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Angewandte Fernerkundung mit der Google Earth Engine

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Changes in forest cover in the Upper Blue Nile Basin, Ethiopia – an analysis with the Google Earth Engine

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Abstract

The aim of this study is to investigate the success of reforestation campaigns in the Upper Blue Nile Basin (UBNB) that were carried out to combat deforestation. Deforestation is mainly caused by short-term economic benefits. In the long term, however, it leads to ecological problems such as soil degradation and loss of biodiversity. The results of the remote sensing studies using the Google Earth Engine show progressive deforestation. Despite decades of efforts to curb deforestation, the UBNB is the most deforested region in Ethiopia with a loss of 43% of forest cover between 2000 and 2022. The analysis of the land cover classifications shows a decrease in forest area with an increase in the Normalized Difference Vegetation Index despite new tree plantings. This indicates that existing forests have been converted into non-forest areas or agricultural land. Furthermore, tree planting has been hampered by the historical top-down approach and hasty actions. The study results underline the insufficient quantity and quality of the campaign-based reforestation measures. However, a shift in reforestation towards community-centred planting and sustainable care of the seedlings has potential for successful long-term reforestation of the UBNB.

1 Introduction

Land degradation is defined as deterioration or loss of the productive capacity of soils (GEF 2023:sec.1) caused by and leading to ecological and socioeconomic issues (Tekle 1999:419). Due to natural and human activities, Ethiopia is facing severe land degradation (Megerssa/Bekere 2019:1955) that acts as an ever-expanding ecological crisis (Egziabher 1989:62). Species extinctions, habitat loss, as well as landscape and ecosystem degradation have increased public awareness of the need to maintain critical habitats and protect biodiversity (Lugo et al. 1993:108f.).

One of the main causes and consequences of Ethiopia's land degradation is deforestation (Megerssa/Bekere 2019:1955), so the Ethiopian government and non-governmental organizations started to act against deforestation and support afforestation measures. Numerous analyses of the changes in forest cover in Ethiopia from 2000 to 2023 are needed to evaluate the measurements. But there is a gap in research. Despite various land restoration efforts for over 40 years, impacts and successes have not been comprehensively evaluated. Hence, there is no clear/quantitative evidence of the success or failure of interventions (Abera et al. 2019:43). Also with afforestation programs, 'there was no follow-up on the planted seedlings and no regular reports after the year of planting' (Tekle 1999:424). Any landscape restoration practices tend to show meaningful impacts only after longer periods of time, but about half of the studies (48 %) were conducted already five or less years after implementation began. Therefore, conducting impact studies of long-established restoration sites will be essential in the future to develop programs for sustainable reforestation and landscape restoration (Abera et al. 2019:43). In particular, the use of remote sensing and geographic information systems in these studies can provide authoritative insights for policy and decision-making regarding investments in restoration projects (Adimassu et al. 2018:19).

This work aims to shrink this gap in research. A monitoring of the success of the afforestation measures shall clarify whether the reforestation measures are persistent in the long term. Consequently, the period from 2000 to 2023 will be considered in terms of the following research questions:

1) How much and which areas of the Upper Blue Nile Basin (UBNB) are covered by forests?

2) How did the extent of forest evolve? Is there a trend of deforestation (forest loss) or afforestation (forest gain) in the UBNB?

To answer these research questions, analyses of the NDVI, a land cover classification (LCC) and other forest related datasets are conducted for the UBNB using the Google Earth Engine (GEE) (see chp. 4.2).

2 Deforestation in Ethiopia

As a result of higher rainfall and temperatures, moist evergreen montane forests naturally occur in southwestern Ethiopia. Dry evergreen montane forests could be found in central, eastern and northern Ethiopia. Highland forests are potentially accompanied by upland grasslands and swamps where drainage and other edaphic factors make tree growth impossible. The wetter western lowlands, which merge into the highlands along river valleys, have savannas, with the higher slopes covered by deciduous forests. The drier eastern lowlands were originally covered by acacia forests and scrub, the eastern escarpments by evergreen scrub and succulents (Egziabher 1989:62).

2. 1 Extent of deforestation in Ethiopia

Deforestation has been a pattern throughout Ethiopian history (Pankhurst 1992:73). As early as the 1940s, in Ethiopia a point was reached where the resilience of the local ecology began to break down (Ståhl 1990:142). At least since the 1970s, land use and land cover have been changing significantly (Duriaux-Chavarría et al. 2020:1446). Anthropogenically, almost all dry evergreen montane forests, upland grasslands and most of the moist evergreen montane forests were converted to cropland and grassland. Acacia forests also had to give way to cropland. Only the acacia scrub is too dry for agriculture and is therefore not severe disturbed. The evergreen scrub, which originally grew on shallow soils and in rock crevices, has spread because of expanding soil erosion (Egziabher 1989:62).

The following graph shows the loss of tree cover in Ethiopia in the period from 2001 to 2020, which already takes reforestation into account. Despite strongly fluctuating loss values, the trend of increasing deforestation is clear. More than 100 km²/year were lost in each year during the study period. The highest deforestation rate occurred in 2012 with 416 km², the lowest in 2015 with 103 km² (fig. 1).

The region around Addis Abeba shows the greatest loss of tree cover at 38.5 %. The percentage loss of the other regions including the whole of Ethiopia ranges from 2 % (Amhara) to 4 % (Oromiya). The least loss of tree cover occurred in the period 2001 to 2005 and was 445 km². The greatest loss happened between 2011 and 2015 at 805 km². All regions except Benishangul and Ethiopia as the whole state lost the most tree cover between 2011 and 2015. Benishangul's highest losses took place from 2006 to 2010. Overall, the decrease in tree cover decreased again after 2015, but remained higher than in the periods before 2011 (fig. 2).[1]

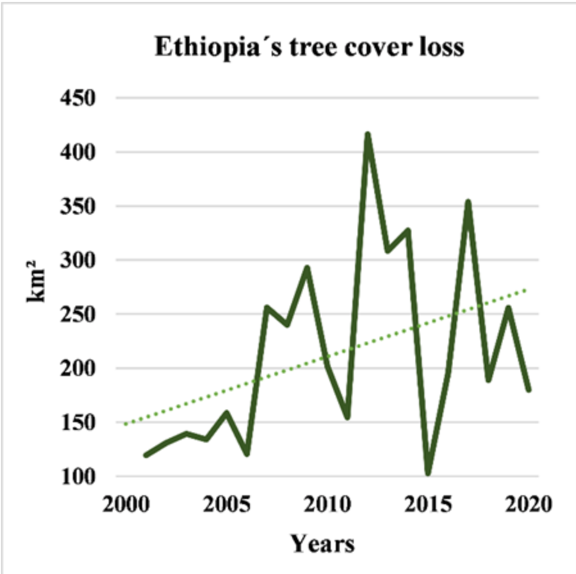

Figure 1: Ethiopia's tree cover loss from 2001 to 2020. Own illustration 2023, source of the data: Mongabay 2022.

In total, Ethiopia loses about 1,410 km² of natural forest every year (Oljirra 2019:1750) due to forest fires and tree cut-ting (Oljirra

[1] Depending on the source, the Ethiopian regions are spelt differently: Oromia/Oromiya, Benishangul/Benishangul-Gumuz/Gumaz or Addis Abeba/Ababa

2019:1753). Trees were in many cases felled by burning the base of their trunks what prevented plants from growing up again (Pankhurst 1992:62).

