forest cover in the study area in 1957, 1975, and 2007.

3.2. Spatial pattern of the predicting variables

Fig. 4 shows the location of the households that were interviewed. Based on the interviews, schematic overviews of the household economy were developed. A household can generate an output by investing capital or own labor force. The output can be consumed within the household or sold on a market to generate a cash income. Based on the importance of the different fluxes of capital and labor, 3 household types were identified: rich farmers, poor farmers, and off-farm laborers. Fig. 5 gives a schematic overview of these fluxes for the 3 different household types.

Rich farmers have sufficient capital to invest in the land. Apart from their own labor they can rent labor from other farmers to cultivate their fields. Typically these farmers cultivate larger areas and reach a higher productivity because they use additional inputs such as fertilizers, animal labor and improved seeds. The production they generate is sufficiently large to support the whole family and to sell crops on the market in either Yebu, Bilida or Jimma. In some cases an additional income is generated by renting out farm tools or oxen. The rich farmers are located nearby the asphalted roads and close to the market place in the northwestern part of the study area (see Fig. 4). Moreover, this area is characterized by nitisols and vertisols which are the most suitable soils for coffee and grain crop production respectively.

Poor farmers have a very limited capital and can only invest their labor force on their own land or on the land of another farmer. Typically these farmers cultivate relatively small areas. Because of the lack of additional inputs their farming productivity is low. In most cases their crop yield is to a large extent consumed within the household. A limited amount of cash is generated by working on the fields of rich farmers and limited sales on the market. These farmers are dispersed over the southern part of the study area, often at remote locations.

The third household type generates a living from non-farming jobs which can be found in the local towns of Yebu and Bilida and the city of Jimma. The non-farmers are involved in a large range of sectors such as small-scale trading, civil administration, education, guarding, the health sector, the construction sector and coffee processing activities. The possible yield from their small gardens is fully consumed within the household and additional food is bought from markets. Most people with an off-farm job live very nearby to road networks. Fig. 4 depicts the zone with a dominant presence of 1 of the 3 identified household types.

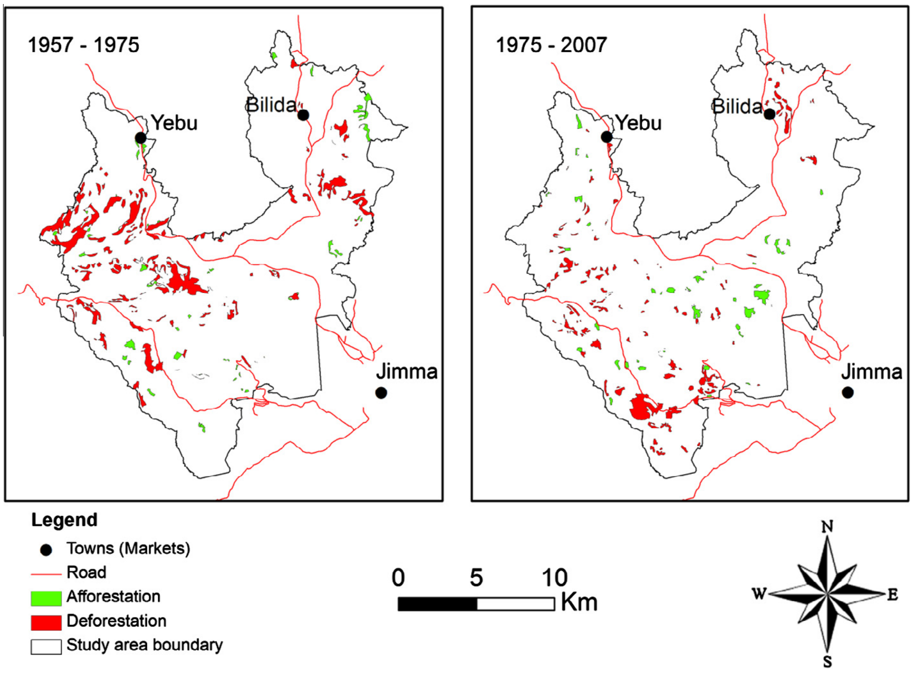

Fig. 3. Evolution of forest cover change in the study area during 1957–1975 and 1975–2007.

