Environment, Forest and Climate change Commission

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Tree-Based Landscape Restoration Potential and Priority Maps: Meket (Amhara Regional State), Ethiopia

Authors: Ashebir Wondimu (Environment, Forest and Climate Change Commission) and Florence Landsberg (World Resources Institute).

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Photo credits: Florence Landsberg.

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1 Introduction

Based on criteria identified by national and regional experts, 82 million hectares in Ethiopia were identified as having potential for additional trees, either through restoration of secondary forests, agroforestry, commercial plantations or as buffers around national parks and waterbodies (MEFCC, 2018). As a follow-up to the national mapping of potential for tree-based landscape restoration (see Box 1 for definitions), the Environment, Forest and Climate Change Commission (EFCCC), with support from the World Resources Institute (WRI), produced potential and priority maps for Sodo Guragie (SNNP Regional State) and Meket (Amhara Regional State). This report presents the results for Meket.

Box 1. A few definitions

- *Tree-based*: Adding more trees in landscapes, which may or may not result in a forest.[1]
- *Landscape*: Constituting a social-ecological system that comprises a mosaic of natural and/or human-modified ecosystems and is delineated based on the restoration objectives (adapted from Buck and Bailey, 2014).
- *Restoration*: Contributing to a long-term natural or human-mediated process of regaining a vegetation cover, and thereby ecological functions, and enhancing human well-being in degraded landscapes. This process may or may not bring the original vegetation back.
- *Potential*: Indicating where restoration potential criteria are met and therefore where a tree-based landscape restoration option could be implemented. Whether a land with potential for restoration is available for restoration ultimately depends on the land user's decision.

Source: Adapted from MEFCC, 2018.

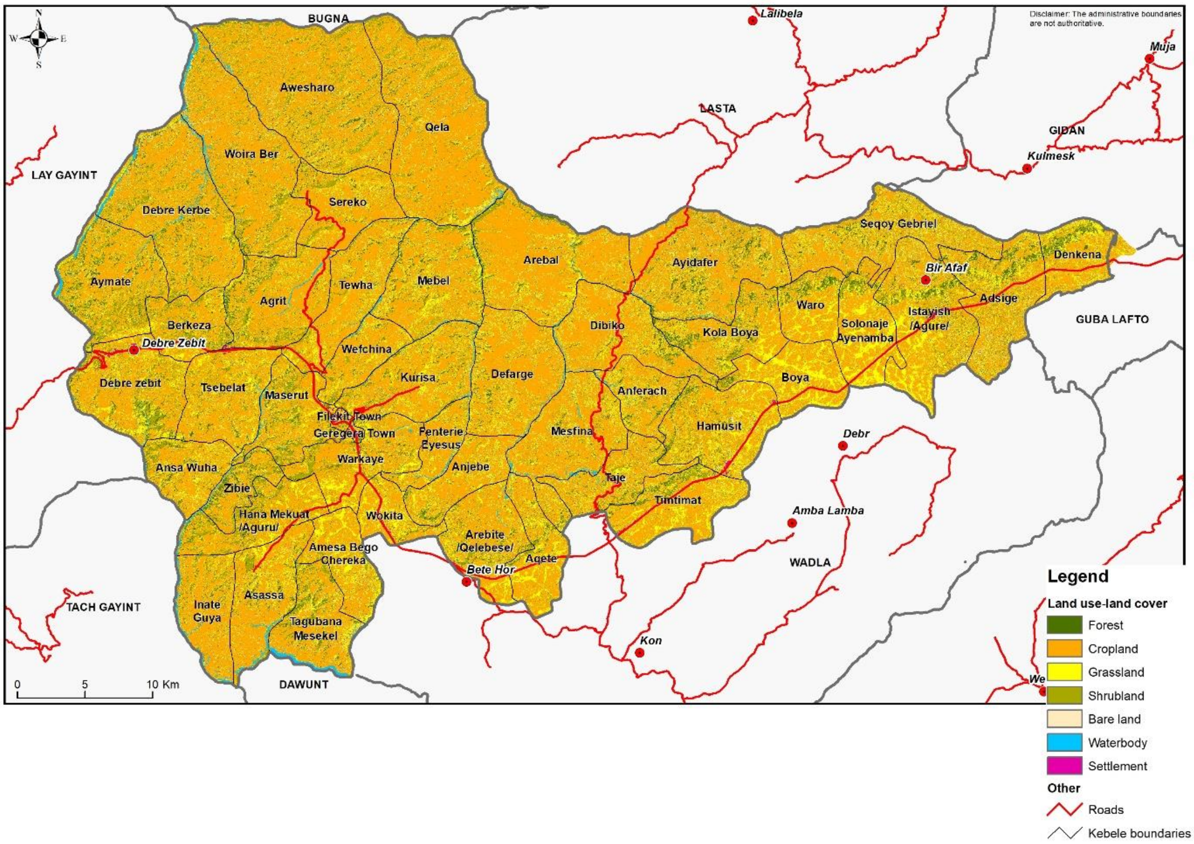
2 Land use-land cover and tree cover classifications

Mapping tree-based landscape restoration potential requires current land use-land cover and percent tree cover data. Recent land use-land cover and percent tree cover maps were produced based on 10m-resolution satellite images (Sentinel-2, see Appendix A for more details on the classification processes) as substitutes for the 2013 national land use-land cover (EMA, 2015) and the 2010 global percent tree cover (Hansen et al., 2014).

Map 1 and Table 1 show that Meket's major land use-land cover is by far cropland.

[1] "Forest" means "trees, plants and other bio-diversity accumulation at and in the surrounding of forest lands, roadsides, riverside, farm and grazing lands as well as residential areas or parks that grow naturally or developed in some other ways;" (FDRE, 2018). Technically, forests in Ethiopia are of a minimum mapping unit of 0.5 hectares, minimum tree height of 2 m and minimum canopy cover of 20 percent (MEF, 2015).

Map 1 | Land use-land cover



Sources: Land use-land cover (2016-2017): EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda boundaries: adapted from CSA's 2007 census boundaries, 2007b.

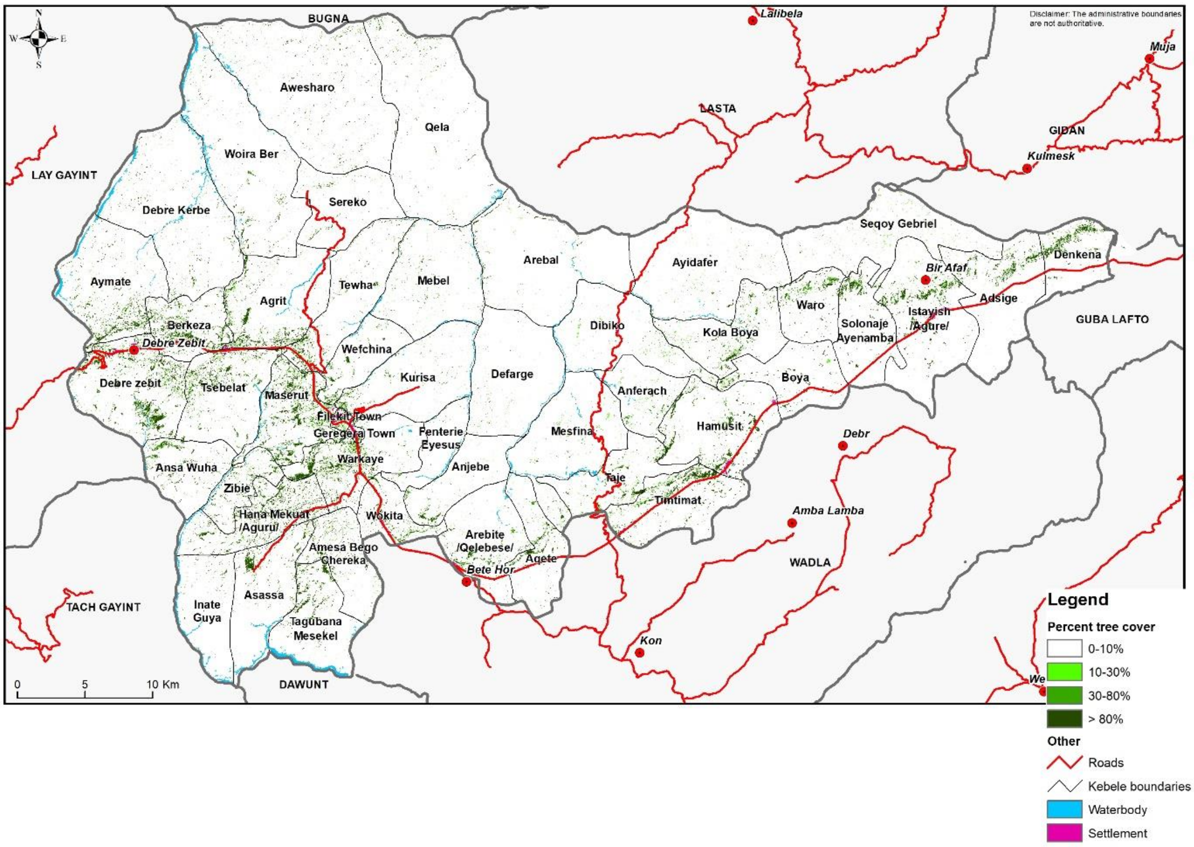
Table 1 | 2016-2017 land use-land cover – area statistics

Land use-land cover class	Area (ha)[2]	Area (%)
Forest	9,300	4.8
Cropland	120,500	62.2
Grassland	29,600	15.3
Shrubland	23,300	12
Bare land	9,200	4.8
Waterbody	1,500	0.8
Settlement	300	0.1
TOTAL	193,700	100

As Map 2 and Table 2 show, most of Meket has less than 10 percent tree cover.

[2] Numbers were rounded to the nearest hundred.

Map 2 | Percent tree cover



Sources: Tree cover (2016-2017): EFCCC, 2019b. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda boundaries: adapted from CSA's 2007 census boundaries, 2007b.

Table 2 | 2016-2017 percent tree cover – area statistics

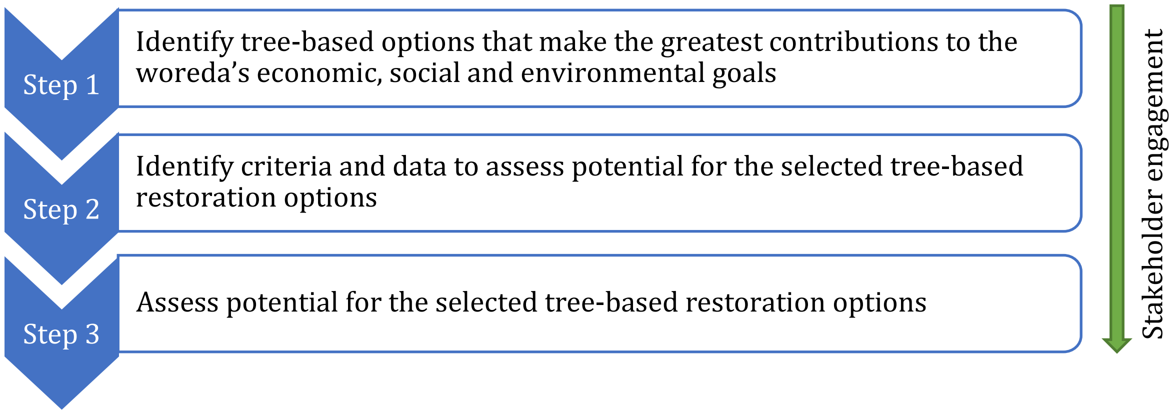
Percent tree cover class	Area (ha)[3]	Area (%)
0-10%	186,100	96
10-30%	2,000	1.1
30-80%	1,200	0.6
80-100%	4,400	2.3
TOTAL	193,800	100

[3] Numbers were rounded to the nearest hundred.