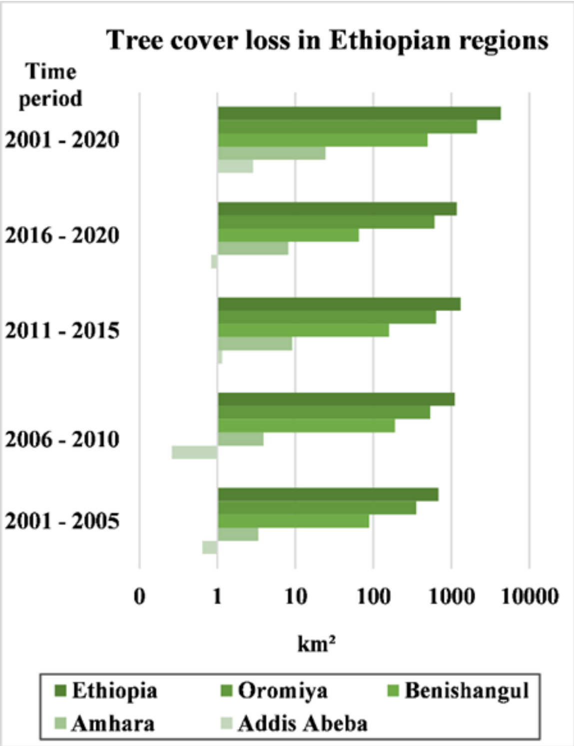

Figure 2: Tree cover loss in Ethiopian regions in different time periods from 2001 to 2020. Own illustration 2023, source of the data: Mongabay 2022.

2.2 *Reasons of deforestation in Ethiopia*

Deforestation mainly took place and expands faster in areas of extensive settlement (Pankhurst 1992:62,73). Thus, deforestation is related to population growth in Ethiopia, leading to the expansion of agriculture. The ambition to improve the economy and political unrest also encourage deforestation, that led to an ecological, social and economic crisis in Ethiopia (tab. 1).

Table 1: Reasons and consequences of deforestation. Own illustration 2023, source of the data: 1: Abera et al. 2019:41, 2: Tekle 1999:425, 3a: Duriaux-Chavarría et al. 2020:1446, 3b: Duriaux-Chavarría et al. 2020:1449, 4a: Oljirra 2019:1749, 4b: Oljirra 2019:1753, 5a: Lugo et al. 1993:106, 5b: Lugo et al. 1993:1075, 6: Culas 2006:436, 7: Megerssa/Bekere 2019:1956.

Reasons of deforestation / vegetation removal	Consequences of deforestation
Population pressure	Land degradation
Increase in population density[4a&b]	Formation of barren deserts[4a]
Urbanization[4a&b]	Reduction of soil quality[4b]
	Increase of soil salinity[4b]
	No longer fixation of soil and bedrock by roots → Landslides[4b]
Improving economy	Lower capacity to hold groundwater[4b]
Short-term economic benefits[4a]: harvesting (fire) wood[7]	Soil erosion and flooding[4b]
	Surface runoff and increased sub-surface flow[4b]
Improvement of food and income supply[3a]	
Plantations of monocultures[5a]	

Maximization of net yield and profit[5a] Seek for wealth and power due to harvesting forests[4a]	
Institutional dimension Corrupt government[4a] Negligent forest management and forest sector policies[6] Deficient environmental legislation[6]	Economic problems Resource depletion[1,7] Decrease in construction materials and fuelwood availability[3a,7] Decrease of agricultural activity by salinity[4b] Lack of medicinal products from forests[4b] Decrease in livestock numbers[3a]
Expanding agriculture Intrusion of cropping land into forest[1] Creation of more cultivation area[2] Increase of crop production after famines[2] Knowledge gap of sustainable agricultural and agroforestry practices[3b]	Exacerbation of climate change[4a] Extreme fluctuations in temperature[4a] Drying out of soils[4a] Drier climate[4b] Reduction in atmospheric moisture (transpiration) and the water table[4b] Lack of shade[4a] Decrease in water availability in rivers[3a]
	Loss of biodiversity[5a] Reduction of genetic variation[5a, 4b] 100 % deforestation → 40 - 100 % species loss[5b] Loss of various rare plant and animal species[4b]

3 Afforestation in Ethiopia

The following chapter´s focus is mainly on tree planting programs (TPP), but there are other methods to restore vegetation cover in Ethiopia, too. The approach of growing indigenous trees as a natural succession in plantations on degraded lands is being pursued but needs proper species selection and adaptation trials as well as adapted management practices of plantations/secondary forests (Lugo et al. 1993:107f.). In parallel to natural regeneration, vegetation and trees can also be restored by seed balls (Duguma et al. 2020:14).

3.1 Importance of afforestation

The multifaceted and complex problems associated with land degradation require comprehensive solutions that include conservation measures and agricultural development activities (Tekle 1999:424). There are compelling reasons to act against Ethiopia's deforestation.

Afforestation and tree planting can lead to a reduction in soil degradation. For this to happen, they must be properly implemented and monitored, because planting itself is no guarantee of increasing vegetation cover (Takele et al. 2022:5). Effective afforestation is ecologically beneficial, because forests serve to protect (cultivated) land against further erosion and destruction by run-off at the foot of the hills and mountains. Forests also enrich biodiversity (Green Ethiopia Foundation 2022:6). Sane forests support a range of biological diversity with endemic among plants, birds and mammals (FSC w.y.a). Forest soils can store and filter the precipitation that falls during the rainy season (Green Ethiopia Foundation 2022:6) and conservate water catchments (FSC w.y.a). In addition, forests soils sustain nutrient cycles in soils (Megerssa/Bekere 2019:1955). Forests benefit the microclimate as trees and forests cool their surroundings (Green Ethiopia Foundation 2022:6). The macroclimate is affected by forests, too. Trees remove CO^2 from the atmosphere and store it in biomass and soils. In this way, they counteract climate change. Forests that are cleared or damaged release the stored carbon and turn from a sink into a source of greenhouse gas emissions (FAO 2023: par.1). Forests also sup-port livelihoods of locals and socioeconomic development of Ethiopia by providing goods and services (FSC w.y.a). For example, farmers can keep bees on the edge of mixed forests. In addition to the wood from the trees (construction, furniture and firewood after 10 years), farmers benefit from the cultivation of organic wild coffee and grasses, which are used to feed live-stock or as roofing material (Green Ethiopia Foundation 2022:6).

One of the big problems is, that there was no traditional policy of rural afforestation or re-afforestation (Pankhurst 1992:62), so conversation and afforestation programs had to be established. The main objectives of these programs are to protect the remaining well-preserved areas of the rural environment in Ethiopia and to rehabilitate those that have deteriorated, maximizing both livelihood and biodiversity. To achieve these development goals, it is crucial to adopt a balanced approach to land use (Duriaux-Chavarría et al. 2020:1449). An essential component of the SLMP is to empower local communities to use natural resources sustainably and thus mitigate the problems of land degradation long term (Tekle 1999:424). Adjusting ecosystems and implementing agroforestry practices are essential for sustainable forest use, as they contribute to poverty reduction among rural farmers who are vulnerable to the negative effects of land degradation (Megerssa/Bekere 2019:1955). Furthermore, the decreasing availability of forest resources, such as wood, has prompted farmers to undertake reforestation activities. Consequently, they support natural regeneration (Duriaux-Chavarría et al. 2020:1446) and plantings of Australian Eucalyptus (Pankhurst 1992:69). Additionally, the occurrence of famines due to land degradation has had political implications, leading to a governmental change in Ethiopia. The succeeding socialist government responded by implementing hillside closures and reforestation activities. These initiatives were carried out through a food-for-work (FFW) program, where participants got grain for planting seedlings and constructing terraces (Tekle 1999:422). Moreover, the local population has increasingly realized the necessity of legal recognition and protection of trees for the sake of future generations (Oljirra 2019:1753).