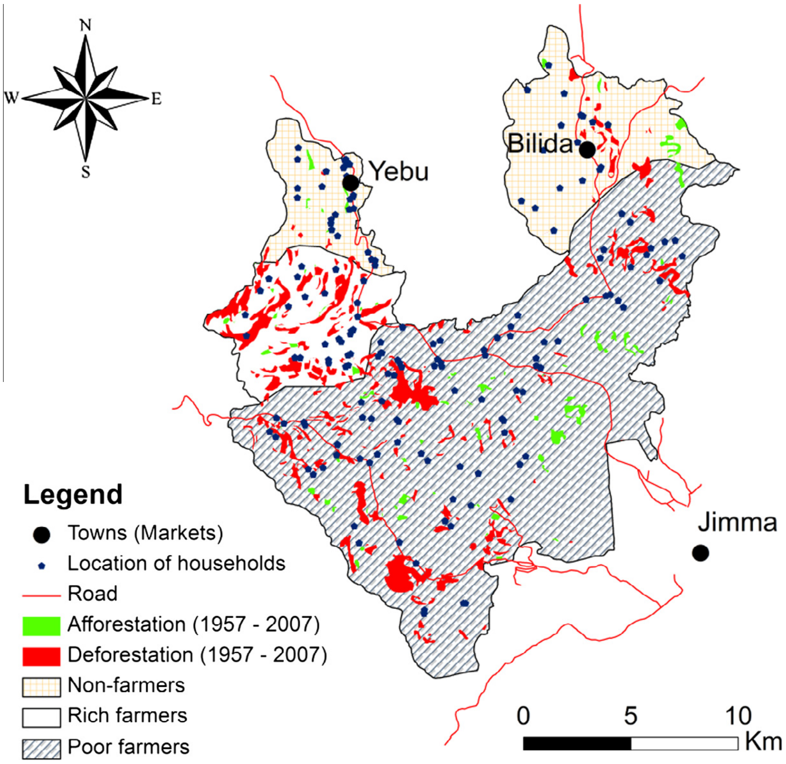

Fig. 4. Location of the interviewees and generalized distribution of the household types.

Fig. 6 shows the spatial pattern of the other socio-economic parameters that were taken into account: distance from the road network, distance from the market places and population density in 2008. The study area is dissected by three major roads that are passable by car and truck: from Jimma to Yebu, from Jimma to Bilida and from Jimma to Segno-Gebeya west of the study area. The remaining part of the study area can only be reached on foot and pack animals. Areas with a higher population density (>300 persons/km^2) are found in the surroundings of Yebu and Bilida and the southwestern part of the study area.

Fig. 7 shows the spatial pattern of the potential biophysical predictors of deforestation. The higher altitudes of the study area can be found in the western part. The climatic conditions in areas above 2000 m.a.s.l are too cold for commercial coffee growing.