3 Mapping potential for tree-based landscape restoration

The development of the woreda potential maps adapted the process used at national level (Figure 1).

Figure 1 | Steps to produce woreda tree-based landscape restoration potential maps



Source: Adapted from MEFCC, 2018.

3.1 Identify tree-based landscape options that make the greatest contributions to the woreda's goals

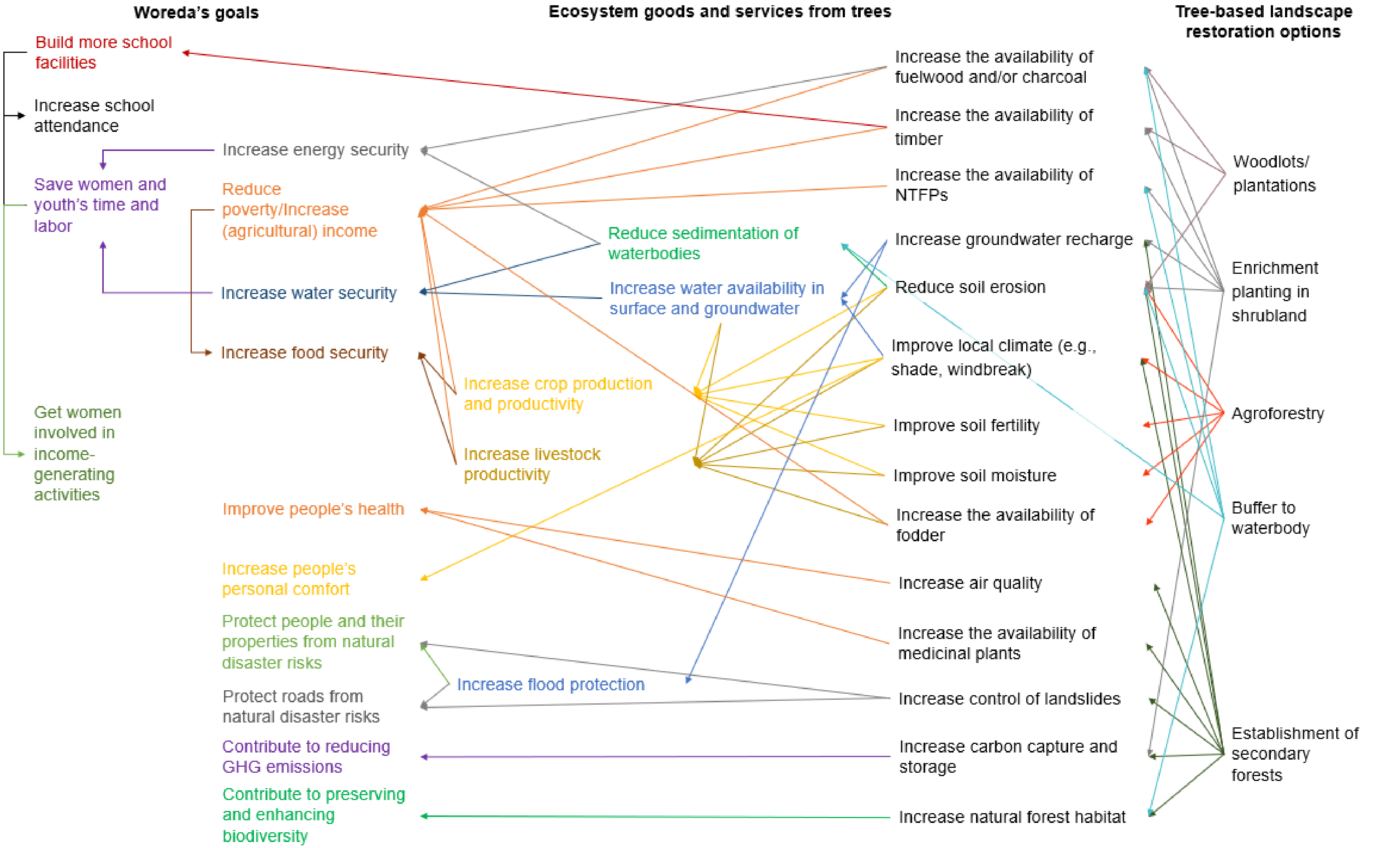
Stakeholders in Meket identified a multiplicity of ways that trees could contribute to human well-being and ecosystem health in their Woreda, including contributions to:

- Income through timber, crop and livestock production, non-timber forest products (NTFPs), charcoal, and woodfuel
- Food security through agriculture production and NTFPs
- Water security through increased water availability and reduction of sedimentation of waterbody
- Energy security through access to charcoal and woodfuel
- Physical security through protection from landslides and increased flood protection
- Greenhouse gas reduction from carbon sequestration
- Biodiversity conservation from restoration of natural forest habitat

Woreda stakeholders selected five tree-based landscape restoration options based on their contributions to the woreda's goals (Figure 2):

- Restoring secondary forests (i.e., (assisted) natural regeneration ((A)NR))
- Agroforestry
- Woodlots/plantations
- Enrichment planting in shrubland
- Buffer to waterbody

Figure 2 | Linking Meket's goals, ecosystem goods and services from trees, and selected tree-based landscape restoration options



3.2 Identify criteria for mapping potential for tree-based landscape restoration options

Tables 3, 4, 5, 6 and 7 present the criteria to assess where each of the tree-based options could take place in Meket.

Table 3 | Criteria for potential for restoring secondary forests

Assessment criteria	Value	Justification and data sources
Potential natural vegetation	Include following classes: • Combretum-Terminalia woodland and wooded grassland • Dry evergreen Afromontane forest and grassland complex	These are the areas where forest could grow in Meket, based on national and regional vegetation and land use maps, field expertise from national botanical experts, and suitability modelling. *Data source: Van Breugel et al., 2015.*

Table 4 | Criteria for potential for agroforestry

Assessment criteria	Value	Justification and data sources
Current land use-land cover	Include cropland with slopes <= 60%	Agri-silviculture takes place on cropland, which should only be on slope smaller than 60%. Rural lands whose slope is more than 60% shall not be used for farming; they shall be used for development of trees, perennial plants and forage production (adapted from FDRE, 2005). *Data source for slope: Derived from SRTM n.d.* *Data source for LULC:* EFCCC, 2019a.
	Include grassland	Agro-silvopastoralism takes place on grassland. It should be noted that areas on slopes greater than 60% shall not be used for free grazing; they shall be used for development of trees, perennial plants and forage production (adapted from FDRE, 2005). *Data source for LULC:* EFCCC, 2019a.
Current percent tree cover	Exclude areas with tree cover > 30%	Agroforestry systems with > 30% tree cover are considered already well-stocked (while ICRAF proposes that "agroforestry" be defined by tree cover > 10% on farms, it also recognizes the potential to improve the existing agroforestry system with 10–30% tree cover [Zomer et al., 2014]). *Data source:* EFCCC, 2019b.

Table 5 | Criteria for potential for woodlots/plantations

Assessment criteria	Value	Justification and data sources
Slope	Exclude areas with slope > 60%	Given the risks of landslides during skidding and harvesting, these lands should rather be converted to secondary forests (see associated potential). *Data source: Derived from SRTM n.d.*
Distance to road	Exclude areas > 1 km from road	Markets need to be easily accessed to transport and sell wood products. *Data source: ERA, 2007.*

Table 6 | Criteria for potential for enrichment planting in shrubland

Assessment criteria	Value	Justification and data sources
Current land cover	Include shrubland	Shrubland can be enriched. Within 1km from cropland and grassland, use high-value trees to decrease pressure on shrubland (if the species competes with the crop or livestock production the trees should be at a certain distance from it (e.g., eucalyptus should be at least 20 m from a cropland). *Data source:* EFCCC, 2019a.
Percent tree cover	Exclude shrubland with > 10% tree cover	Based on the definition of forest, 20% is the threshold for forest. Since there isn't a class for 20% and above in the available data, areas with 10% and more were excluded. *Data source:* EFCCC, 2019b.

Table 7 | Criteria for potential for buffer to waterbody

Assessment Criteria	Value	Justifications and Data Sources
Distance to Waterbodies	Include 10m buffer from perennial river banks	The original buffer distance identified by the local experts was 5m but the LULC resolution being 10m, the buffer zone was set at 10m from the river banks. *Data source for perennial rivers: Friis et al., 2010.*
Current Land Use-Land Cover	Exclude closed shrublands	This natural vegetation is already protecting waterbodies from sedimentation. *Data source: No data.*

In addition, as Meket has a high interest in promoting frankincense, a map of potential for *Boswellia papyrifera* was produced based on the criteria presented in Table 8.

Table 8 | Criteria for potential for frankincense

Assessment criteria	Value	Justification and data sources
Potential natural vegetation	Include 1. Acacia-Commiphora woodland and bushland 2. Acacia wooded grassland of the Rift Valley 3. Wooded grassland of the Western Gambela region 4. Combretum-Terminalia woodland and wooded grassland	These are the natural potential vegetation types where frankincense grow (Dr. Tefera, personal communication); http://www.worldagroforestry.org/usefultrees/pdflib/Boswellia_papyrifera_ETH.pdf) *Data source: Van Breugel et al., 2015.*
Distance to road	Exclude areas > 5 km from road	Markets need to be easily accessed to transport and sell incense. The distance was determined by local experts. *Data source: ERA, 2007.*

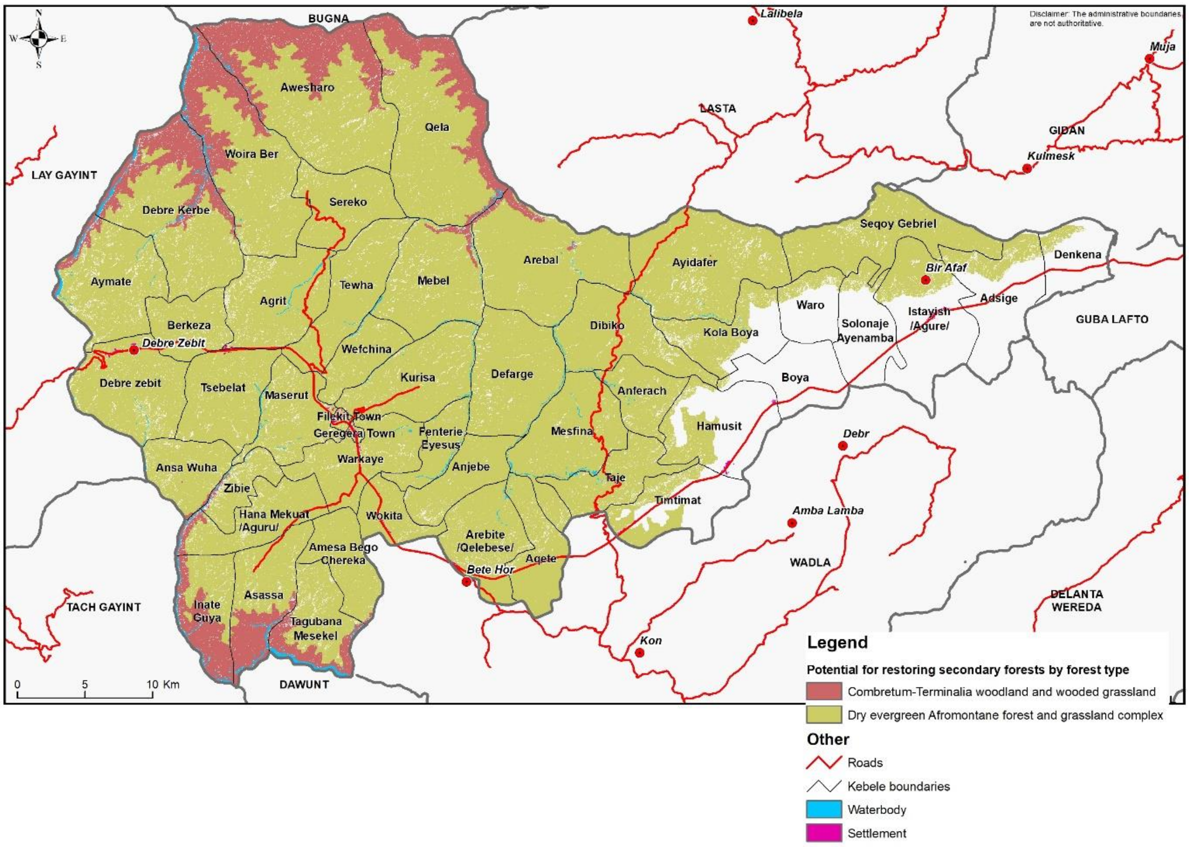
3.3 Map potential for tree-based landscape restoration

Mapping potential for a specific tree-based option means that the map shows where the option could take place, not where it *should* take place. As Map 7 shows, multiple potentials can overlap. The people managing and depending on the land are the ones who should choose which restoration option to implement.

