Chapter 13
Monitoring State of Biomass Recovery in the Blue Nile Basin Using Image-Based Disturbance Index

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Abstract The heavy dependence of the Ethiopian rural population on natural resources, particularly land, to maintain their livelihood is an underlying cause for the degradation of land and other natural resources. The Ethiopian highlands, which are the center of major agricultural and economic activities, have been eroding for many years. Various actors have undertaken reforestation programs with an aim to

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mitigate the land degradation problem; however, the status of these plantations has never been evaluated at a basin scale. The image-based disturbance index (DI) measures the status of the ecosystem on the basis of the ratio of long-term enhanced vegetation index (EVI) and the land surface temperature (LST). This study applied the DI to assess the current state of biomass in the upper Blue Nile basin with a focus on areas where degradation mitigation measures are implemented through reforestation campaigns. The DI maps are validated through field visits to 19 selected sites and inventory data obtained from the World Food Program (WFP) over five sites. The results showed that the largest expansion of plantations has taken place in five subbasins and is between 6 and 8.5 % of the subbasin area with expansion in the remaining 11 subbasins ranging from 3 to 5 %. Despite the very low annual rate of expansion, it can be concluded that the mitigation measures implemented through reforestation campaigns contribute to the total recovered forest area.

13.1   Introduction

Land degradation is a major problem in Ethiopia. It takes place in the form of soil erosion, gully formation, soil fertility loss, and severe soil moisture stress, which is partly the result of loss in soil depth and organic matter (Hagos et al. 1999). The excessive dependence of the Ethiopian rural population on natural resources, particularly land, as a means of livelihood is an underlying cause for degradation of land and other natural resources (Bekele 2008). Agriculture accounts for 45 % of the gross domestic product (GDP), 85 % of export revenue, and 80 % of employment (EPA 1997). The demand for farmland, timber, fuel wood, and grazing lands drives the overexploitation of forest resources (Gebremedhin et al. 2003) in the Ethiopian highlands where the bulk of the population lives. As a consequence, the Ethiopian highlands have experienced accelerated soil erosion for many years.

The annual soil erosion in Ethiopia ranges from 16 to 300 tons/ha/year depending mainly on the slope, land cover, and rainfall intensities (Hawando 1997; Tebebu et al. 2010). A reclamation study by the Food and Agriculture Organization (FAO) estimated the degraded area on the highlands at 27 million ha, of which 14 million ha is very seriously eroded with 2 million ha of this having reached a point of no return (Constable and Belshaw 1986). High population growth and the need for further agricultural expansion into marginal areas of fragile soils or critical habitats for biodiversity will lead to significant environmental degradation and deterioration of resilience for future environmental shocks unless intervention measures are introduced (Jagger and Pender 2003).

With an aim to mitigate land degradation problems in Ethiopia, the federal and local governments and various nongovernmental organizations (NGOs) have undertaken soil and water conservation measures. The World Food Program (WFP) "Project 2488," Managing Environmental Resources to Enable Transitions to More Sustainable Livelihoods (MERET) project, the Millennium "one man two tree"

campaign, and other similar initiatives are part of the ambitious soil and water conservation efforts that have been made by the Ethiopian government (Nedessa and Wickrema 2010). Some studies show that by the mid-1980s, nearly 180,000 hectares had been afforested and 460,000 ha had been treated through soil conservation practices (Admassie 1998), together amounting to 5 % of the area in the highlands requiring conservation (Shiferaw and Holden 1999).

13.2 Review of the Disturbance Index Theory

The capacity of the landscape to sustain biomass longer (biomass longevity) is an important marker of its state of degradation. Such a capacity can be improved by measures such as increasing organic matter, increasing plow depth (in agricultural fields), conserving water on the landscapes, and devising better drainage infrastructure (in waterlogged areas). In this research context, biomass longevity refers to the landscape's ability to support the growth of vegetation that has been put in place through past reforestation campaigns. Such plantings are sustainable only when there is enough water available for photosynthesis and human interference is controlled. These plantations avoid further degradation by reducing rainfall impact and interrupting surface runoff. Because of the cooling effect of vegetation on the ground, soil evaporation is reduced and infiltration is facilitated, making more water available for the increased biomass.

The evaluation of the state of biomass can be made by quantifying biomass disturbance trajectories using vegetation indices (Michener and Houhoulis 1997; Ruiz and Garbin 2004; Jin and Sader 2005; Leeuwen 2008; Ferreira et al. 2010; Spruce et al. 2010). Here, the image-based disturbance index (DI) tool suggested by Mildrexler et al. (2007) is used to assess the trend in the area expansion of these plantations. The method is used to assess the status of the biomass on the basis of the ratio of long-term enhanced vegetation index (EVI) and the land surface temperature (LST) as measured by the Moderate Resolution Imaging Spectroradiometer (MODIS).