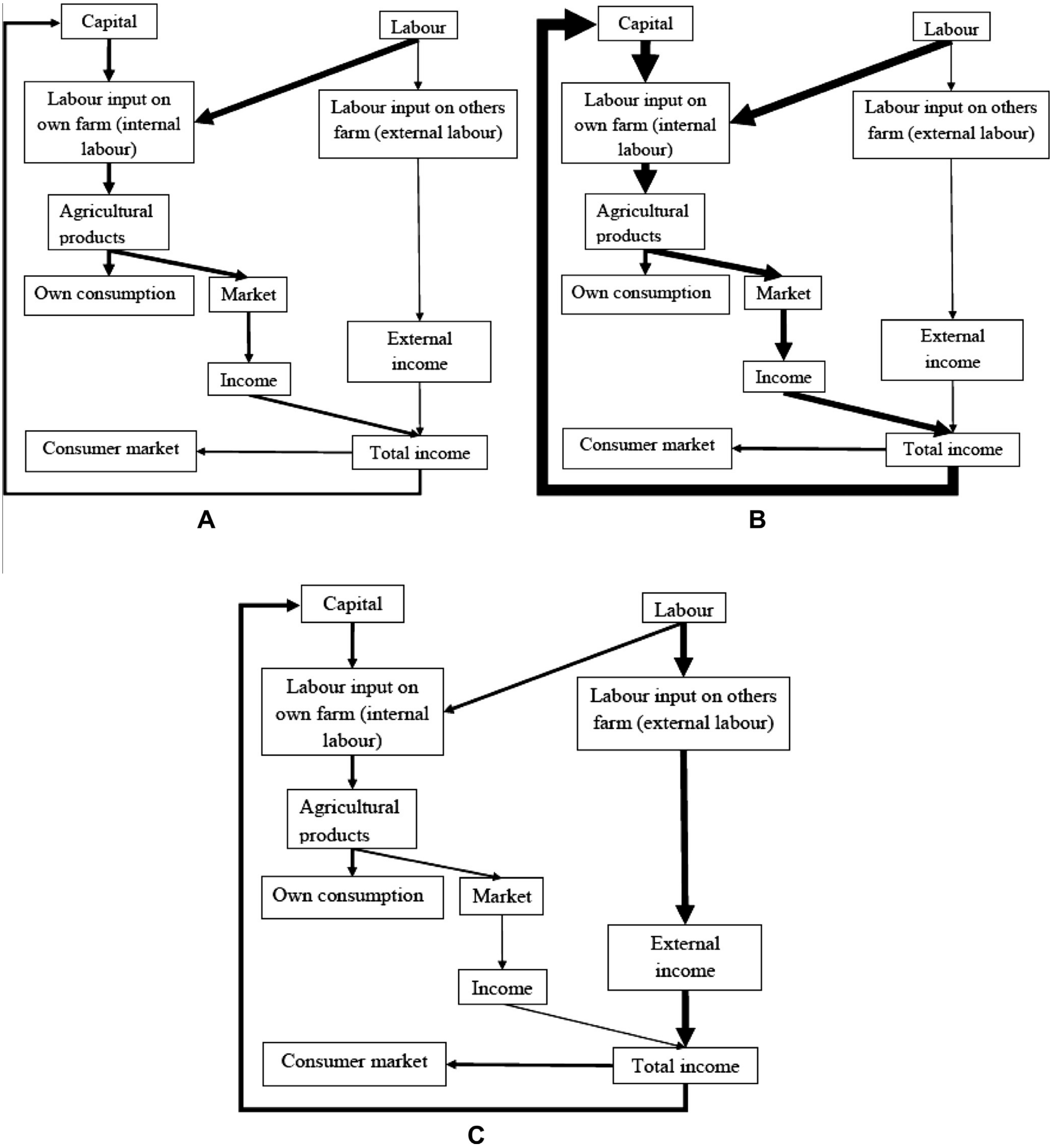

Fig. 5. Schematic diagram showing fluxes of capital and labor in the 3 household categories: (A) poor farmers, (B) rich farmers, (C) non-farmers. The width of the arrows indicates the relative importance of the fluxes of labor and capital for each household type.

The spatial pattern of the slope gradients shows a similar pattern with steeper slopes in the west of the study area. The dominant soil types are dystric nitisoils. In the west the more fertile chromic vertisoils and eutric nitisoils can be found.

3.3. Analysis of controlling factors

Possible predicting variables were linked with deforestation patterns by calibrating a logistic regression. The stepwise regression, in which non-significant predictors were excluded, resulted in the coefficients shown in Table 3.

The predictors soil type (ST) and population density (POPD) were found to be not significant for all the studied periods. This can be explained by the fact that the available soil map is derived from a relatively coarse resolution source (1:5,000,000) and has therefore a generalization level which is too high to detect possible correlations with land use change. The available population density map is only available at the level of village for the present-day situation. Possibly population change between 1957 and