3.3.1 Potential for restoring secondary forests

The woreda has potential for secondary forests on most of its land (Map 3 and Table 9). However, as land is scarce, it is important to balance the restoration of secondary forests necessary to supply the desired level of ecosystem services with the production of food in cropland and grassland. Section 4 presents where to prioritize restoration of secondary forests for lesser sedimentation rates.

Map 3 | Area with potential for restoring secondary forests



Sources: Potential for restoring secondary forests: EFCCC, 2019c. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda boundaries: adapted from CSA's 2007 census boundaries, 2007b.

Table 9 | Potential for restoring secondary forests – area statistics

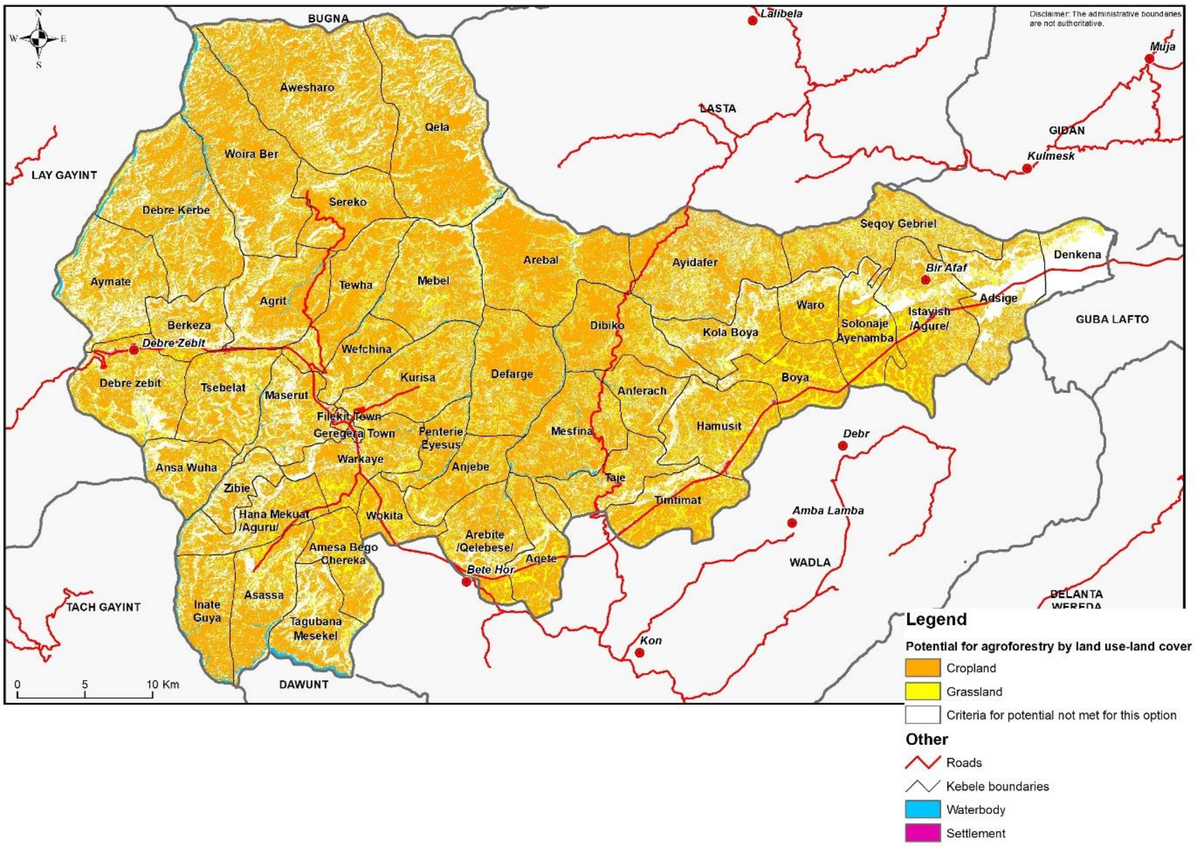
Potential for restoring secondary forests by forest vegetation type	Area (ha)[4]	Area (%)
Combretum-Terminalia woodland and wooded grassland	16,400	10
Dry evergreen Afromontane forest and grassland complex	143,400	90
TOTAL	159,800	100

[4] Numbers were rounded to the nearest hundred.

3.3.2 Potential for agroforestry

Almost the totality of Meket's cropland and grassland could increase its tree cover (Map 4 and Table 10). Increasing the use of agroforestry trees for various purposes (e.g., soil fertility, fodder) should be promoted.

Map 4 | Area with potential for agroforestry



Sources: Potential for agroforestry: EFCCC, 2019d. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda boundaries: adapted from CSA's 2007 census boundaries, 2007b.

Table 10 | Potential for agroforestry – area statistics

Potential for agroforestry	Area of cropland/grassland with potential (ha)[5]	Percent of cropland/grassland with potential for agroforestry (%)
Cropland	112,000	93%
Grassland	28,400	96%
TOTAL	140,400	94%

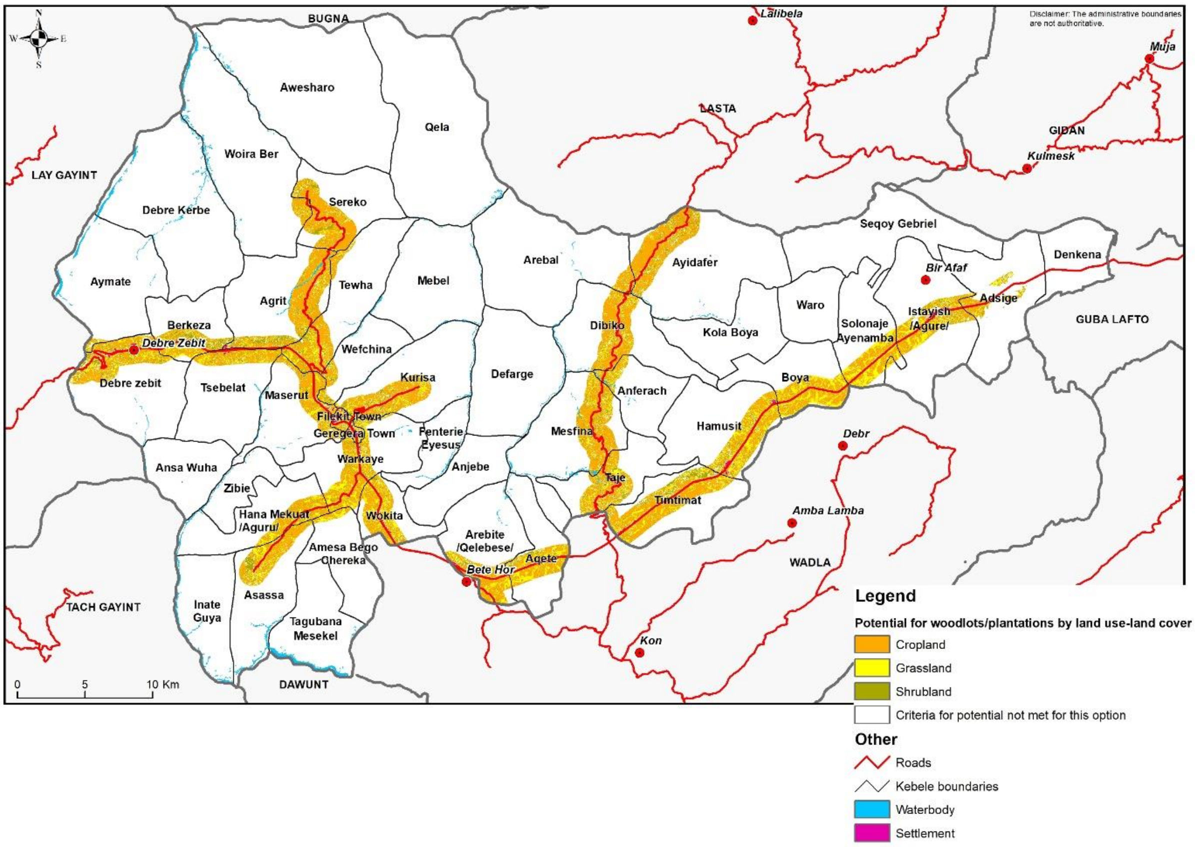
3.3.3 Potential for woodlots/plantations

Around twenty-six thousand hectares of cropland, grassland, and shrubland are deemed to have potential for woodlots/plantations (Map 5 and Table 11). As farmers are highly dependent on their land for food security and therefore not receptive to converting cropland to

[5] Numbers were rounded to the nearest hundred.

woodlots/plantations, such an option will require livelihood strategies to be put in place to encourage, or even allow, families to transition from food to timber production.

Map 5 | Area with potential for woodlots/plantations



Sources: Potential for woodlots/plantations: EFCCC, 2019e. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda boundaries: adapted from CSA's 2007 census boundaries, 2007b.