Vegetation indices and LST are the most vulnerable biotic and abiotic components, respectively, of a terrestrial ecosystem to detect alteration during disturbance events (Huete et al. 2002). The EVI, which is sensitive to vegetation changes, is calculated from red, near infrared, and blue bands (Huete et al. 2002):

$$EVI = G \times \frac{(NIR - Red)}{(NIR + C1 \times Red - C2 \times Blue + L)} \tag{13.1}$$

where *NIR, Red,* and *Blue* are surface reflectance at the respective bands; *L* is the canopy background adjustment factor; $C1$ and $C2$ are the coefficients of the aerosol resistance term; $L = 1$, $C1 = 6$, and $C2 = 7.5$ are coefficients in the EVI algorithm; and *G* (gain factor) $= 2.5$ (Huete et al. 1994, 1997).

Vegetated areas generally yield high EVI values as they reflect more in NIR band but less in the visible band. More importantly, LST is strongly related to vegetation density due to the cooling effect of the vegetation through latent heat transfer (Coops et al. 2009). Thus, higher vegetation density results in lower LST. Capitalizing on these phenomena, long-term measurements in the form of remotely sensed images
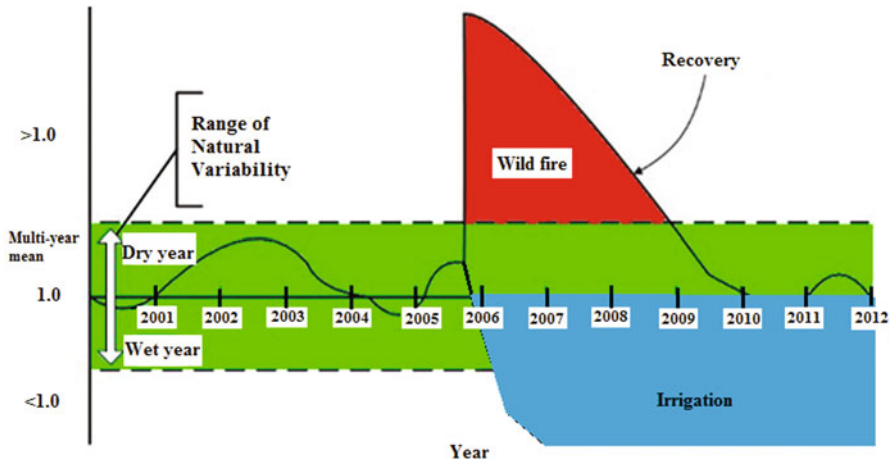
Fig. 13.1 The disturbance index plot (Mildrexler et al. 2007) explains the undergoing process; instantaneous events (e.g., wild fire) cause a sharp decline of biomass and a recovery taking place over extended time

can be used to observe the temporal change in the biomass in the larger spatial extent of the river basin. Causes for disturbance should, however, be properly identified.

There are various causes for changes in biomass that result in positive or negative disturbances. Drought and wildfire are major stressors that affect forest ecosystem functioning and processes (Leeuwen 2008). A number of studies have mapped fire disturbance using the EVI (Coops et al. 2009; Forzieri et al. 2010). Disease, geological incidences (landslide, volcano, etc.), infrastructure expansion, resettlement, and clear cutting also cause positive disturbance. Vegetation recovery due to reforestation and irrigation result in negative disturbance values.

Disturbances may also be short-lived or prolonged (Fig. 13.1). The usual cycle of cropping and harvesting causes increased EVI and reduced LST in the peak vegetation season followed by reduced EVI and increased LST at harvest. On the other hand, drought, disease, and urbanization result in prolonged reduction in the EVI and, thereby, an increase in LST for longer duration. Thus, the length of prevalence of the DI indicates the type of phenomenon causing the disturbance (positive or negative). Seasonal increases or decreases in DI that occur, mainly due to vegetation phenology, fall within an explainable range of variability.

Various image sources are available for use in the DI calculation. Although high-spatial-resolution satellite images may offer a more detailed view of land surfaces, their limited area coverage and temporal sampling have restricted their use to local research rather than large-scale monitoring (Ruiz and Garbin 2004). To be used for regional-scale studies, the high-spatial-resolution images require significant image processing skills. For example, using Landsat Thematic Mapper/Enhanced Thematic Mapper (TM/ETM) images for vegetation monitoring in the upper Blue Nile basin requires the mosaicking of 17 image tiles, applying geometric correction, radiometric normalization and transformation, cloud screening, and atmospheric correction.

The fact that the images are not taken on the same dates further complicates the atmospheric correction, making these images challenging for use by professionals with limited remote-sensing data processing skills. On a regional scale and in heterogeneous environments, such as the Blue Nile region, moderate-resolution images are preferred over finer resolution images for their reduced data volume and processing requirement and increased temporal coverage. Ruiz and Garbin (2004) used Advanced Very High Resolution Radiometer (AVHRR) 8-km images to estimate the burn area for tropical Africa. Coops et al. (2009) and Mildrexler et al. (2009) applied MODIS images to monitor a large swath of area in Northern America. In the current study, archives of satellite data from MODIS are used. Despite their relatively coarse resolution, these images have been successfully used to study vegetation cover change at regional to global scales (Hill et al. 2008). MODIS images provide the advantages of high temporal resolution and smaller data volume and require minimum technical skill for analysis. More importantly, in using MODIS images, much of the uncertainty associated with atmospheric corrections can be avoided.