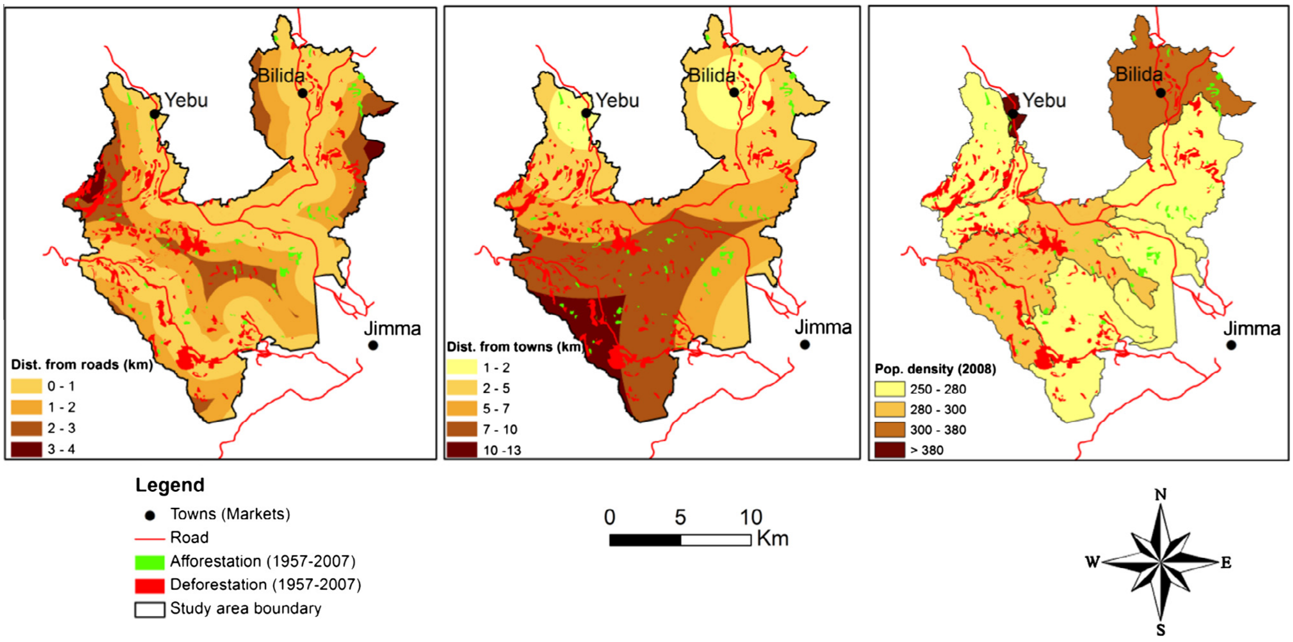

Fig. 6. Potential socio-economic predictors of deforestation.

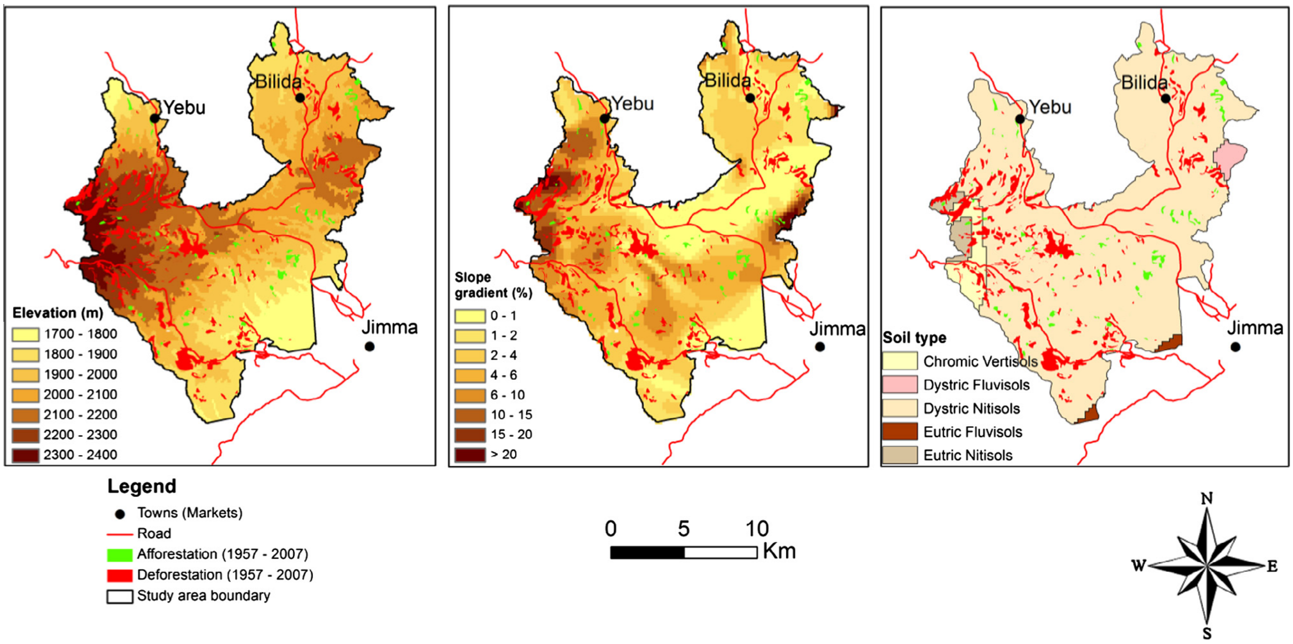

Fig. 7. Potential biophysical predictors of deforestation.

2007 could correlate with the deforestation pattern but population data from 1957 are lacking to test this hypothesis. A visual inspection of the D-NM (distance to the nearest market place) map shows that areas in the southwest which are at relatively remote location appears to be crossed by a road which improves the accessibility. Distance to the market place was not a significant predictor for deforestation in the period 1957–1975, but became significant in the second period (1975–2007) implying that new and accessible off-farm jobs were able to slow down deforestation. Accessibility was not found to be a significant predictor for the period 1957–2007 because it is only at the end of this long period that off-farm jobs became important.