3.2 Afforestation Programs in Ethiopia

There have been many afforestation initiatives in Ethiopia in the past several decades (Takele et al. 2022:5) to stop deforestation and reverse the damages of land degradation. An example for TPPs is the program Reducing Emissions from Deforestation and forest Degradation, plus the sustainable management of forests, and the conservation and enhancement of forest carbon stock (REDD). It is intended to mitigate climate change by stopping deforestation and reforesting land (FAO 2023: par.1). Another cost-effective land restoration method is Farmer Managed Natural Regeneration (FMNR). It involves regrowing and managing trees and shrubs from stumps, roots or seeds. These regrown plants are integrated into crops and pastures, restoring soil quality, preventing erosion and conserving soil moisture. Additionally, FMNR promotes the rejuvenation of springs and water tables, while also enhancing biodiversity. FMNR provides significant benefits to subsistence farmers like access to natural forest re-sources, thus higher incomes and improved living standards for farming families and their communities (World Vision Australia 2019). In general, nurseries mostly from the Ministry of Agriculture and communal tree nurseries raise several million seedlings annually. Eucalyptus, Cupressus and Acacia are most grown and planted. Some nurseries also grow grass seeds for the stabilization of terraces and the improvement of pastures (Ståhl 1990:143). Also, international foundations like the Swiss Green Ethiopia Foundation plants millions of trees in Ethiopia every year. They have planting sites in the Oromiya region, but they are located outside the UBNB (Green Ethiopia Foundation 2022:4). Other sites of the foundation are in the Amhara Region in the watersheds of Lake Tana, draining into the BN. In 2022 3,142,960 forest trees, 24,947 fruit trees and 303 coffee trees have been planted in this area (Green Ethiopia Foundation 2022:7). The foundation uses seedlings of mainly indigenous tree species (Green Ethiopia Foundation 2022:6) which are planted on slopes, in fields or in home gardens. On average 2500 plants per ha up to 10,000 seedlings are planted in very severely eroded areas (Green Ethiopia Foundation 2022:7). Four to six months the seedlings are nurtured in nurseries by women and landless youth until they are transported to the mountains (Green Ethiopia

Foundation 2022:8). Subsequent plantings take place two to three weeks after the beginning of the rainy season (July), so the soil is saturated with water (Green Ethiopia Foundation 2022:6). 95 % of the seedlings planted in 2022 survived the first months after dry season (Green Ethiopia Foundation 2022:2). The greatest danger to young trees is the intrusion of livestock into the forests (trampling, feeding), so protective measures are agreed with the farmers (Green Ethiopia Foundation 2022:9).

To reduce pressure on resources and conserve forests (Culas 2006:436), people need to be encouraged to plant more trees and protect forests (Oljirra 2019:1753). This is done, for example, through the state granting ownership of forests to local people (Culas 2006:436) and the execution of re-forestation and conservation measures on farms and community land (Megerssa/Bekere 2019:1955). In addition, there is a need to provide alternative housing and farming materials (Oljirra 2019:1753). For example, new homesteads should be established in areas with low tree density. Households then plant trees, grasslands and woodlands nearby, resulting in larger areas of perennial vegetation including trees (Duriaux-Chavarría et al. 2020:1448). For nature and livelihoods of the population, a mosaic of a diverse agricultural matrix with high tree cover and forest is most beneficial (Duriaux-Chavarría et al. 2020:1447).

In addition to plantations, new political laws and guidelines as well as forest use certifications accompany the afforestation programs. From the government side, it is crucial to identify and regulate the threshold for the removal of trees and other forest products before degradation of forest resources occurs (Duriaux-Chavarría et al. 2020:1449). Furthermore, it is necessary to define some forest areas to be used and some to be protected (Oljirra 2019:1753). The establishment of an ecologically, economically and socially responsible forest management (see FSC w.y.b) contributes to the protection of forests, too. Therefore, the development of a Forest Stewardship Council (FSC) standard for forest management is initiated for Ethiopia (FSC w.y.a).

3.3 Evaluation of afforestation programs

The fight against land degradation and de-forestation has been driven by policy changes, TPPs and natural regeneration of degraded areas. At the beginning of the reforestation programs, land was nationalized because of Ethiopia’s agrarian reform in the mid-1970s, which should contribute to the success of the various conservation programs (Tekle 1999:424). Administrative cooperation between farmers' organizations, the Ministry of Agriculture (MOA) and donors was successful, too (Ståhl 1990:148). But problems and failures arose that jeopardized the success. Environmental rehabilitation programs were initially incapable of combating environmental degradation (Ståhl 1990:140). Even in the past decade, afforestation programs did not necessarily lead to higher vegetation cover in the planted sites. This might have happened, because the rate of deforestation was higher than the rate of reforestation and/or because the seedlings did not survive (Takele et al. 2022:3).

Within TPPs, wrong priorities are set. For example, the focus is on the number of seedlings planted rather than on their survival, management and use (Ståhl 1990:148). Farmers who planted seedlings often do not know what would happen to their trees or who would use them. As a result, it is difficult to establish reliable figures on the survival rate of planted tree seedlings in the FFW programs. Likely, the survival rate of the planted tree seedlings was low in the beginning (Tekle 1999:424), about 40 %. The reasons for this are that the species and provenances planted do not al-ways match the local ecotype (Ståhl 1990:143, cf. Duguma et al. 2020:23). Planting foreign eucalyptus e. g., was not a good choice and led to further degradation (see Pankhurst 1992:72). But 'native tree species […] require a longer time of at least 5 years to become trees' (Duguma et al. 2020:12) and most restoration projects do not last such a long time. Similarly, the locations for the TPPs are not well chosen. Restoration does not take place on abandoned land but on productive land (Ståhl 1990:142, Duriaux-Chavarría et al. 2020:1448). Programs protect only a small part of the highlands. Away from the major roads, where most highlanders live, only few conservation measures have taken place (Ståhl 1990:144). Thus, the lack of development of rural areas also affected the implementation of afforestation measures (Ståhl 1990:147). Moreover, the main objective is not to reduce risk by diversifying the landscape, what is necessary, but to restore essential utility services (Duriaux-Chavarría et al. 2020:1448).

In addition, the care and management as well as the transport of the seedlings from the nurseries to the transplanting sites was inadequate (Ståhl 1990:143). TPPs often lack sustainable commitment and investment in the maintenance of trees after planting. As the growth of the trees is not guaranteed, the plantations can be regarded as a form of greenwashing (Duguma et al. 2020:16). Furthermore, the trend continued to point towards degradation because the scope and funding of the programs were (Ståhl 1990:144) and still are far too low. Due to a short-sighted mindset, tree planting is often carried out only as a single event and thus does not contribute to achieving the restoration goals (Duguma et al. 2020:13f.). The official campaign-based approach failed against local initiatives because it is prescriptive and commanding rather than consultative (Ståhl 1990:148). In most conservation programs of the past decades, the local population was neither consulted nor involved in the planning (Tekle 1999:424). It was also not possible to motivate the local population to participate in the programs for the purpose of environmental protection. On the one hand, the population lacked a responsibility for the maintenance and, on the other, a right to use the forests (Egziabher 1989:66). TPPs do not focus on what the local communities want (Duguma et al. 2020:15). Most of the time, farmers only participated in the FFW programs because they needed the grain for nutrition or because they were forced to (Tekle 1999:422). Incentives for farmers to participate in conservation measures were insufficient (Ståhl 1990:140f.). Negative associations with state institutions may have contributed to the wanton destruction of slopes and forests (Tekle 1999:424). In addition, the lack of government support among the population and civil wars made TPPs difficult (Ståhl 1990:140f.,147). Even today, civil wars like in the Tigray region (since 2020) prevent TTPs locally (Green Ethiopia Foundation 2022:7). Furthermore, the lack of government support among the population complicated the conduction of TPPs (Ståhl 1990:140f.,147).

4 Analysis of forest cover changes in the Upper Blue Nile Basin

To answer the research questions mentioned in chapter 1.2, analyses of the NDVI, a land cover classification (LCC) and of other for-est related datasets for the UBNB are conducted using the GEE.

4.1 The Upper Blue Nile Basin

The UBNB extends between 7◦40′ - 12◦51′N and 34◦06′- 40◦00′E in the northwestern part of Ethiopia. The basin has a total area of ~197,000 km² and covers the regions of Addis Abeba, Amhara, Benishangul, and Oromiya. The UBNB is the biggest Ethiopian river basin in terms of runoff volume and the second biggest in terms of area. The UNB covers 16 % of Ethiopia's land area (Conway 2000:49). The elevation of the UBNB ranges from 494 m in the lowlands on the Ethiopian-Sudanese border to 4,221 m in the highlands of Mount Guna, east of Lake Tana (see fig. A1).