The objective of this research is to evaluate the state of the conservation measures in the upper Blue Nile basin which are put in place through reforestation campaigns using the DI computed with MODIS images. The resulting DI maps are validated through field visits to areas flagged by the analysis and independent inventory data from WFP. The expected outcome of this study is a measure of the total recovered area, spatial distribution of the recovered areas within the basin, and the recovery trend. As equivalent tools are currently nonexistent, the results of this research will help decision makers to apply similar methods to monitor the recovery trend of biomass in conserved areas for the future. It will also help to locate areas in which reforestation has been successful so as to recommend those practices for scaling up at a river basin scale.

13.3 Method and Materials

13.3.1 Study Area

The Blue Nile is located between 16° 2' N and 7° 40' N latitude, and 32° 30' E and 39° 49' E longitude (Fig. 13.2). It has an estimated area of 311,437 km^2 (Yilma and Awulachew 2009). The Blue Nile basin (Abbay), with a total area of about 200,000 km^2 (20 % of Ethiopia's land mass), and accommodating 25 % of the population, is one of the most important river basins in Ethiopia. About 40 % of agricultural products and 45 % of the surface water of the country are contributed by this basin (Erkossa et al. 2009). The Blue Nile represents about 8 % of the total Nile catchment area but contributes about 60 % of the flow of Nile at Aswan, Egypt. A highland plateau, steep slopes adjoining the plateau that tilt to the west, and the western low lands with gentler topography characterize the basin. The steep slopes and the plateaus extend from 1,700 m (Bahir Dar) to 4,000 m (northeast highlands) above sea level. Geologically, the basin is comprised of 32 % exposed crystalline basement, 11 % sedimentary formations, and 52 % volcanic formations. The dominant
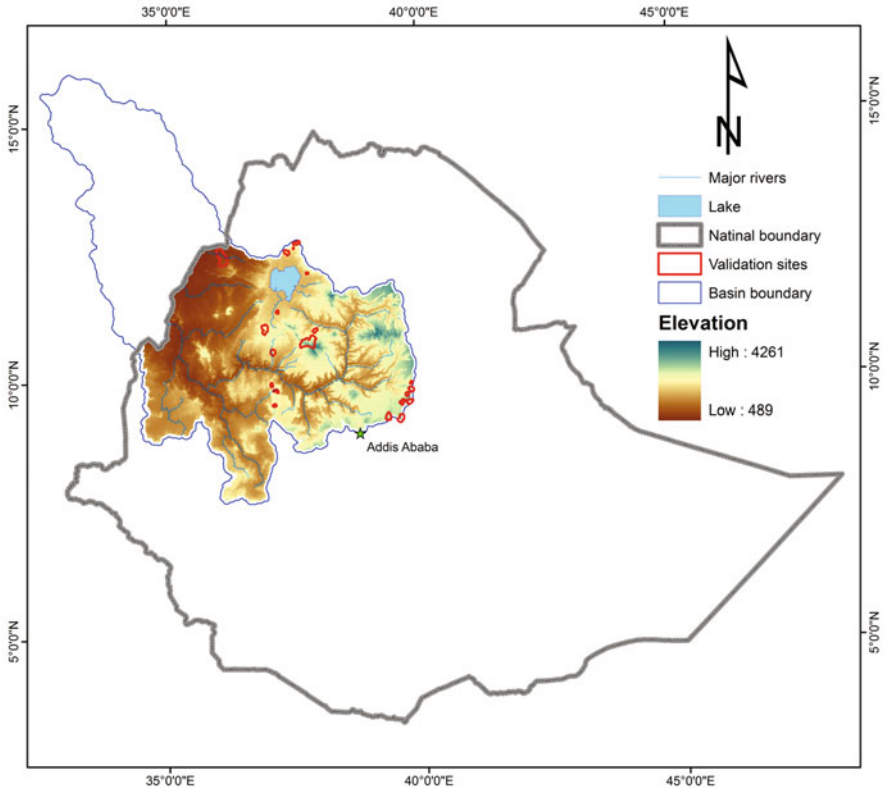
Fig. 13.2 *Upper Blue* Nile Basin (Abbay Basin) and selected ground validation sites

soil texture is Vertisol, covering about 15 % of the Basin (Gebrehiwot et al. 2011). The Blue Nile basin has a short rainy season that extends from March to May, a main rainy season that extends from June to September, and a dry season extending from October to February. The rainfall within the basin shows high seasonality with the peaks in July. The annual rainfall in the Blue Nile ranges from 880 to 2,200 mm (Taye and Willems 2012).