Table 3 shows that deforestation is correlated with the dominant presence of a certain household type (HT). Regions with a dominant presence of non-farmers were significantly less deforested, which can be explained by the fact that because of their off-farm income there was no need to claim new arable land. No significant distinction could be made between the deforestation in regions with poor or rich farmers. The correlation with the distance variables (D-AR and D-GR) shows that accessibility is a significant parameter to explain the observed deforestation pattern during all the studied periods (Table 3). Deforestation typically occurred at remote places away from the road system. A visual inspection of the forest map from 1957 (Fig. 2) shows that the forest was still intact nearby the roads. This is also confirmed by Table 4 that shows the percentage of forest cover within three stratified distance zones (<3 km, 3–6 km and >6 km) away from roads in 1957. The forest percentages in these distance zones show

Table 4
Percent of forest cover within 3 stratified distance zones from road network in 1957.

Distance zones (km)	Forest cover (%)
0–3	21.39
3–6	9.27
>10	4.44

that already before 1957 the landscape was more deforested farther away from the roads. The two gravel roads were only constructed in the 1970s (Fig. 2). Before the 1970s the study area was only enclosed by the main asphalt road from Jimma in the southeast to Yebu in the northwest. Therefore, the two gravel roads were only taken into account to explain the deforestation in the second period (1975–2007). Some parts of the asphalt road received minor upgrades and maintenance over time without a strong impact on the transport capacity. These minor upgrades were not considered in the analysis of the deforestation process.

Table 3 shows that the deforestation probability is positively correlated with elevation which means that land units at a higher elevation such as in the west of the study area were more prone to deforestation. The deforestation was found to correlate negatively with slope gradient: flat land units were preferred over steep land units for expansion of the arable land. Elevation (EL) and slope gradient (SG) were found to be important predictors of deforestation in the periods 1957–1975 and the overall period 1957–2007. During 1975–2007, however, these topographic variables were no longer significant in the regression equation implying that deforestation was also taking place on the steeper slopes at lower altitudes.

The Wald X^2-values of the model for the periods 1957–1975, 1975–2007 and 1957–2007 were assessed at 131.17, 44.93 and 97.76 respectively which are significant at a 1% confidence level. The percentages of concordant pairs for the respective periods were 79.4, 79.8 and 74.4.

4. Discussion

The results presented above show that the deforestation that was observed in the study area can be linked with the expansion of arable land by smallholder farmers. These smallholders make strategic decisions which explain their spatial behavior. In the neighborhood of the small towns off-farm jobs are available, which relieves the pressure on the land and therefore lower deforestation rates. Farming households rely for their income completely on the availability of farming land. The most suitable land is found on good accessible places nearby roads on relatively flat land units. Therefore steep areas were less deforested while high elevation was preferred for deforestation (because these land units are less suitable for coffee production) in the periods 1957–1975 and 1957–2007. Such biophysical control has been observed in many parts of tropical highland areas (e.g. Costa Rica, Sander and Joyce, 1988; Ecuador, Vanacker et al., 2005; Ethiopia, Teka et al., 2013). During 1975–2007, however, the pressure on the land became so high that these land characteristics were no longer significant as controlling factors of deforestation in the study area. From 1975 onwards deforestation took place at lower elevations including land units on steep slopes especially in the south of the study area. The deforestation in these localities can probably be linked with immigration from northern Ethiopia, which resulted in an increase of the population pressure resulting in the reclamation of farmland even on less suitable land units. For a more in- depth analysis of this local phenomena detailed and reliable data on migrations at village level should be collected and analyzed.

Another finding from this study is that deforestation occurred in relatively remote places away from the road systems. The results show that the impact of an asphalted road is even stronger than the impact of a gravel road. In many case studies (e.g. Brazil, Malingreau and Tucker, 1988; the Philippines, Liu et al., 1993; Cameroon, Mertens and Lambin, 1997; Belize, Chomitz and Gray, 1996; Congo, Wilkie et al., 2000) of tropical deforestation the opposite was reported: high rates of deforestation occur along roads as new regions are made accessible for new farmers that clear the land for arable farming of cattle holding. The landscape studied in this paper was however already occupied before 1957. As a response to the great famines of the 1980s, which took place in the northern part of Ethiopia many people migrated from the northern to Southwest Ethiopia (Wood, 1993). Since all the accessible land was already occupied these new immigrants were forced to settle in remote locations of higher elevations and clear the land to make a living. Even after three decades these immigrants were on average not able to obtain the living standards of the original farmers because the profits they can generate with their farming activities are much lower due to a lower soil quality and higher transportation costs.