Table 11 | Potential for woodlots/plantations – area statistics

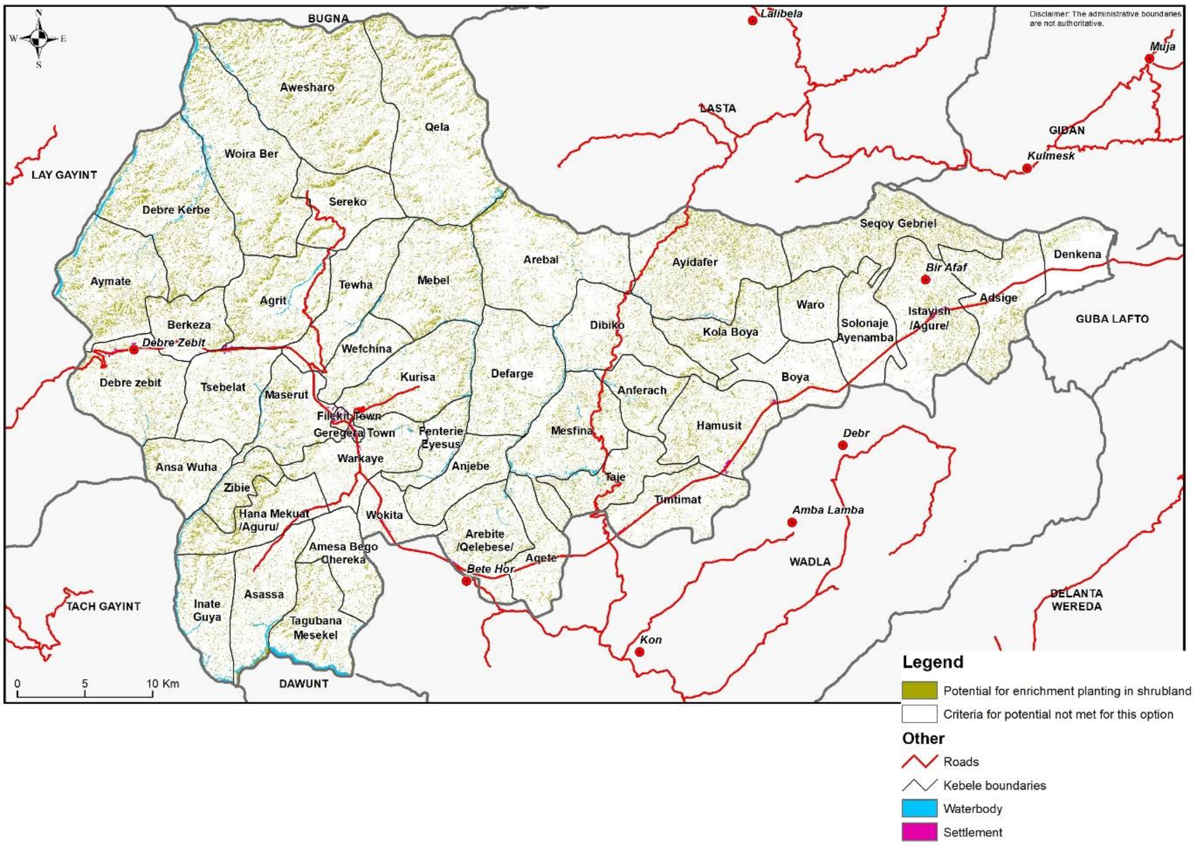
Potential for woodlot/plantation by land use-land cover	Area (ha)[6]	Area (%)
Cropland	17,100	66.3
Grassland	5,600	21.6
Shrubland	3,100	12.1
TOTAL	25,800	100

3.3.4 Potential for enrichment planting in shrubland

Increasing the benefits derived from shrublands helps prevent their degradation and the degradation of natural forests they often buffer. More than four fifths of Meket's shrublands have potential for additional trees (Map 6 and Table 12).

Map 6 | Area with potential for enrichment planting in shrubland

[6] Numbers were rounded to the nearest hundred.



Sources: Potential for enrichment planting in shrubland: EFCCC, 2019f. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda boundaries: adapted from CSA's 2007 census boundaries, 2007b.

Table 12 | Potential for enrichment planting in shrubland – area statistics

Potential for enrichment planting in shrubland (ha)[7]	19,300
Percent of shrubland with potential for enrichment planting (%)	83

[7] The area was rounded to the nearest hundred.

3.3.5 Potential for buffer to waterbody

While the scale of this potential is inappropriate to be visualized at Woreda level, Table 13 shows that more than half the buffer zone would be taken out of cropland, which means that trees in the buffer area should be selected to contribute to farmers' livelihood to compensate for the loss in crop production.

Table 13 | Potential for buffer zone to waterbody- area statistics

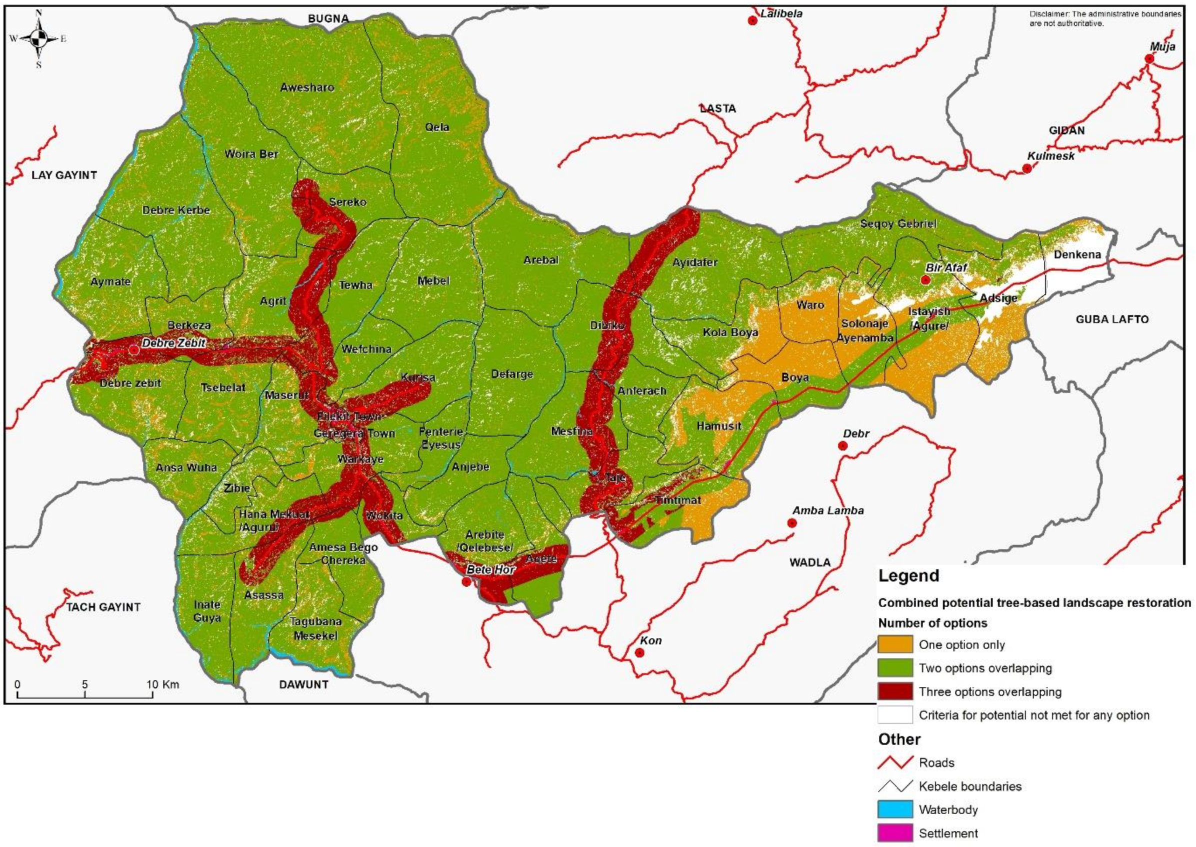
Land use-land cover class in area with potential for buffer zone to waterbody	Area (ha)[8]	Area (%)
Cropland	130	55.7
Grassland	40	16.1
Shrubland	50	21.5
Bare land	20	6.7
TOTAL	240	100

3.3.6 Combined potential for tree-based landscape restoration

The opportunity to increase the contribution of trees to human well-being and ecosystem health in Meket is high, with 92% of the woreda with potential for additional trees. There are overlaps between different restoration options in 84% of the 178 thousand hectares with combined potential (Map 7 and Table 14), which means it will be important for experts to discuss the trade-offs with the people who manage and/or depend on the land.

[8] Numbers were rounded to the nearest ten.

Map 7 | Area with combined potential for tree-based landscape restoration



Sources: Combined potential for tree-based landscape restoration: EFCCC, 2019g. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda boundaries: adapted from CSA's 2007 census boundaries, 2007b.

Table 14 | Combined potential for tree-based landscape restoration – area statistics

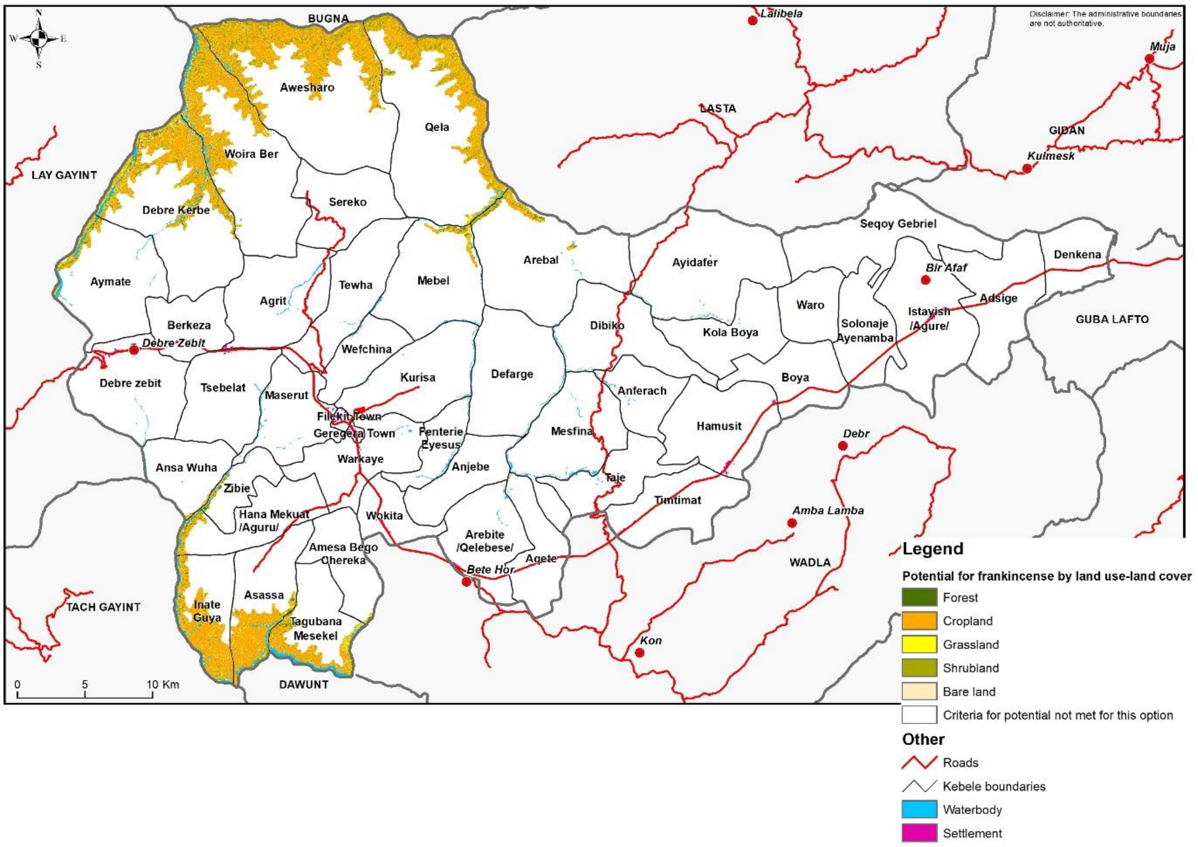
Number of tree-based landscape restoration options	Area (ha)[9]	Area (%)
1	29,100	16.4
2	129,800	73
3	18,900	10.6
TOTAL	177,800	100
Percent of the woreda with potential for tree-based landscape restoration	92%	

[9,10] Numbers were rounded to the nearest hundred.

3.3.7 Potential for frankincense

Based on the agro-ecological factors mapped, there is potential for 17,100 hectares[10] of frankincense in the Northern and Southern tips of Meket (Map 8 and Table 15).

Map 8 | Area with potential for frankincense



Sources: Potential for frankincense: EFCCC, 2019h. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda boundaries: adapted from CSA's 2007 census boundaries, 2007b.