13.3.2 Methodology

13.3.2.1 DI Map Development

The DI map is developed by computing the ratio of annual maximum composite LST and EVI on a pixel-by-pixel basis, such that:

$$DI_i = \frac{LST_{imax}/EVI_{imax}}{\sum_{i-1}(\overline{LST_{max}/EVI_{max}})} \qquad (13.2)$$

where DI_i is the DI value for year i, $LST_{i\max}$ is the annual maximum 8-day composite LST for year i, $EVI_{i\max}$ is the annual maximum 16-day EVI for year i, $LST_{\max}$ is the multiyear mean of $LST_{\max}$ up to, but not including, the analysis year $(i-1)$ and $EVI_{\max}$ is the multiyear mean of $EVI_{\max}$ up to, but not including, the analysis year $(i-1)$. The DI is a dimensionless value that, in the absence of disturbance, approaches unity.

The annual $LST_{\max}$ and $EVI_{\max}$ values are computed for each of the 10 years (2003–2012) and the $LST_{\max}$ for each year is then divided by the corresponding $EVI_{\max}$ value on a pixel-by-pixel basis, resulting in a ratio of $LST_{\max}$ to $EVI_{\max}$ from 2003 to 2012. These annual DI layers are then divided by the long-term average of the index for that pixel, averaged over all previous years (Eq. 13.2). For example, the DI for the year 2005 is calculated as the ratio of $LST_{\max}$ to $EVI_{\max}$ of 2005 divided by the multiyear mean for the years previous to 2005 (i.e., mean of 2003 and 2004). Any DI values within the range of natural variability will be considered as having undergone no change, whereas, pixels outside of this central range are flagged as subject to disturbance.

The biophysical relationship outlined by Nemani and Running (1997) is also tested for validity. For each land cover type, the annual maximum LST and EVI raster are produced and the mean of the raster values recorded as mean-maximum LST and mean-maximum EVI.

13.3.2.2   Identifying Disturbed Areas

Coops et al. (2009) recommend values within ± 1 standard deviation of the long-term mean be considered as within the natural variability range. Both instantaneous (fire, disease, and the like) and prolonged (drought, urbanization, and the like) phenomena extend out of this natural range of variability. Therefore, a departure higher than ± 1 standard deviation will be flagged as potential disturbance areas. The ability of the calculated DI to capture these phenomena should be verified by a field survey in strategically selected flagged areas. In addition, the validation work involves the compilation and thorough review of ancillary data collected from organizations implementing reforestation campaigns.

13.3.3   Data

13.3.3.1   Image and Vector Data

MODIS images of 8-day maximum LST (MOD11A2) and 16-day EVI (MOD13A2) products from 2002 to 2010 are downloaded. The International Satellite LandSurface Climatology Project, Initiative II MODIS International Geosphere–Biosphere Program (ISLSCP II MODIS IGBP) land cover (Friedl et al. 2010) data are used to stratify mean-maximum LST and EVI over the study area. The data consist of 18 land cover types with water, forest, shrub land, savanna, cropland, built-up, snow, and barren land as main categories. Vector data layers are used to extract the DI

values to analyze biomass recovery patterns at subbasins level. The disturbed area (positive or negative) for the 16 subbasins is extracted and the total area calculated for each subbasin on a year-by-year basis. Boundaries for validation sites are manually digitized and imported into a handheld geographic information system (GIS).

13.3.3.2 Field Data

Based on the DI map generated, 19 sites were selected and field campaigns were carried out to compare the DI map results with actual ground conditions and to verify the type and extent of the disturbance and peasants' perception of the different conservation measures. Semi-structured interviews with key informants were conducted at several households. Focus group discussions were held to facilitate information exchange on the environmental impact of the disturbance areas and the overall participation of the community in initiating, undertaking, and sustaining the gains.

13.3.3.3 Ancillary Data for Validation

Ancillary data include details on watershed conservation and microirrigation projects within the basin. As irrigated areas certainly add to the negatively disturbed area (which may wrongly be considered as recovered areas), the field validation campaigns help in identifying irrigated areas and excluding them from the area calculation of recovered areas.

   The data on conservation work within the basin are obtained from agricultural bureaus of Amhara region and the WFP MERET project (Fig. 13.3). The ancillary data include list of location, areas, and time of implementation of plantations. The land covers where the Soil and Water Conservation (SWC) works concentrate are assumed to be those where no existing agricultural activity takes place. Thus, water bodies, grasslands, permanent wetlands, croplands, and urban/built-up areas are masked out. On the remaining land cover types, the areas showing biomass recovery trends are taken to be pixels with DI values less than one standard deviation from the long-term mean. The total recovering area is then calculated for the 16 subbasins in the 2004–2012 time span. The proportion of the recovering area to the subbasin area is used to standardize the results and for ease of comparison.