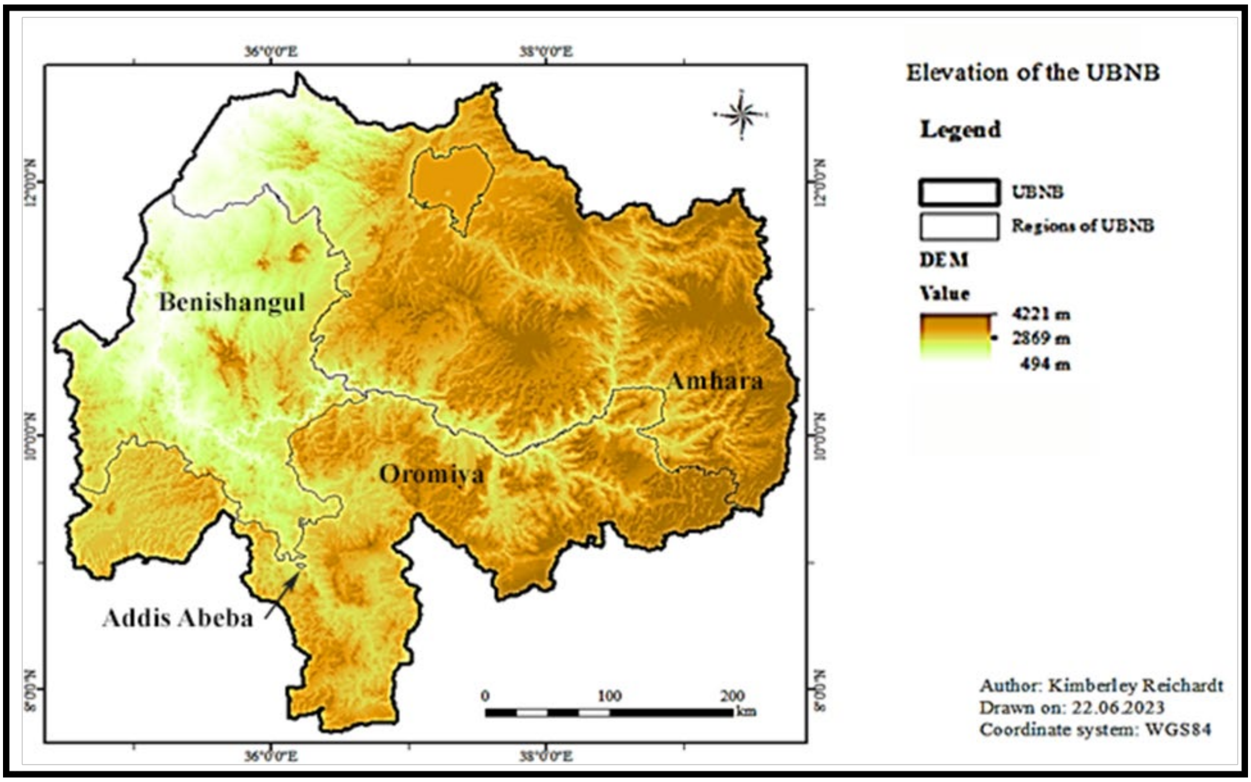

Figure A1: Elevation of the UBNB. Own illustration 2023, source of the data: Copernicus 2015.

The Blue Nile (BN) flows from Lake Tana to the Sudanese border (Kim/Kaluarachchi 2008:42) and is the largest tributary to the Nile (Bayissa 2019:16). The river carved a kilometer-deep channel into the central Ethiopian highlands, with a meandering course (Conway 2000:49). Severe erosion is prevalent in the UBNB and adjacent regions with 380 Mill. Tons annually (Hurni et al. 2015:81). Precipitation is highly seasonal. The main rainy season extends from June to September (Mellander et al. 2013:1), with 82 % of annual precipitation falling from July to October (Mellander et al. 2013:3). The UBNB faces topographic-induced variations of climate (Tadesse 2001:815). Annual precipitation shows a gradient from over 2,000 mm in the southwest to less than 1,000 mm in the northeast. The mean annual precipitation from 1961 to 1990 was 1,421 mm (Conway 2000:60). Climate in the UBNB ranges from humid to semi-arid (Kim/Kaluarachchi 2008:42). Mean mini-mum and maximum temperatures are 11º C and 26º C (Mellander et al. 2013:3). A smaller range occurs in the mean annual temperature (18.5º C ± < 3º C) due to seasonal variations (Kim et al. 2008:1234). The basin consists mainly of volcanic and Precambrian bedrock with small areas of sedimentary rock. Soils on gentle slopes are latosols, while flatter areas are characterized by deep vertosols exposed to waterlogging (Conway 2000:49f.).

Land cover in the UBNB is dominated by drylands, croplands, pastures, savannas, grasslands, forests, water bodies and sparse plant cover (cf. MOA 2004:33). The UBNB is dominated in appr. equal parts by cultivated land and forest. ‘Cultivated and man-aged vegetation / agriculture’ is mainly located in the central area of the UBNB and in the eastern part (see fig. A2).

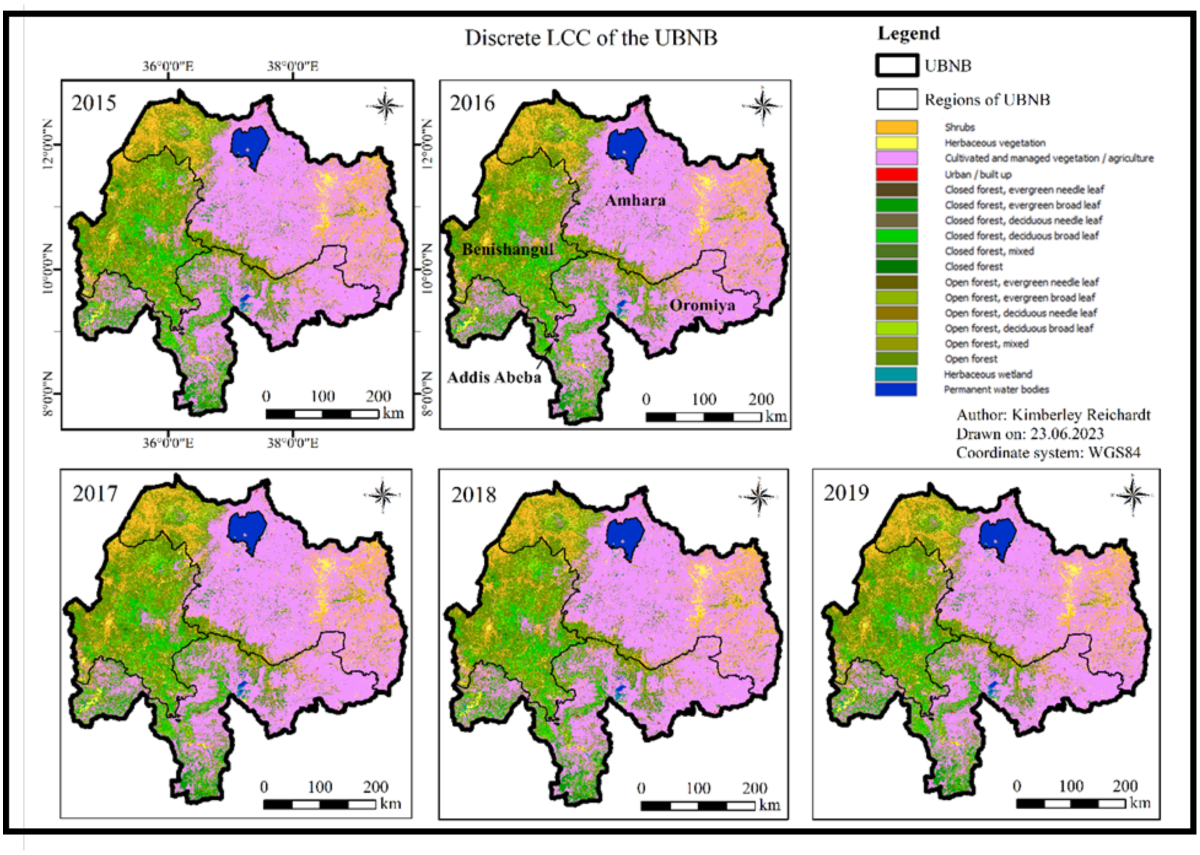

Figure A2: Discrete LCC of the UBNB. Own illustration 2023, source of the data: Copernicus 2019.