Table 15 | Potential for frankincense – area statistics

Land use-land cover class in area with potential for frankincense	Area (ha)[11]	Area (%)
Forest	700	4.3
Cropland	11,200	65.7
Grassland	1,600	9.2
Shrubland	2,600	14.9
Bare land	1,000	5.9
TOTAL	17,100	100

[11] Numbers were rounded to the nearest hundred.

4 Spatial targeting: restoring secondary forests to decrease waterbody sedimentation in Meket

Restoring secondary forests can play an important role in decreasing the sedimentation of waterbodies, both in terms of diminishing soil loss compared to other land uses and trapping soil erosion. Secondary forests' contributions to sedimentation control vary according to where these new forests are in the landscape (e.g., on sloped or flat areas, in low or high rainfall areas), their relative location vis-à-vis the hydrological network, and the original land use-land cover and management practices.

Based on the data and criteria considered to map potential for restoring secondary forests, most of Meket (Map 3) could be converted to secondary forests. However, residents of Meket depend upon the land for growing crops and poles, and raising cattle. Secondary forests should therefore be strategically restored to supply desired levels of ecosystem services such as groundwater recharge, erosion and sedimentation control, and biodiversity habitat, while taking as little land as possible out of production.

To determine where new secondary forests would most reduce water sedimentation, this study used InVEST's Sediment Delivery Ratio (Box 2). This tool calculates how land use and management practice changes affect sediment export, i.e., the amount of sediment eroded that actually reaches the hydrological network.

Box 2. InVEST Sediment Delivery Ratio

The Sediment Delivery Ratio (SDR) model maps overland sediment generation (i.e., soil erosion caused by surface runoff) and delivery to the hydrological network. In this work, SDR was used to compute (see Appendix B for more details):

1- *Amount of annual soil loss* (in tons/ha/year), which is influenced by variables such as the climate (especially rainfall intensity), soil properties, relief and type of land use-land cover;
2- *Sediment delivery ratio (SDR)* or proportion of soil loss actually reaching the catchment outlet, which is influenced by the location of the source of sediments relative to the hydrological network; and
3- *Sediment export* (in tons/ha/year) or the amount of sediment eroded that actually reaches the hydrological network.

While many of the model parameters are associated with local climate and physical attributes and are therefore largely unalterable, land use-land cover (e.g., restoring secondary forests) and land management practices (e.g., building of bunds/terraces, contour farming, no-till farming) can be modified, and changes can substantially affect sediment export.

Source: Adapted from http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/sdr.html#interpreting-results

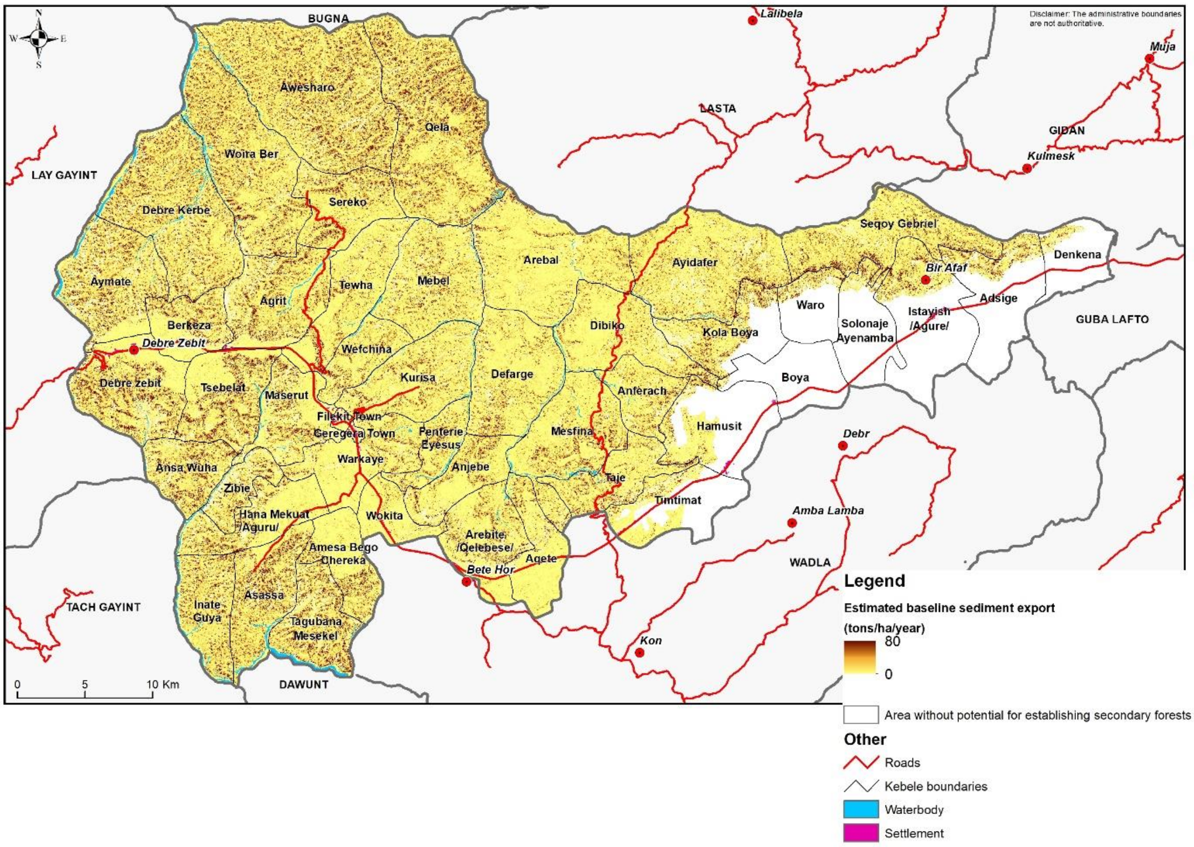
The spatial targeting for restoring secondary forests with the goal of decreasing sediment export followed three steps:

- Step 1: Estimate baseline sediment export from areas with potential for restoring secondary forests
- Step 2: Estimate change in sediment export from restoring secondary forests
- Step 3: Identify implementation sites for restoring secondary forests

4.1 Step 1: Estimate baseline sediment export from areas with potential for restoring secondary forests

Map 9 shows the baseline sediment export from areas that have potential for restoring secondary forests.

Map 9 | Baseline sediment export from areas with potential for restoring secondary forests



Sources: Baseline sediment export: EFCCC, 2019i. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda census boundaries: adapted from CSA's 2007 census boundaries, 2007b.

Across all areas with potential for new secondary forests, the total sediment export is almost 3.5 million tons/year. Figure 3 presents accumulated sediment export, starting from the areas that contribute most to it. As expected, contributions to sediment export vary spatially. As the curve shows, the source of sediment export is concentrated in 40,000 hectares out of the 159,800 hectares that have potential for restoring secondary forests. Table 16 shows the distribution of the 159,800 ha across the various slope classes.

Figure 3 | Cumulative sediment export from areas with potential for restoring secondary forests

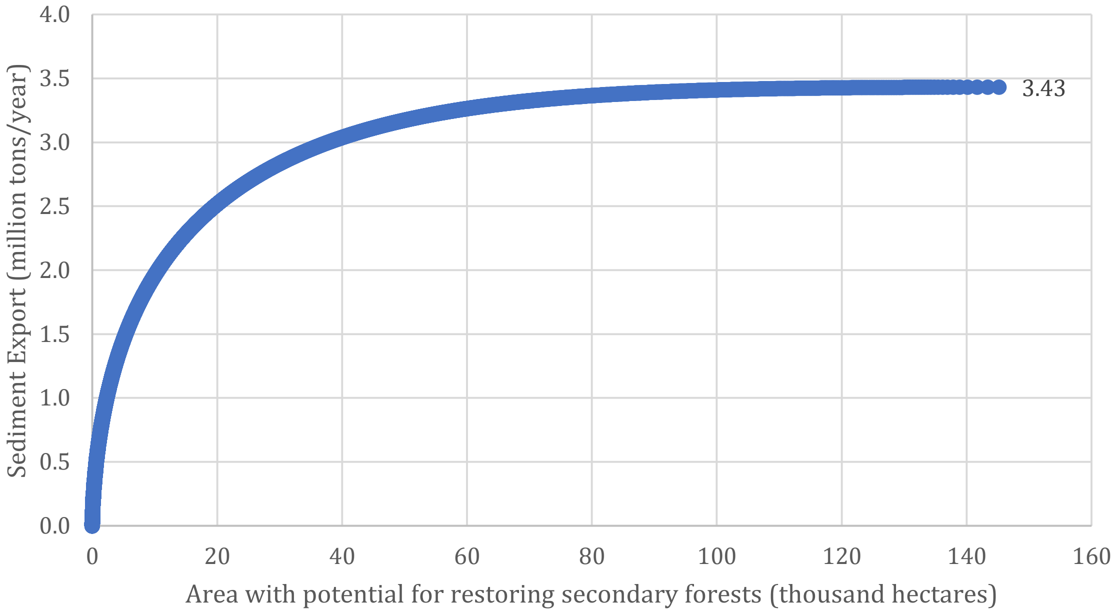


Table 16 | Sediment export from areas with potential for restoring secondary forests by slope class

Slope class	Area (ha) with potential for restoring secondary forests	Mean sediment export (tons/ha/year)	Total sediment export (tons/year)
0 – 2%	9,200	0.06	600
2 – 8%	11,500	1.04	12,000
8 – 15%	20,300	3.15	63,900
15 – 30%	45,000	11.15	502,200
30 – 50%	41,300	28.31	1,169,200
> 50%	32,500	51.84	1,684,900
TOTAL	159,700[12]		3,432,700

Note: Area and total sediment export numbers were rounded to the nearest hundred.

[12] The area is slightly different from the total in Table 9 because of the different projections in which the analyses were conducted.

4.2 Step 2: Estimate change in sediment export from restoring secondary forests

This section describes where to restore secondary forests to most efficiently achieve specific sediment export reduction targets. It also describes how much sediment export is associated with converting certain areas to secondary forests.

4.2.1 Step 2.1: Identify scenarios

Two scenarios at woreda level and one at kebele level were considered (Table 17). The woreda-level scenarios have the advantage of targeting the areas that can make the greatest contributions to controlling sedimentation across the entire woreda. The disadvantage with this approach is that it would disproportionally impact (i.e., take land out of production) kebeles that contribute the most to waterbody sedimentation. The scenario at kebele level would entail the opposite trade-off: it would distribute the responsibility of increasing secondary forests across all the kebeles, but would not necessarily target the areas that would most efficiently decrease sedimentation at woreda level.

- **Scenario 1 – Halve sediment export from areas with potential for restoring secondary forests**: identify where new secondary forests would reduce by half the baseline annual sediment export from the areas with potential for restoring secondary forests, i.e. 1.72 million tons/year.
- **Scenario 2 – Restore secondary forests on 10% of Meket's area**: restore 19,400 ha of secondary forests where it will decrease most sediment export.
- **Scenario 3 – Have at least 10% natural forests in each kebele**: restore secondary forests to achieve at least 10% of each kebele under natural forests (primary and secondary) where it will decrease most sediment export. The new secondary forests target is set for each kebele depending on how much natural (either primary or secondary) forest it already has.

Table 17 | Restoring secondary forests scenarios for Meket: information known

Scenario	Total area of new secondary forests	Reduction in sediment export from areas with potential for restoring secondary forests
Scenario 1: Halve sediment export from areas with potential for restoring secondary forests	To be calculated; location to be identified	+/- 1.72 million tons/year
Scenario 2: Restore secondary forests on 10% of Meket's area	19,400 ha; location to be identified	To be calculated
Scenario 3: Have at least 10% natural forests in each kebele	10,000 ha*; location to be identified	To be calculated

Note: Areas were rounded to the nearest hundred.
*This number is the sum of the area of secondary forests to be restored for each kebele to have at least 10% of its area under natural forest (either primary or secondary).