13.4   Result and Discussion

13.4.1   Validity of Disturbance Trajectory

Figure 13.4 shows the biophysical relationship between mean-maximum LST and mean-maximum EVI for the 2003–2012 dataset. The figure depicts the disturbance trajectory for the different ISLSCP II MODIS IGBP land cover types.
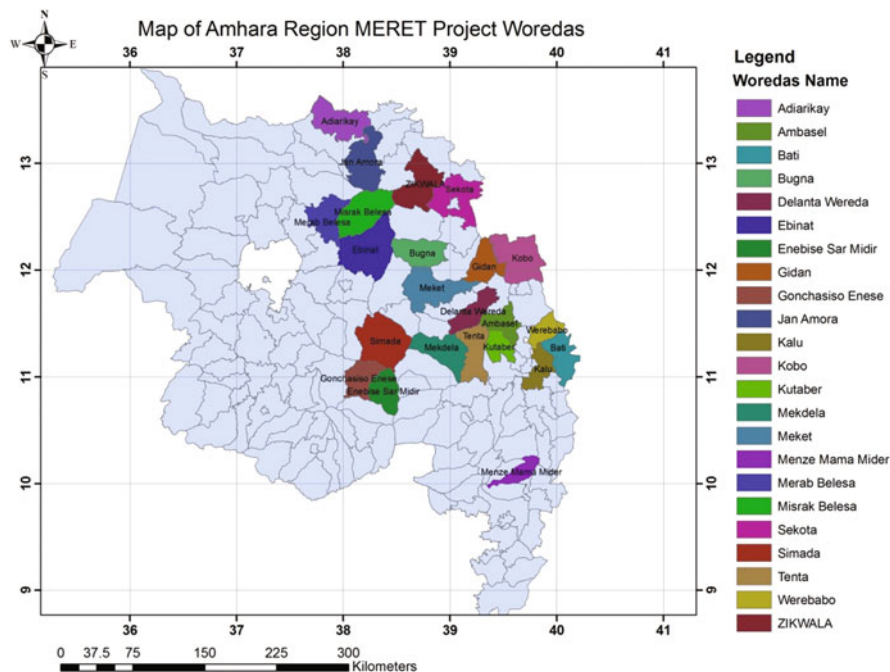
Fig. 13.3 Districts of community-managed watershed projects in Amhara region, five of the districts are used to validate the DI maps. (Source: MERET project, https://sites.google.com/site/meretproject04/. Accessed 1 November 2012)
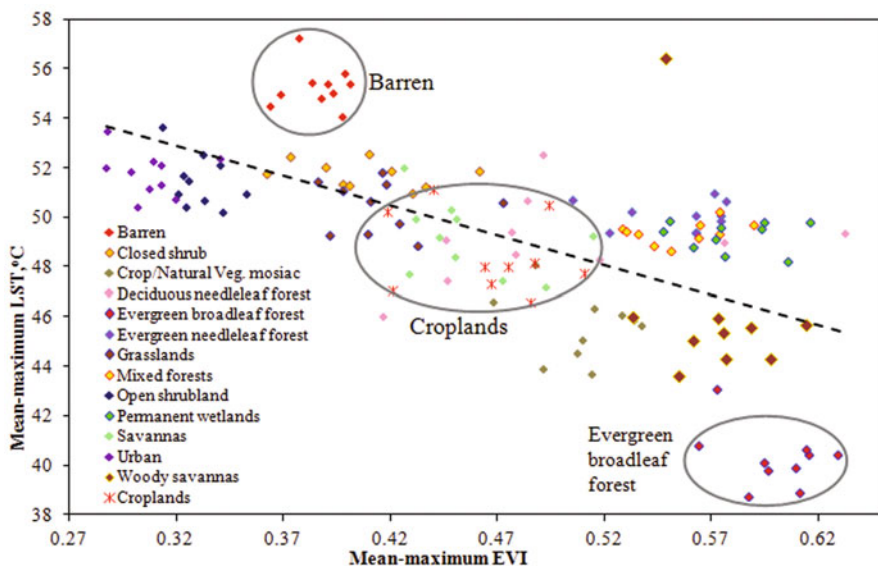

Fig. 13.4 Biophysical relationship between mean-maximum EVI and LST (2003–2012), higher LST is associated with low biomass due to lower latent heat transfer. LST on barren, open shrub, savanna, and woody savanna peaked in 2011 with reduced EVI

Table 13.1 Biomass recovery trend (2008–2012) as percentage of area ((ha/ha) × 100) recovered at subbasin level

| Name	Area proportion with DI below one standard deviation of the long term mean				
	2008	2009	2010	2011	2012
Anger	1.4	1.2	2.5	2.2	0.7
Beles	1.3	0.3	1.9	0.5	0.9
Beshelo	4	8.5	2.7	2.1	2.3
Dabus	1.3	0.7	2	1.7	2
Didessa	1.1	4	4	1.4	0.9
Dinder	1.7	0.3	2	0.4	0.5
Fincha	3.7	3.5	5.6	2.5	1.8
Guder	1.5	1.3	8.4	1.1	1.2
Jemma	4.4	3.8	6	5.2	2.7
Muger	3.3	1.5	6.9	4.4	1.5
North Gojjam	1.1	2.1	5.2	1.8	4.4
Rahad	0.6	0.2	1.4	0.8	0.4
South Gojjam	2.6	1.7	3.5	2.8	1.6
Tana	1.3	2.7	2	2.2	3.5
Welaka	5.8	2.8	3.9	2.6	2.3
Wenbera	1.4	0.7	0.8	1.5	0.8