44% of the total area is cropland, with predominant rainfed agriculture (cf. MOA 2004:33). Especially Amhara and Oromiya areunder intensive agricultural management (Haileslassie et al. 2005:14). In Benishangul lowland bamboo is cultivated (MOA 2004:33). The forests consist of roughly equal amounts of ‘Open forest’, ‘Open forest, deciduous broad leaf’ and ‘Closed forest, deciduous broad leaf’. ‘Closed forest’ and ‘Closed forest, ever-green broad leaf’ are present in smaller amounts, too. UBNB’s vegetation is supplemented by sporadic ‘Herbaceous vegetation’ and ‘Shrubs’ extending over the north-east and north-west. In the forested regions, especially in the west, shrubs and forests form a land use mosaic with small islands of herbaceous and cultivated vegetation (see fig. A2). Addis Abeba is exclusively urban. In turn, the Amhara region is composed primarily of cultivated land and scrubland, complemented by grassland and woodland. The Benishangul region consists mainly of wood- and scrubland. The area of Oromiya is mostly wood land, cultivated land and scrubland, with some grassland areas (MOA 2004:33).

4.2 Method of detecting changes in forest cover

Using the GEE, it is analyzed whether there is a trend of increasing deforestation or afforestation in the UBNB starting from year 2000. On the one hand, the starting time is based on the availability of 'Modis'' satellite images. On the other hand, the assumption is made that the initially failed afforestation measures (c.f. Ståhl 1990, Tekle 1999, Duguma et al. 2020, Duriaux-Chavarría et al. 2020) have become more effective since this century (c.f. Green Ethiopia Foundation 2022). This impression is supported by successful initiatives such as the Green Ethiopia Foundation starting in the early 2000s (Green Ethiopia Foundation 2022:7). The monitoring period ends in 2023, using the most recent satellite imagery available. To evaluate the success of the reforestation programs in the UBNB several data sets are evaluated (tab. 2).

Table 2: Data sets used to evaluate the success of the reforestation programs in the UBNB. Own illustration 2024.

	'Modis'	'Copernicus'	'Non/Forest'	'Hansen'
Name	MODIS Terra Daily NDVI	Copernicus Global Land Cover ; CGLS-LC100 Collection 3	Global 4-class PALSAR-2/PALSAR Forest/Non-Forest Map	Hansen Global Forest Change v1.10 (2000-2022)

Data period used	24.02.2000 - 17.02.2023	01.01.2015 - 31.12.2019	01.01.2017 - 01.01.2021	01.01.2000 - 01.01.2022
Resolution	463.31 m	100.00 m	25.00 m	30.92 m
Data type	Image Collection	Image Collection	Image Collection	Image
Data set provider	Google	Copernicus	JAXA EORC	Hansen/UMD/ Google/USGS/ NASA

The data sets do not provide data covering the same period, but they are all clipped to the study area (selfcreated shapefile of the UBNB) to minimize the amount of data to be calculated and presented in the GEE.

The focus of the analysis is on the Normalized Difference Vegetation Index (NDVI) over a long period of time for the UBNB like provided by the Modis dataset used. NDVI values are useful for obtaining information on the extent of land degradation, as they are used to assess the development of green vegetation. The NDVI is based on the standard formula (Eq. 1):

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

Equation 1: NDVI. NIR: spectral reflectance in the near infrared (800 - 1,000 nm). RED: spectral reflectance in the red range (620 - 750 nm) of the electromagnetic spectrum.

NDVI values range from -1 to 1, the higher the value, the more vegetation is present. 'Very low values of NDVI (0.1 and below) correspond to barren areas of rock, sand or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while high values indicate temperate and tropical rainforests (0.6 to 0.8)' (Weier/Herring 2000). The NDVI time series is generated for the years from 2000 to 2023 from December to May during the dry season to map only trees but no other vegetation that is temporarily green (cf. Takele et al. 2022:3). The time series were then analysed and depicted (see fig. 3) to identify trends in NDVI from 2000 to 2023. Finally, the determined NDVI values are compared with the results of Takele et al. 2022.

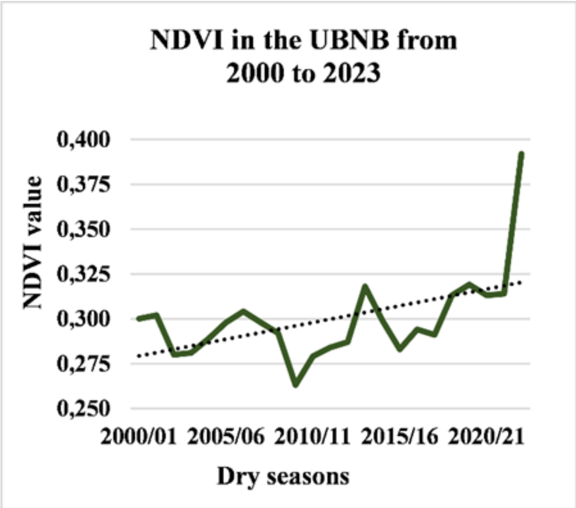

Figure 3: NDVI in the UBNB from 2000 to 2023. Own illustration 2023, source of the data: Google 2023.

To further exclude whether the vegetation detected consists of plants other than trees, the

Copernicus land cover dataset is used. For this purpose, its discrete LCC of the UBNB is compared annually from 2015 to 2019. Further, the forest LCC and the No/Forest dataset are used to analyse the extent of forest in the UBNB from 2015 to 2020 (see fig. 4). With the Hansen dataset the loss of forest area in the UBNB is examined from 2000 to 2022 (see fig. 5).

4.3 Changes in NDVI and forest cover

The time series for the mean NDVI values of the UBNB in the dry seasons from 2000 to 2023, which was generated with the GEE, shows temporally fluctuating values. The NDVI values are always higher than 0.25. The lowest value was recorded in the dry season 2009/10 with 0.263. The dry season with the highest NDVI value was last season with 0.392. Thus, the mean value over the period from 2000 to 2023 is 0.3. However, an increasing trend in the NDVI value by about 0.04 can be identified (fig. 3).

Referring to its spatial distribution, there is generally more vegetation in the south of the UBNB. In years with high NDVI values, such as 2013/14 or 2019/20, significantly more area is shown in green and white/pink, as more vegetation is present. However, a correlation of the vegetation distribution with the topography is not visible (see fig. A3).

A detailed distribution of forest vegetation is provided by the Copernicus 'forest_type' classification. This classification shows that the forest distribution is very much limited to the west of the UBNB. Only very few, small forest areas are located east of Lake Tana. The forest areas in the UBNB are classified as 'Deciduous broad leaf' and 'Evergreen broad leaf', with deciduous broad leaves being very predominant. Evergreen broad leaves occur almost exclusively in the south of the UBNB. There, the dominance of one class is no longer evident. In addition, the 'forest_type' classification illustrates clear spatial and temporal changes in forest cover. On the one hand, the assigned classes change in some places, on the other hand, the location of forested areas shifts (see fig. A4).

In 2015, the forest area in the UBNB is about 86,000 km² and increases steadily to 106,000 km² in 2018. Towards 2019, however, there is a sharp decrease in forest area to only 71,000 km². This decrease is particularly evident in the northern and central areas of the UBNB. On average there were 88,600 km² of forest. The Non/Forest dataset shows a sharp increase in forest area for the UBNB from 483,000 km² in 2017 to 491,000 km² in 2019. On average, the Non/Forest analysis shows 484,200 km² of forest (fig. 4). The absolute forest areas differ in the LCC and Non/Forest analysis. The forest areas are larger by a factor of 5.6 in Non/Forest than in LCC. If the LCC value is high and the Non/Forest value is low, the two values converge. However, the curve of the forest areas for the two data sets is similar despite the different period. LCC indicates a sharp drop from 2018 to 2019. In the Non/Forest analysis, this takes place to a similar extent from 2019 to 2020.