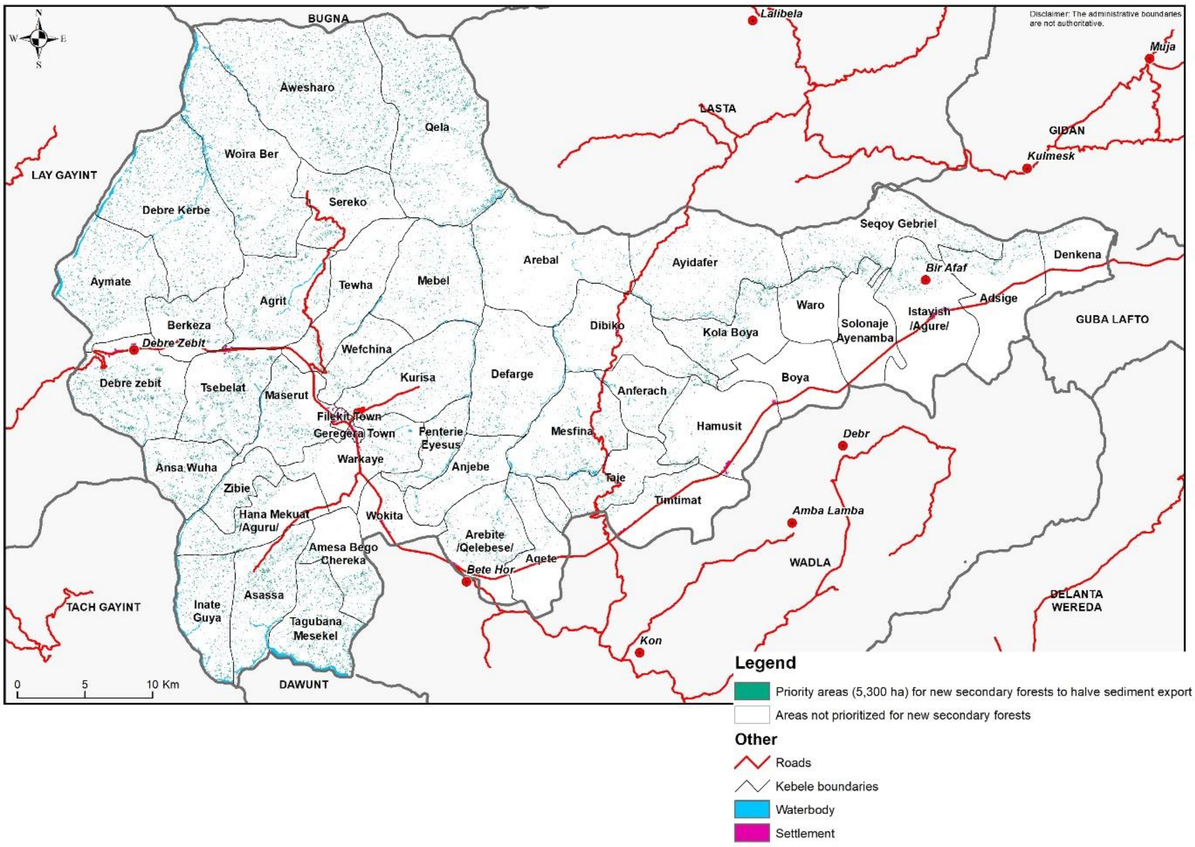
4.2.2 Step 2.2: Run SDR model for scenarios

In each scenario, InVest's SDR model was run to assess sediment export once some of the areas with potential for restoring secondary forests were actually converted to secondary forests. The specific locations of these new forests were identified through LegalGeo, an ArcGIS toolbox that allows to easily identify areas that meet specific criteria, in our case the highest contribution to sediment export.

1.1.1.1 Scenario 1: Halve sediment export from areas with potential for restoring secondary forests

Running InVest's SDR model iteratively[13], the restoration of secondary forests on 5,300 ha is estimated to be needed to reduce sediment export originating from the area with potential for restoring secondary forests to 1.72 million tons/year sediment export (Map 10 and Table 18).

Map 10 | Location of the 5,300 ha where to restore secondary forests to halve sediment export from areas with potential for restoring secondary forest



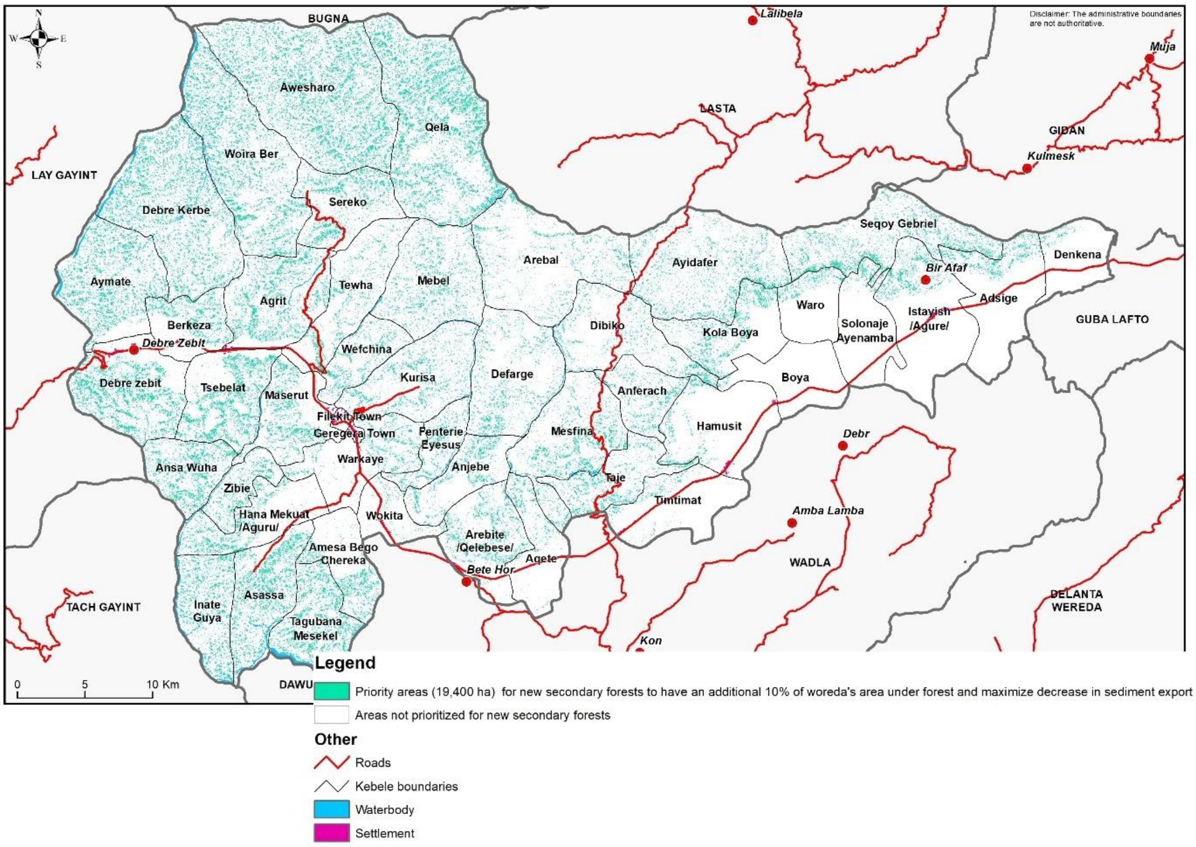
Sources: Priority areas (5,300 ha) for restoring secondary forests under scenario 1: EFCCC, 2019j. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda census boundaries: adapted from CSA's 2007 census boundaries, 2007b.

[13] As a change in land use-land cover (i.e., in our case restoring secondary forests) influences both the annual soil loss and the sediment delivery ratio, the relationship between area of new secondary forests and sediment export is not linear. As a result, the model was run iteratively till the sediment export was about 1.72 million tons/year.

1.1.1.2 Scenario 2: Restore secondary forests on 10% of Meket's area

The location of the new secondary forests, i.e., 19,400 ha, were based on where these new secondary forests would contribute the most to decreasing sediment export (Map 11). The resulting sediment export reduction is 76% of the baseline sediment export originating from the area with potential for restoring secondary forests (Table 18).

Map 11 | Location of the 19,400 ha where to restore secondary forests to decrease most sediment export

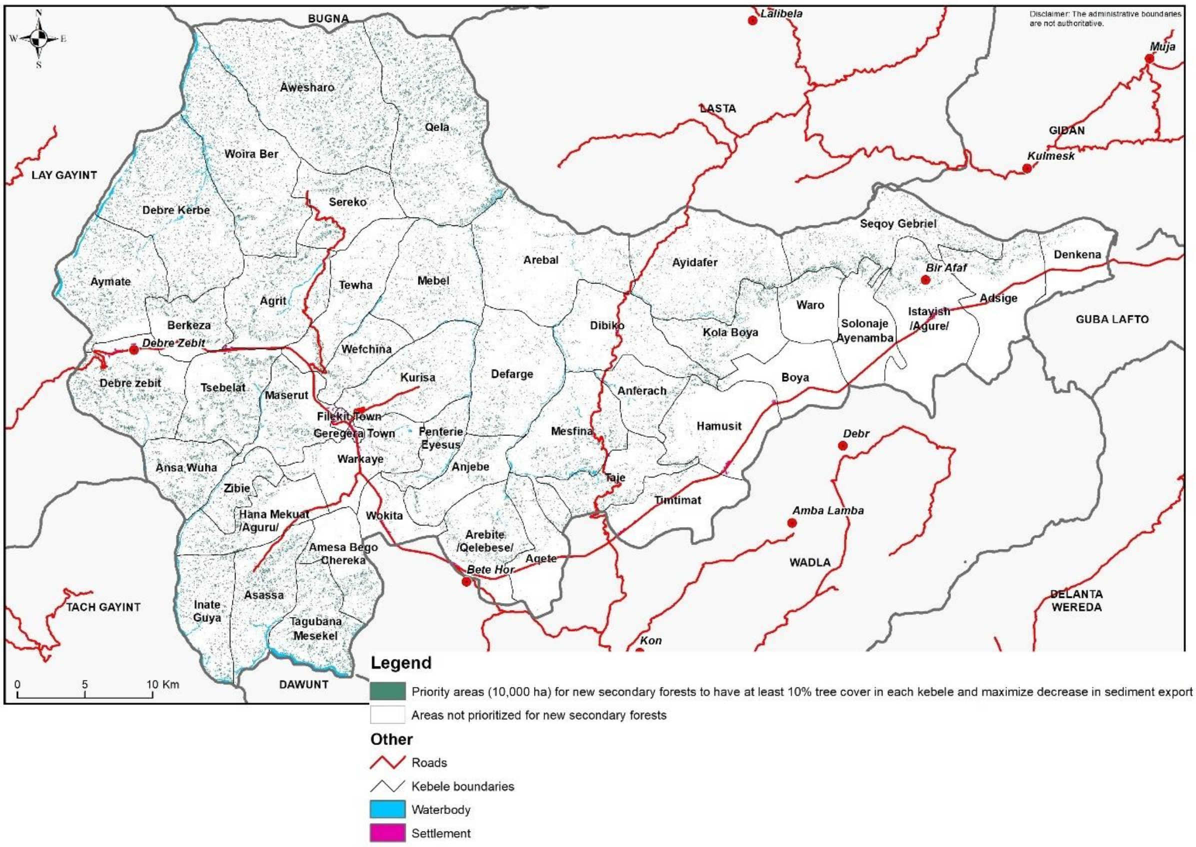


Sources: Priority areas (19,400 ha) for restoring secondary forests under scenario 2: EFCCC, 2019k. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda census boundaries: adapted from CSA's 2007 census boundaries, 2007.