The mean-maximum LST and mean-maximum EVI are strongly negatively correlated with higher LST associated to low biomass due to lower latent heat transfer. This validates the hypothesis that the energy balance relationship for the land cover grouping is related to the disturbance trajectory. High mean-maximum LST values are not anomalies; instead, they are the effect of fire seasonally set to clear agricultural fields and stimulate growth. As the fire removes all biomass, the evaporative cooling potential diminishes and albedo increases due to a blackened surface (Running 2008).

13.4.2 Biomass Recovery Trend

The long-term (i.e., 10-year) average DI for the selected land cover classes was 1.47 and for the whole basin it was 1.53 with standard deviations 0.64 and 0.69, respectively. The threshold value for one standard deviation below the long-term mean is thus 0.83 (i.e., 1.47–0.64). Field visits helped to identify that the majority of the areas identified as spots of biomass recovery are plantations initiated by the previous government after the 1984 drought. Eucalyptus trees dominate plantations with a considerable mix of coniferous trees and some indigenous trees in the center and southeast of the basin. This is in agreement with the national statistics in that out of the reported 161,000 ha that the state planted up to the year 1989, Eucalyptus accounts for more than 55 % (EFAP 1994).

Table 13.1 shows the area of recovered biomass for the years 2008–2012, reclassified based on the threshold given as proportion of the subbasin area. Taking the

Fig. 13.5 **a** Subbasins. **b–e**
DI maps for 2008–2012:
green areas are recovering
areas; irrigated land adjacent
to the Blue Nile River
(Sudan) appears as a
recovering area due to
the year-round high
biomass availability due to
adequate water supply and
energy availability for
photosynthesis
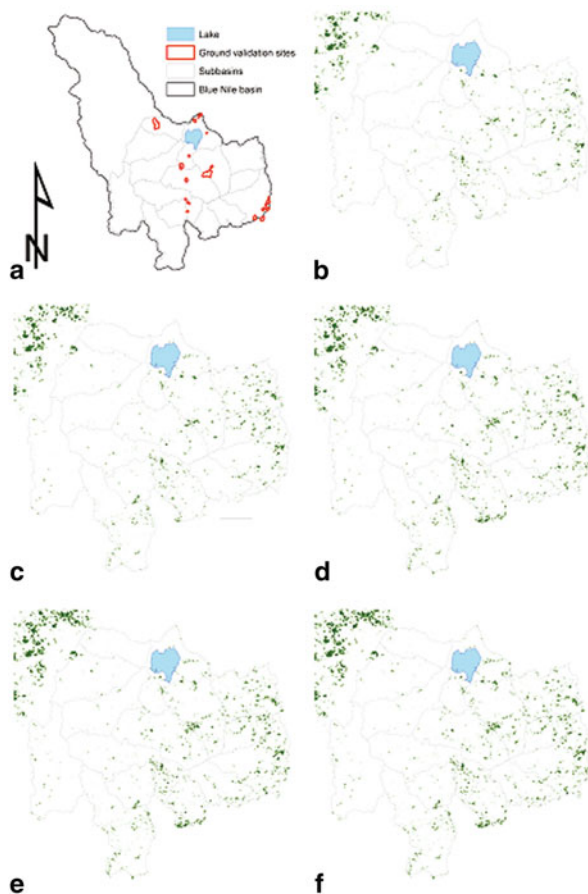
Lake Tana subbasin as an example, the results for 2008 and 2012 can be interpreted. In 2008, 1.3 % of the subbasin area had LST to EVI (i.e., DI) ratio, which is less than one standard deviation to the long-term DI, whereas in 2012 the area expanded to 3.5 % of the subbasin area. The results of the DI analysis showed a negative biomass recovery trend for 12 out of the 16 subbasins. North Gojjam, Dabus, Rehad, and Tana basins showed a positive biomass recovery trend.