Of the approximately 197,000 km² area of the UBNB, 171,305 km² (87 %) were covered by forest in 2000. In the following years, an average of 1.1% of the forest area was lost per year.

The loss of forest area shows strongly fluctuating values, especially in the years from 2009 to 2017. The highest loss occurred in 2003 (1,899 km²) and the lowest in 2022 (1,730 km²). The average loss is 1,835 km² per year and in total, the area of UBNB lost 40,365 km² (21 %) forest from 2001 to 2022 (fig. 5, see fig. A5).

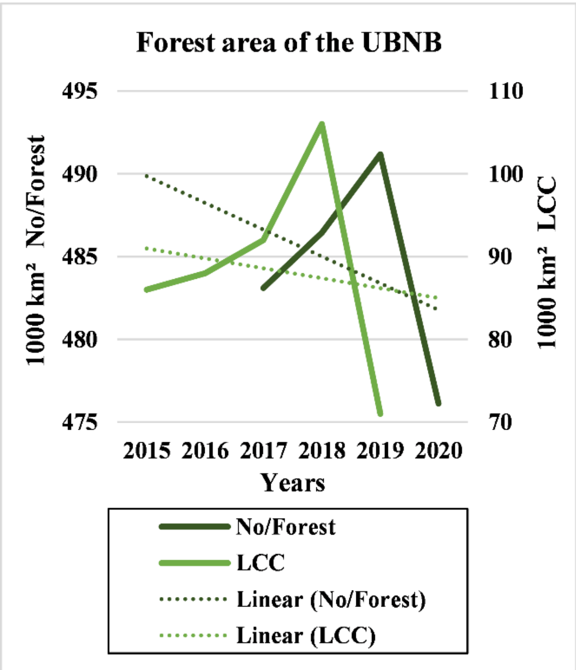

Figure 5: Forest Area of the UBNB from 2015 to 2020. Own illustration 2023, source of the data: Copernicus 2019 and JAXA EORC 2021.

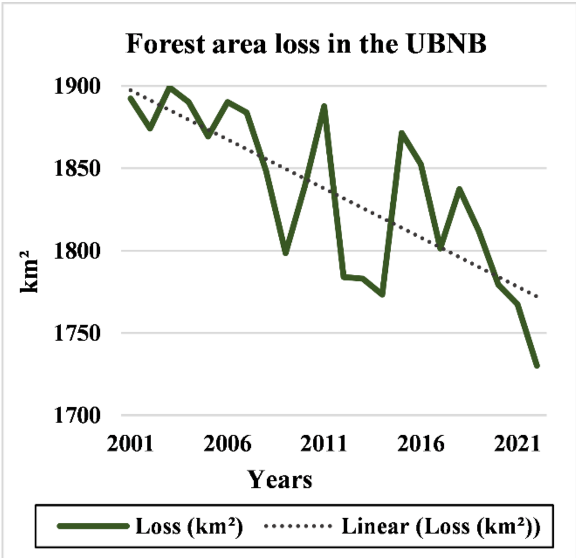

Figure 4: Forest area loss in the UBNB from 2000 to 2020. Own illustration 2023, source of the data: Hansen/UMD/Google/ USGS/NASA 2022.

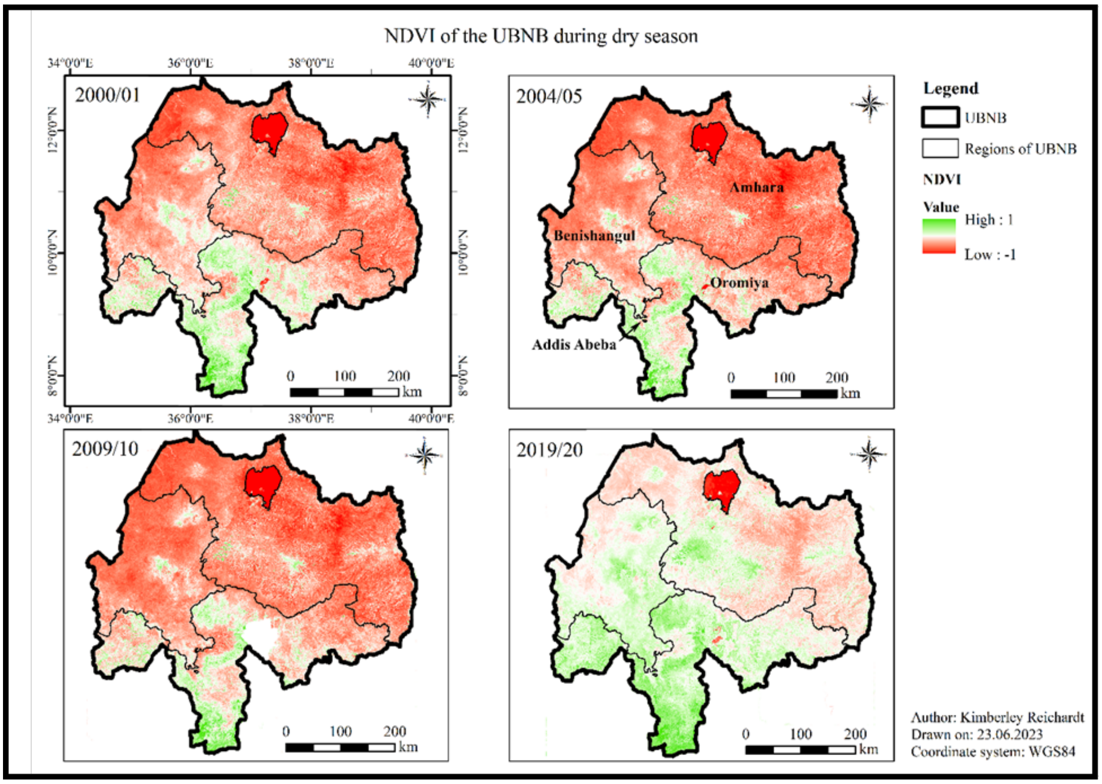

Figure A3: NDVI of the UBNB during dry seasons. Own illustration 2023, source of the data: Google 2023.