1.1.1.3 Scenario 3: Have at least 10% of natural forests in each kebele

Based on the existing forest cover in each Kebele, the SDR model and LegalGeo were run for each kebele with the goal of achieving a minimum of 10% tree cover while simultaneously having the greatest impact on decreasing their sediment export. Across all the kebeles, the total area to be converted to secondary forest is 10,000 ha (Map 12), and the resulting sediment export reduction is about 63% of the baseline sediment export originating from the area with potential for restoring secondary forests (Table 18).

Map 12 | Location of the 10,000 ha to achieve at least 10% tree cover and decrease most sediment export in each kebele



Sources: Priority areas (10,000 ha) for restoring secondary forests under scenario 3: EFCCC, 2019l. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda census boundaries: adapted from CSA's 2007 census boundaries, 2007b.

Table 18 | Sediment export from area with potential for restoring new secondary forests by scenario

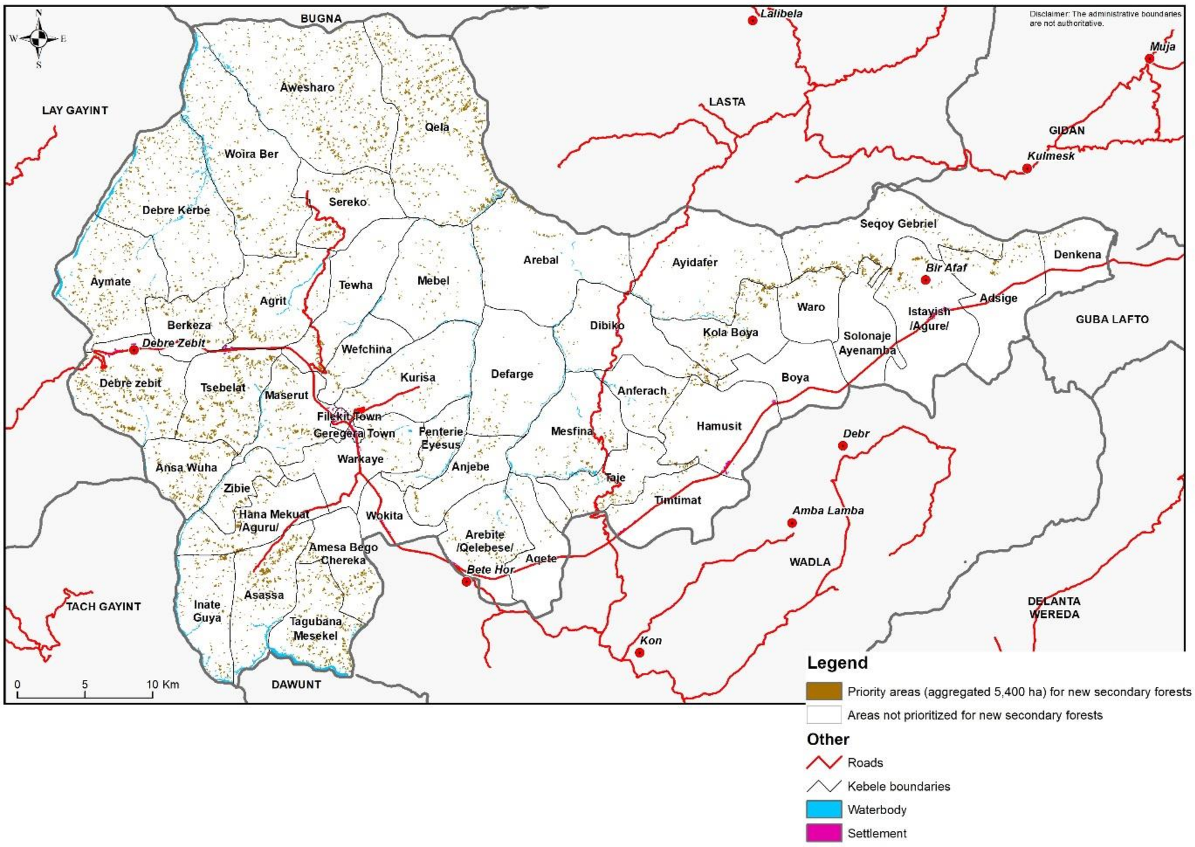
Scenario	Total area of new secondary forests (ha)	Percent of area with potential for restoring secondary forests	Total annual sediment export (tons/year)	Sediment export reduction in percent of baseline sediment export (%)	Average annual reduction in sediment export by area of new secondary forests (tons/ha/year)
Scenario 1: Halve the baseline sediment export from areas with potential for restoring secondary forests	5,300	3%	1,716,800	50	324
Scenario 2: Restore secondary forests on 10% of Meket's area	19,400	12%	827,800	76	134
Scenario 3: Have at least 10% natural forests in each kebele	10,000	6%	1,271,600	63	216

Note: Area and reduction in sediment export numbers were rounded to the nearest hundred.

4.3 Step 3: Identify implementation sites for restoring secondary forests

In terms of ease and cost-efficiency, it is preferable to restore secondary forests on relatively large areas rather than on multiple small, isolated ones. Consequently, a fourth scenario was run. Scenario 4 aggregates areas prioritized under the most efficient scenario (scenario 1 with an average annual reduction in sediment export of 324 tons/ha/year) to be at least 0.5 ha, if necessary through inclusion of areas that do not contribute most to sediment export. The total area was topped around 5,300 ha (Map 13).

Map 13 | Location of the aggregated 5,400 ha candidates for restoring secondary forests



Sources: Priority areas (aggregated 5,400 ha) for restoring secondary forests under scenario 4: EFCCC, 2019m. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda census boundaries: adapted from CSA's 2007 census boundaries, 2007b.

While priority areas are much more aggregated (Figure 4), scenario 4 contributes much less to decreasing sediment export since the aggregated 5,400 ha exclude isolated areas that contribute most to sediment export and added in areas that contribute less to sediment export than in scenario 1 to reach the minimum 0.5 ha size (Table 19).

Figure 4 | Comparison of areas prioritized under scenarios 1 and 4

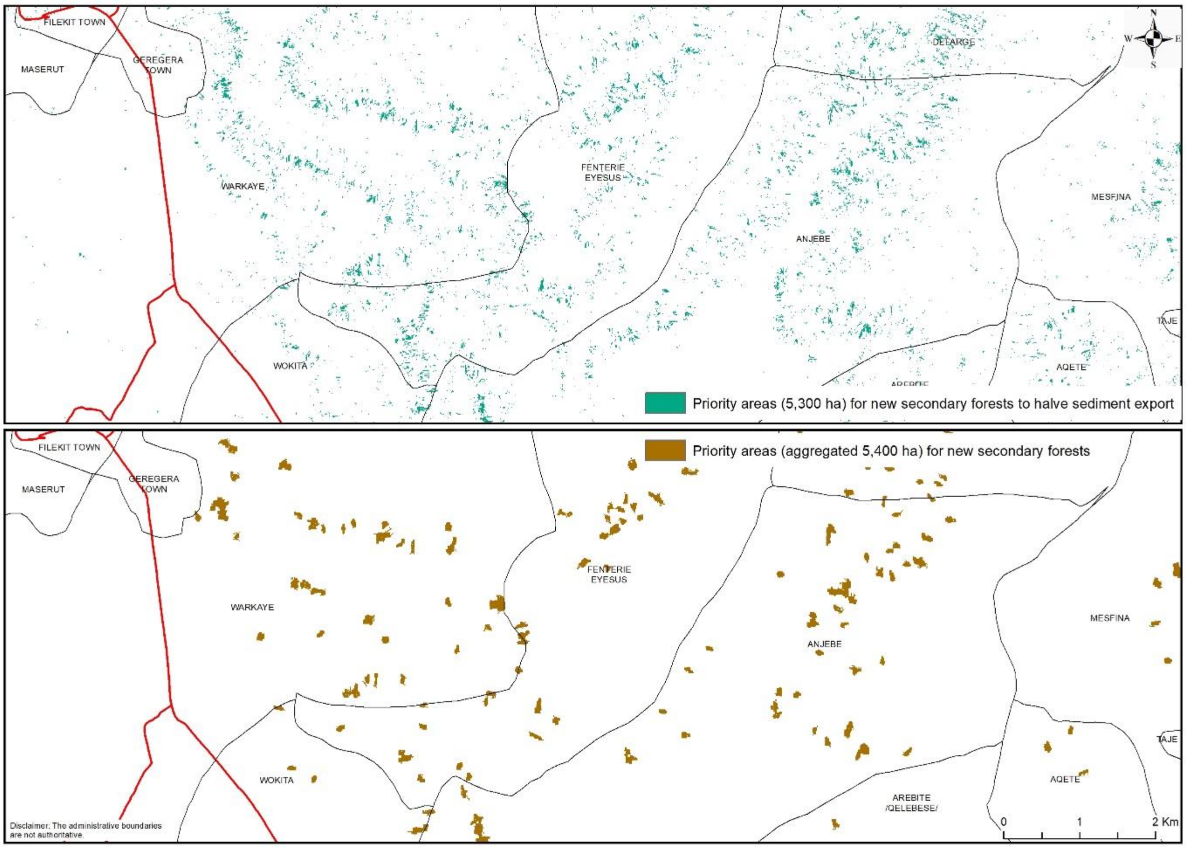


Table 19 | Comparing scenario 1 and 4

Scenario	Total area of new secondary forests (ha)	Percent of area with potential for restoring secondary forests	Total annual sediment export (tons/year)	Sediment export reduction in percent of baseline sediment export (%)	Average annual reduction in sediment export by area of new secondary forests (tons/ha/year)
Scenario 1: Halve the baseline sediment export	5,300	3%	1,716,800	50	324
Scenario 4: Implementation	5,400	3%	2,605,300	24	153

Note: Area and reduction in sediment export numbers were rounded to the nearest hundred.

Table 20 presents the amount of sediment export by slope class. Almost all the areas proposed for restoring secondary forests under scenario 4 have slope greater than 30%, which have the highest sediment export means and are not deemed as conducive to agriculture (MoA/LAUD, 2012).

Table 20 | Sediment export for scenario 4 by slope class

Slope class	Area (ha) for implementation	Mean sediment export (tons/ha/year)	Total sediment export (tons/year) from areas prioritized under scenario 4
0 – 2%	0	0.05	800
2 – 8%	10	0.99	14,600
8 – 15%	20	2.89	74,200
15 – 30%	270	9.54	519,900
30 – 50%	1,470	20.94	982,500
> 50%	3,610	27.44	1,013,100
TOTAL	5,400		2,605,300

Note: Area and total sediment export numbers were rounded to the nearest ten and hundred, respectively.

5 Conclusions

Traveling around Meket makes it clear that forests are rare, and that tree cover outside forests, like agroforestry systems or trees along rivers for sedimentation control is sparse. As the potential maps in this report demonstrate, there is great potential for more trees, whether through (assisted) natural regeneration of forests, agroforestry, or woodlots/plantations.

Until recently, efforts to increase tree cover in Meket, and in Ethiopia in general, have been mostly planned at project level, with little broader analysis of what tree-based landscape interventions can be done where. The national tree-based landscape restoration potential and priority maps have demonstrated that spatial data and tools can help facilitate a science-based targeting of restoration efforts.