Figure 13.5 depicts subbasins, ground validation sites, and DI maps for 2008–2012. The five subbasins with largest biomass recovery are Muger, Dabus, Weleka, Dinder, and Beles. The recovered areas represent 6–7 % of the subbasins. Fincha, Wenbera, Tana, South Gojjam, and Anger subbasins are least recovering with recovered areas of 3–4 %. The total basin level biomass recovery is 2 % as of 2012. The annual recovered area is in a declining trend in all the subbasins except Tana and North Gojjam subbasins. The positive trend in these two subbasins may be explained by the steady increase in irrigated land at the Koga irrigation (Tana subbasin) scheme which expanded to 6,000 ha towards the end of 2011 (Eguavoen and Tesfai 2012).
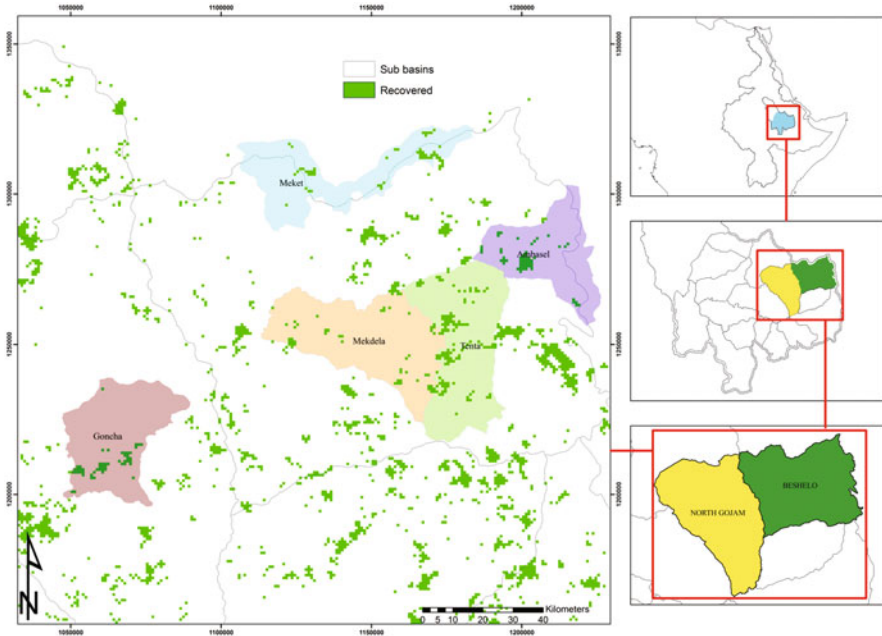
Fig. 13.6 Biomass recovery trend in five community-managed watersheds supported by the MERET project since 2003 is compared with the biomass recovery trend in their respective subbasins with similar biomass recovery trajectories observed at both scales

In the North Gojjam subbasin, a considerable expansion of commercial Eucalyptus plantations has been observed during the field visit.

13.4.3 Comparison with Ancillary Data

Plantations initiated after the 1984 famine have become the dominant features of the Ethiopian highland landscapes. With a relatively longer protection, the plantations survive deforestation except in the case of those plantations planned for fuelwood consumption. The plantation campaigns are aimed at dislodging farmers from steep slope areas and covering the land with plantation. In 80 % of the field validation sites visited, farmers responded that planning was not participatory. In all of these plantations, communities participated against their will and oftentimes land for plantation was acquired by evicting farmers plowing the steep slopes. Bewket and Sterk (2002) reported similar observations. Recent SWC works had implemented a different approach in that the activities are undertaken as community managed SWC projects. Even though the outcome of these conservation works cannot be seen on the DI analysis output as in the case of the large plantations undertaken by the previous government, comparison of reported recovered area is found to be consistently identical with overall biomass recovery trend of the subbasins in which these projects are situated as shown in Fig. 13.6.
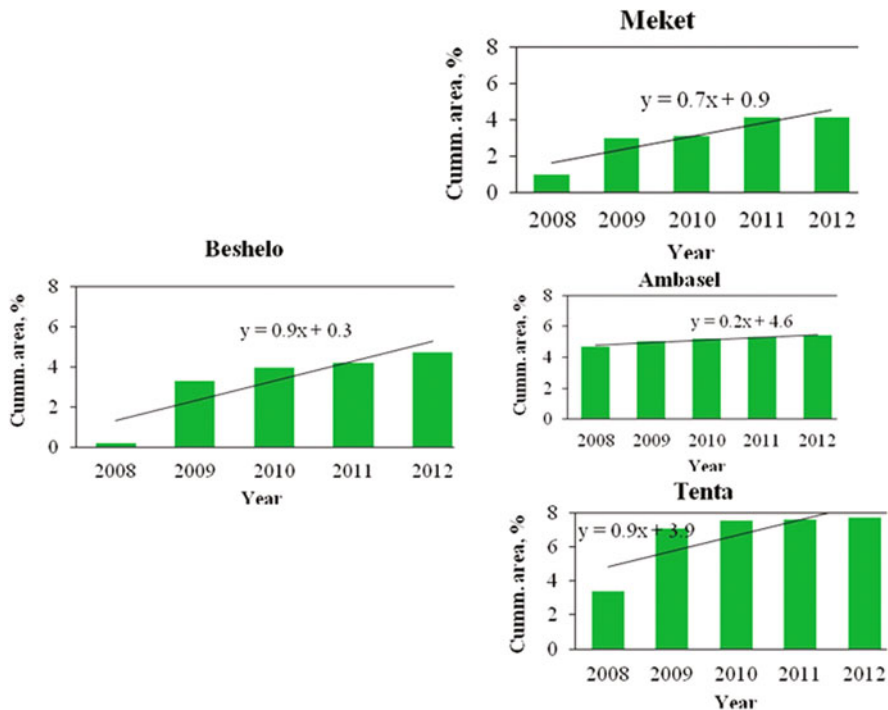
Fig. 13.7 The trend in total recovered area of Beshelo subbasins determined from the DI analysis was identical to the biomass recovery trend reported by the community-managed SWC trend in five community-managed watersheds supported by the MERET project since 2003 and are compared with the biomass recovery trend in their respective subbasins with similar biomass recovery trajectories observed at both scales