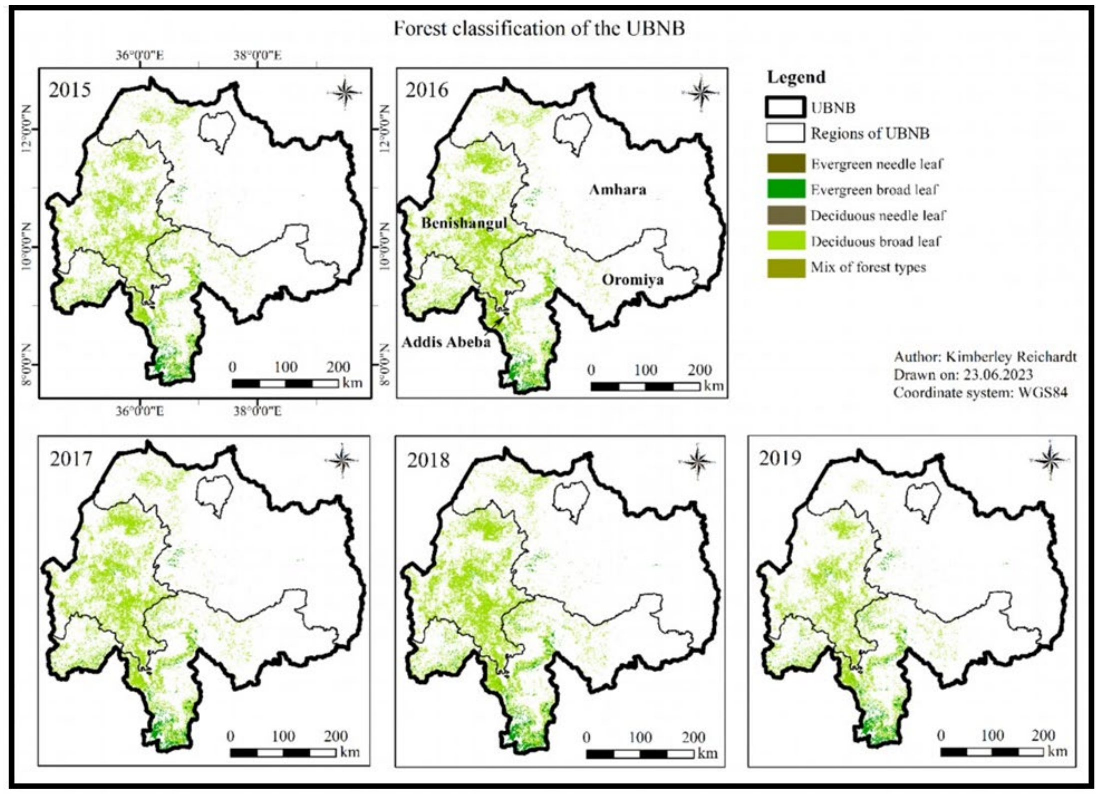

Figure A4: Forest types of the UBNB. Own illustration 2023, source of the data: Copernicus 2019.

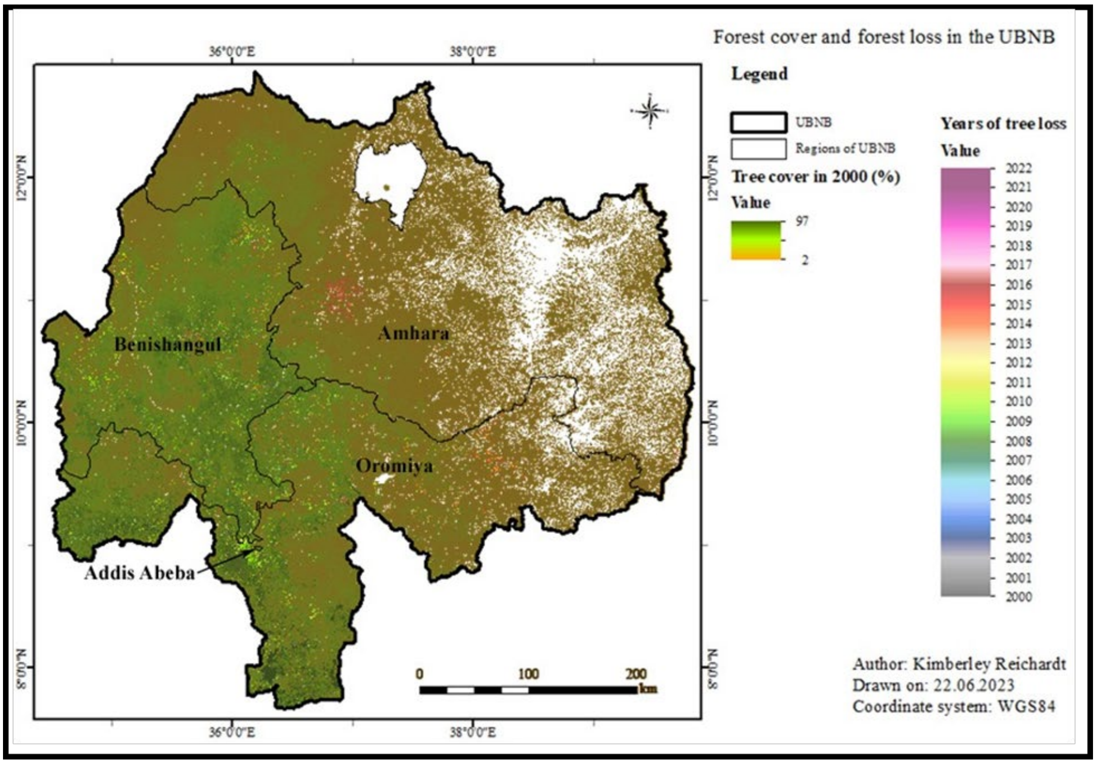

Figure A5: Forest cover and forest loss in the UBNB. Own illustration 2023, source of the data: Hansen/UMD/Google/USGS/NASA 2022.

4.4 Interpretation of the change in forest cover in the UBNB

Using the classification of NDVI values by Weimer/Herring (2000), the range from 0.26 to 0.32 indicates that there is a moderate amount of green vegetation present even during the dry season in the UBNB. Values between 0.2 and 0.3 indicate shrub and grassland. Even the values slightly above 0.3 can still be assigned to this vegetation, as it corresponds to the land use classification of the MOA. Moreover, there are neither large differences between the years nor spatially within the UBNB. The vegetation determined by NDVI in the dry season is therefore evenly distributed over the study area and over time with a slight increase. In contrast, Takele et al. (2022) calculated a decreasing trend in NDVI values for the lower Awash basin from 2013 to 2020. This trend cannot be confirmed for the UBNB, neither for this period nor for the entire study period from 2000 to 2023.

The tree cover extent of the UBNB in 2019 (see fig. A5) accounts for 61 % of the tree cover extent of the whole of Ethiopia in 2020 (cf. Mongabay 2022). The UBNB is therefore the most forested area in Ethiopia. The distribution of forest areas in the UBNB is subject to spatial and temporal anomalies. The analysis of the Copernicus dataset (see fig. A4) illustrates that the location of the forest areas is shifting. This can be explained by deforestation and afforestation of the areas concerned. However, it is striking that only very few, small forest areas are present east of Lake Tana during the entire study period. The reason of this distribution is that agriculture is concentrated there (see fig. A2).

The results of the analysis for the expansion of forest areas and their development in the UBNB match the development of whole Ethiopia. The loss of forest area from 2018 to 2019 in the UBNB matches the overall Ethiopian forest area loss in these years. Moreover, relatively low forest losses were recorded in 2015 in both the UBNB and Ethiopia (see fig. 1, 2). Ethiopia's tree cover loss from 2001 to 2020 was approximately 4,278 km². For the regions that make up the UBNB, the tree cover loss was 2,665 km². This means that 62 % of Ethiopia's total loss is attributable to these regions. However, the UBNB is smaller than the four regions, so the loss is also smaller: on average 1,834 km² annually. Consequently, about 43 % of Ethiopia's tree cover loss is due to forest cover loss in the UBNB.

The key message on the development of forest area in the UBNB is supported by all datasets used and illustrates that the forest area has been declining since the turn of the millennium until today. The decline has decreased, but there is still no increase in forest area in the UBNB (see fig. 4,5). According to Hansen's dataset, the UBNB has 72,361 km² of forest area in 2020. Using the LCC, 70,750 km² of forest area could be determined for 2019. These values can be considered as matching, considering different dataset bases. The average forest area loss in the UBNB is about 1,835 km² per year, therefore a total of about 40,365 km² forest area was lost from 2000 to 2022. Therefore, if only regarding the losses, the extent of forest area should have decreased by about 21 % from 2000 to 2022. However, the four UBNB regions only report 2,644 km² less tree cover in 2020 than in 2000 (cf. Mongabay 2022). Massive afforestation measures must have taken place, but were not sufficient to compensate for the losses.