An additional element in the strategic decision making of households in the study area is the suitability for coffee cultivation. Forest areas above 2000 m.a.s.l are of very little use for the local population since they cannot be used for coffee growing because the frost risk is too high (Girma et al., 2007). The more productive forests at lower elevations were therefore protected to a certain extent. The fact that the study area is to a certain extent suitable for coffee growing explains why the observed deforestation rate of 0.38% per year is substantially lower than the national Ethiopian average, which was assessed at 2.4% for the 1975–1999 period (Reusing, 2000). It is also lower than the rate for Baro-Akobo basin in western Ethiopia, which was assessed at 1.2% per year in 1987 and 1.6% per year for the period 2005–2010 (Sutcliffe, 2009). In Baro-Akabo basin the deforestation rate is increasing over time, while this study area showed a decrease over time from 0.76% during 1957–1975 to only 0.19% in 1975–2007. This can be interpreted as a consequence of an increase in the coffee price at the world market. Coffee became gradually a significant income source for smallholder farmers which adapted their behavior: instead of generating an additional income from new arable fields, the coffee producing forests are considered as a source of income that justifies their protection. The observation that suitability for coffee growing can slow down the deforestation process is, however, only valid in the case of shade coffee, whereby the coffee plants need to be protected from direct sunlight. In areas suitable for sun coffee, the increase of the coffee price has been reported as a driver of deforestation. Verbist et al. (2005) reported where 60% to 10% conversion of the forest to monoculture sun coffee in Lampung province of Sumatra in Indonesia following the local increase in coffee price.

5. Conclusions

This study has examined biophysical and socio-economic factors that could potentially influence the likelihood of deforestation in Southwest Ethiopia. Patterns of deforestation in the study area are mainly controlled by elevation and slope gradient on the one hand, and distance from roads and the types of household economy on the other hand. This resulted in deforestation patterns that are quite different from other tropical areas such as the Amazon and the Congo basins where deforestation took place next to newly constructed roads.

The observation that in the study area deforestation occurred mainly away from the roads cannot be explained by a delay effect whereby initial deforestation (before 1957) took place nearby the roads. The results from this study suggest that deforestation occurred away from roads because (1) deforestation is primarily part of a subsistence strategy in this region, and (2) the presence of roads is positively correlated with the availability of off-farm jobs. The further implication of these findings is that poverty and deforestation are positively correlated in this region whereby the poor households are typically located farther away from roads.

The findings have also indicated the huge economic impact of coffee causing a certain amount of forest to exist to-date in the region. One of the conclusions that can be drawn from this study is that factors controlling patterns deforestation are region-specific to a certain extent. Thus the explanatory variables can rarely be generalized. It is therefore crucial to start with a general conceptual framework to investigate and understand local causes and controlling factors of deforestation as they may contribute heavily towards forest evolution. The findings from this study would therefore have the following relevance for policy makers that aim at reducing deforestation:

(1) In the case of deforestation driven by smallholder farmers it is important to reduce the number of self-subsistence farmers. This can be done by increasing the accessibility of relatively isolated places by road upgrading or road construction. This gives the relatively poor households the opportunity to find off-farm jobs in local towns or to access the market with their crops. This should lead to the gradual abandonment of low-productive farming where production costs are higher than the market price.

(2) In areas that are suitable for coffee-growing, shade coffee production and forest conservation can be combined. This study showed that coffee growing slowed down deforestation. Policy makers could stimulate this mechanism by setting up market systems that ensure that a sufficient part of the profits of the coffee economy trickles down to the local households who will consider it as an important alternative for the installation of new arable fields.

Acknowledgements

This research was supported by VLIR, IUC-JU (Interuniversity partnership program between Belgian universities and Jimma University in Ethiopia). The authors are thankful to all ministries and institutions in Ethiopia which provided the necessary data to undertake this research. They are also grateful to professional and administrative workers of the Mana Woreda (district) Agriculture and Rural Development Office (ARDO) in Jimma Zone for facilitating the whole course of field data collection process. Last but not least, our appreciation goes to the two anonymous reviewers for their constructive comments and suggestions that helped to improve the quality of the paper.

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