   Recovered area statistics of five watersheds in two subbasins as recorded by WFP are compared with the DI maps for the subbasins where these watersheds are located. Four watersheds are in Meket, Tenta, Ambassel, and Mekdela provinces located within the Beshelo subbasin (Fig. 13.7) and one watershed is located in Goncha province in the North Gojjam subbasin (Fig. 13.8). The total recovered area in these watersheds showed a similar trend to their respective subbasins. The low level of total recovered area in 2008 in the subbasins is identical to the total recovered area in the provinces.

13.5   Conclusion

Tracking the state of biomass recovery trend is a necessary step in evaluating the effectiveness of SWC measures. The DI tool was previously tested on continental USA using 2 years of MODIS EVI and LST products (2003–2004). It was difficult to represent the range of natural variability using 2 years' data. In this research,
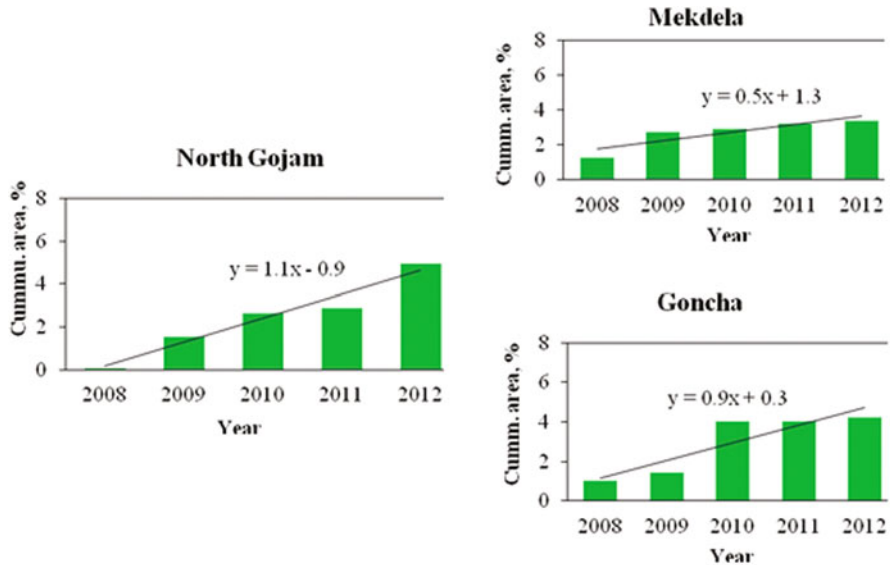
Fig. 13.8 The trend in total recovered area of North Gojjam subbasins determined from the DI analysis was identical to the biomass recovery trend reported by the community-managed SWC trend in five community-managed watersheds supported by MERET project since 2003, and are compared with the biomass recovery trend in their respective sub basin with similar biomass recovery trajectories observed at both scales

10-year (2003–2012) data were used in applying the tool to monitor the state of biomass in the Blue Nile River basin. As a result, disturbance detection of ecosystems with high interannual variability is improved and false disturbance detection is minimized. The DI maps can be also be easily updated with an additional year of data. Nonetheless, precaution should be taken in interpreting the maps. With a number of irrigation projects under implementation, it is also important to note that inflated biomass recovery figures may result. The interpretation on the index should thus be further rectified by masking out irrigation land. The major limitation of the method is its shortfall in detecting small-scale and fragmented SWC works. This shortfall is attributed to the coarser resolution EVI and LST data availability. Such SWC works are typical in community-managed watersheds and should be quantified in some way. Additional steps are required to apply the method for use in small-scale SWC using finer resolution images.

The implementation strategy of the plantations determines their sustainability. The top-down approach in the past did not bring about significant results. Plantations are often associated with subsidence of the groundwater level mainly manifested by drying up of local springs. The current community-managed SWC approach is instrumental in uprooting past oversights and instating a participatory approach. The investment returns of the new approach are yet to be seen in the future. The cost–benefit analysis of investment on SWC should incorporate the change in soil

composition, water availability, production of woody biomass, and crop and horti-cultural productivity. In this regard, the DI can be applied as a typical tool to measure the production of woody biomass.

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