Some analysis results are subject to limitations due to assumptions made or the data collection. For instance, the highest NDVI value of 0.392 in 2022/2023 is unusually high compared to the other recorded values and could therefore be an outlier. Also, the dry season period for the 2022/23 value had not yet ended at the time of its calculation. Therefore, the value should not be focused. Accordingly, the second largest value of 0.319 (2019/20) is considered the maximum value. Based on the determined NDVI values for the UBNB, the region is categorized as shrubland and grassland, because they were calculated for the dry season. Calculations of NDVI values for the rainy season should result in higher values and thus in a different categorization. It cannot be determined whether the NDVI values include only (evergreen) trees or also some very drought-tolerant plants. Furthermore, the occasional increase in vegetation cover (see fig. 1) can be attributed to other land restoration programs instead of TPPs. This is supported by the fact that the forest areas are dominated by losses. The forest areas determined from the Non/Forest analysis exceed the extent of the study area and must therefore be incorrect. The LCC forest areas, on the other hand, cover less than half of the UBNB. These values are more in line with the real land use (cf. MOA 2004:33) and the forest area derived from it. Furthermore, the comparability of the results of the different data sets is limited due to different resolutions, time periods and forest definitions. For example, the decrease in forest area in 2018/19 or 2019/20 calculated from the LCC and Non/Forest datasets should be accompanied by a higher loss of forest area from the Hansen dataset in the corresponding years. However, this is not the case. The extent of the forest area and losses vary between datasets as it is influenced by the forest definition and the satellite image resolution (see chp. 4.2). That 87 % of the UBNB area was covered by forest in 2000 seems to be a high percentage. However, this area includes all land with vegetation more than 5 m high and not 0 % tree canopy cover (range: 0 - 100 % in Hansen). So, only few forested areas are dense forests (see fig. A6).

In addition, the analysis results only show the extent of forest areas and their loss in different years within the UBNB. No reasons for the observed changes can be determined from satellite images, but possible reasons can be inferred from Chapter 2.2 and 3.3.

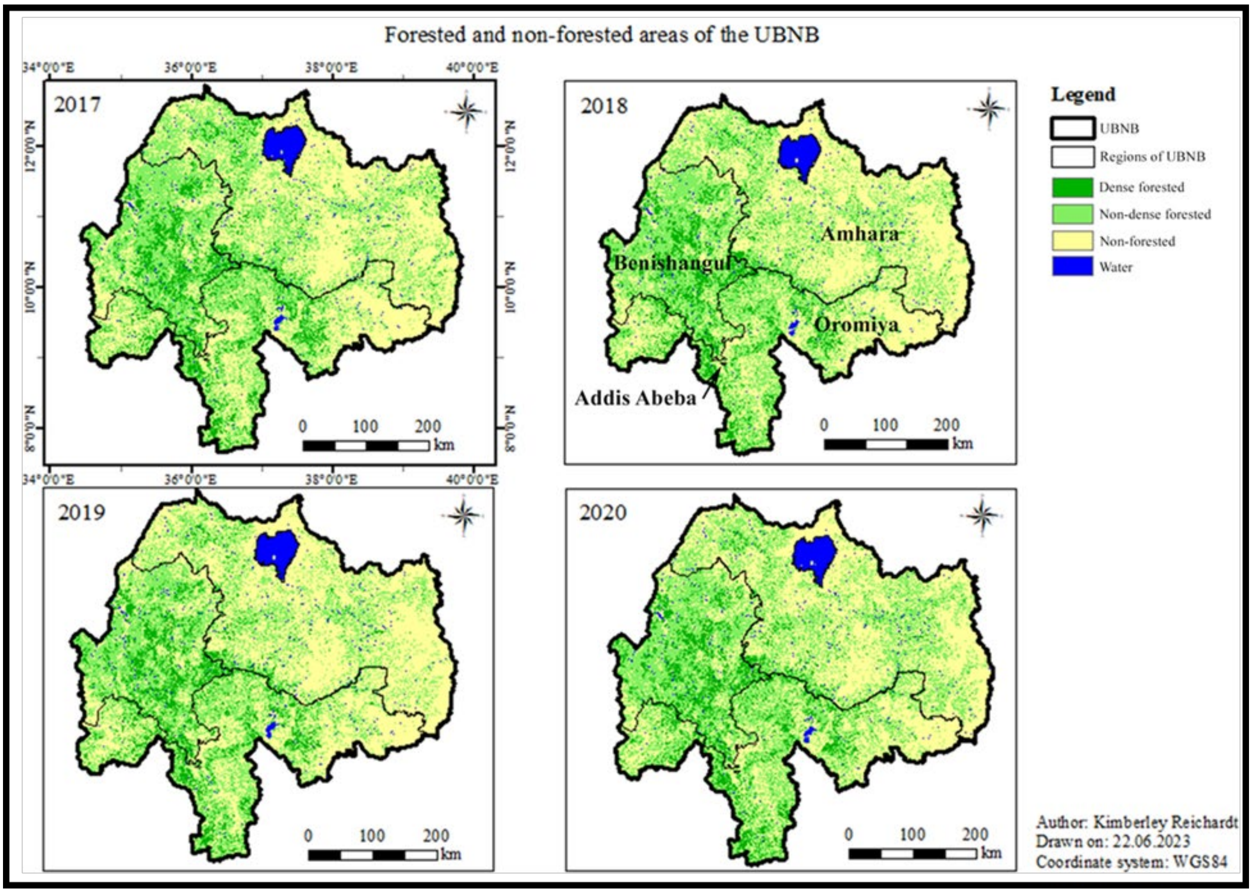

Figure A6: Dense and non-dense forested areas of the UBNB. Own illustration 2023, source of the data: JAXA EORC 2021.

5 Conclusion

Reasons for Ethiopia's deforestation, such as timber extraction and the expansion of cultivated and settled land are aimed at short-term economic gain but lead to long-term ecological problems such as soil degradation and loss of biodiversity. However, measures against deforestation and thus against soil degradation were taken decades ago. These measures are based on the political impact of famine, the decreasing availability of resources, the importance of forests and trees in combating degradation, and the recognition of tree conservation for the well-being of future generations.

A moderate amount of green vegetation is evenly distributed in the UBNB and is also present in the dry season. The NDVI value of the UBNB is 0.2 and 0.3 (dry season), characterizing the area as scrubland and grassland. The large forest cover in the west of the study area, thus in the lowlands, is also noteworthy, as the UBNB is the most heavily forested area in Ethiopia, with 72,361 km² of forest cover (2020). This underlines the need to select this area for TPPs and other land restoration programs. Like Ethiopia as a whole, it is also affected by progressive deforestation. The forest area has declined since the turn of the millennium until today. The UBNB is the region in Ethiopia with the greatest forest loss. 43% of the tree cover loss in Ethiopia is due to the loss of forest cover in the UBNB. On average, 1,834 km² of forest area was lost per year, adding up to a total loss of about 40,365 km² from 2000 to 2022.

Initially, TTPs and other restoration projects had little success due to the top-down approach and hasty actions. Until today, many of the critical points of the projects that were criticized at the turn of the millennium have been remedied. So that the situation of deforestation and land degradation should have improved. But that is not the case. The LCC (Copernicus) for the UBNB from 2015 to 2019 shows no significant changes in general vegetation, but in areas classified as forest. There was also significant deforestation from 2000 to 2022 (Non/Forest, Hansen). The decrease in forest area in the UBNB is accompanied by a simultaneous increase in NDVI (Modis). This indicates the growth of plants other than trees and/or the expansion of cultivated land. Vegetation helps to combat land degradation. Agricultural expansion, on the other hand, leads to increased deforestation and thus soil degradation. Instead of in-creasing forest cover through TPPs, it is likely that forests have been cleared and that the land converted to scrubland and grassland or got used for agriculture. If only the losses were considered, the forest area should have decreased by about 21 % from 2000 to 2022. However, the four UBNB regions, which cover a larger area than the study area, report only 2,644 km² less forest area in 2020 than in 2000. The trend of forest area loss is declining, there is still no gain in forest area in the UBNB. This indicates that more deforestation than afforestation must have taken place. It can be deduced from this that the TPPs that have taken place are not qualitatively and/or quantitatively sufficient to counteract the continuing deforestation. The TPPs, maybe apart from exceptions such as the ones of the Green Ethiopia Foundation, do not appear to be successful in the long term. The trees, naturally and anthropogenically indebted, do not live long enough to build up forests. This can be attributed to the often-pursued campaign-based planting instead of community-centred planting and protracted care of the seedlings. Accordingly, there is still great untapped potential for environmental protection and sustainable forest management in the UBNB in the sense of successful long-term afforestation.

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