Nested in the current effort to increase the use of data in tree-based landscape restoration decision-making, version 0.0 of Meket's potential and priority maps is a first attempt to provide the woreda with an understanding of where trees and forests can help it achieve its economic, social and environmental goals. For example, Map 4, which shows the *extent* of potential for agroforestry, can help Meket assess the associated resources (input, financial, human, technical) needed to boost agroforestry practices across the woreda. On the other hand, Map 13, which shows where to restore secondary forests to decrease Meket's sediment export, could inform the design of a Payment for Ecosystem Services in the context of the Tekeze hydropower dam.

The maps presented in this report use the best spatial data currently available, and draw upon proven tools and methodologies. However, they should be used in combination with local field knowledge as they have not yet been ground-truthed. Their value will increase with the use of better spatial input data.

Trees and forest serve important functions in the landscape, but so do other land uses. New forests and trees must therefore be strategically located in order to most efficiently provide the ecosystem goods and services that people inside and outside Meket depend upon for their well-being, now and in the future.

6 Acknowledgements

The Environment, Forest and Climate Change Commission (EFCCC) would like to thank Ashebir Wondimu (EFCCC) and Florence Landsberg (World Resources Institute (WRI)) for managing the technical team in delivering this work. Mapping potential for tree-based landscape restoration in Meket would not have been possible without the input from various institutions: Meket Administration; Environmental Protection, Land Administration and Use Office; Office of Agriculture; Office of Water and Energy; Office of Trade; Women and Child Office; Water Resource Development Office; Micro and Small Enterprise Office; Cooperative Office; Institutional Strengthening for the Forest Sector Development Program; Office of Finance; ORDA; Amhara Forest Enterprise; Debre Tabor University; and Amhara National Regional State Environment, Forest and Wildlife Protection and Development Authority. Specifically, the Commission would like to thank Mekuanint Getachew and Tadesse Guadneh Ayalew (Office of Agriculture); Kassa Dametie Alemu and Zinabu Mengista (Environmental Protection, Land Administration and Use Office); and Melak Dagnaw, Achamyeleh Kassie Belete, Temesgen Tadesse Ereta and Mulat Ashagrai (Institutional Strengthening for the Forest Sector Development Program) for their continuous guidance and input.

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8 Appendix A: Land use-land cover and percent tree cover classification processes

A mosaic of 459 10-meter resolution Sentinel-2 images spanning the years 2016 and 2017 was classified using the Random Forest Classification Algorithm in Google Earth Engine for mapping recent land use-land cover and percent tree cover. Eight bands were used for classification: blue (2), green (3), red (4), one band at the edge of visible and Near Infra-Red (5), Near Infra-Red (8), an annual Normalized Difference Vegetation Index (NDVI), a NDVI for the wet season, and a NDVI for the dry season.

8.1 Land use-land cover

For each of the five land use-land cover classes (forest, cropland, grassland, shrubland and bare land[14]), field data was used for training and accuracy assessment. The JavaScript API used to produce the land use-land cover map for Meket can be found in Google Earth Engine at https://code.earthengine.google.com/78d7796a69ae94709135b0020be9d219.

The overall accuracy[15] of the land use-land cover classification is 67%. Table A.1 presents the error matrix for the individual land use-land cover classes.

Table A.1 | Error matrix for the land use-land cover map

		***Classified Map* (number of pixels)**							
Land use-land cover		**Forest**	**Cropland**	**Grassland**	**Shrubland**	**Bare land**	**Total**	**Error of Commission[16]** (%)	**Error of Omission[17]** (%)
***Reference data* (number of pixels)**	**Forest**	34	30	6	7	2	79	17%	57%
	Cropland	3	320	31	10	8	372	30%	14%
	Grassland	4	34	65	8	4	115	44%	43%
	Shrubland	0	46	11	59	9	125	34%	53%
	Bare land	0	30	4	6	33	73	41%	55%
	Total	41	460	117	90	56	764		

14 Waterbody and settlement were extracted from ancillary data.
15 The "overall accuracy" is the proportion of pixels classified correctly across all classes.
16 The error of commission is the percent of pixels mistakenly classified in a specific class (e.g., pixels that are classified as "forest" but are in another class than "forest" in the reference data).
17 The error of omission is the percent of pixels of a certain class in the reference data that are not classified as such (e.g., pixels that are classified in another class than "forest" but are in "forest" in the reference data).

8.2 Tree cover

The training and validation sets used for percent tree cover were compiled by nineteen experts for 1,200 plots in Meket through Collect Earth. The original 6 classes (0-10%, 10-20%, 20-30%, 30-50%, 50-80%, 80-100%) were aggregated into 4 (0-10%, 10-30%, 30-80%, 80-100%) because there were too many pixels misclassified between the second and third classes, and between the fourth and fifth ones. Percent tree cover was estimated by visual interpretation of very-high-resolution images over 70m x 70m plots.

The JavaScript API used to produce the percent tree cover map for Meket can be found in Google Earth Engine at https://code.earthengine.google.com/fd85bda439c45d852270fc6443ef31c9.

The overall accuracy[18] of the percent tree cover classification is 91% and Table A.2 shows the error matrix for the individual percent tree cover classes. As mentioned, the validation set is based on the visual interpretation of very-high-resolution images on Google Earth by 19 experts, not on field data. The "0-10%" class is the only one to have acceptable errors. The higher errors observed for percent tree cover can be partially explained by the continuous nature of percent tree cover and the smaller size of the training sample for the four last classes. Additionally, percent tree cover was assigned to the centre of the Collect Earth plot even though it was assessed over the Collect Earth's plots, assuming a homogenous percent tree cover over the whole plot. Finally, the data were generated by different interpreters, increasing the variability in interpreting percent tree cover.

Table A.2 | Error matrix for percent tree cover

		***Classified Map* (number of pixels)**						
Tree Cover (%)		**0-10**	**10- 30**	**30-80**	**> 80**	**Total**	**Error of Commission[19]** (%)	**Error of Omission[20]** (%)
***Reference data* (number of pixels)**	**0-10**	7753	28	18	25	7824	7%	1%
	10-30	416	59	23	9	507	48%	88%
	30-80	97	19	26	26	168	67%	85%
	> 80	87	7	12	96	202	38%	52%
	Total	8353	113	79	156	8701		

[18] The "overall accuracy" is the proportion of pixels classified correctly across all classes.

[19] The error of commission is the percent of pixels mistakenly classified in a specific class (e.g., pixels that are classified as "forest" but are in another class than "forest" in the reference data).

[20] The error of omission is the percent of pixels of a certain class in the reference data that are not classified as such (e.g., pixels that are classified in another class than "forest" but are in "forest" in the reference data).

9 Appendix B: SDR parameters and input data

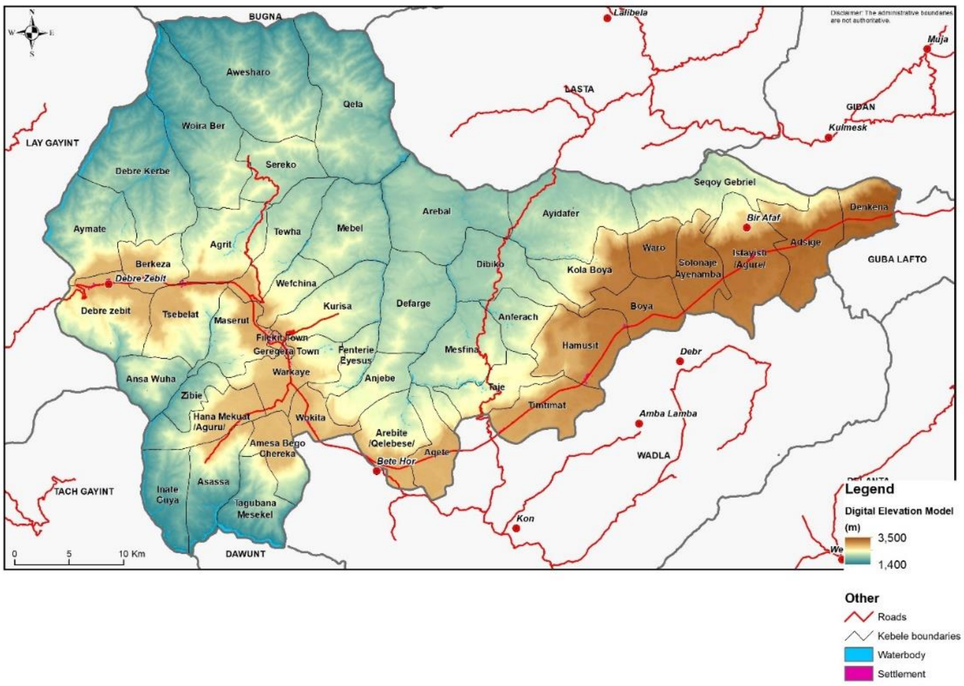
9.1 Inputs

Table B.1 presents the data required to run the SDR model, the source of information for each layer, and any modification applied to it, if any.

Table B.1 | Input data

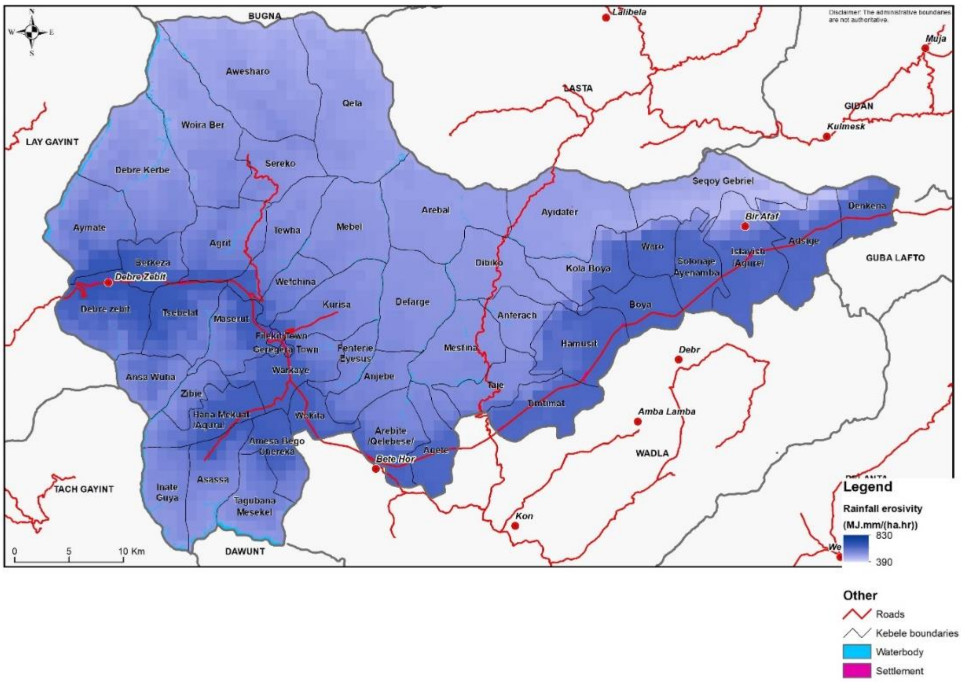
Input data	Description	Source
Land use-land cover (Map 1)	Current land use-land cover map	EFCCC, 2019a (10m resolution)
Digital Elevation Model (Map 14)	Digital elevation model resampled to 10m to match the land use-land cover data resolution	Original DEM: NASA and METI, 2011 (30m resolution)
Rainfall Erosivity (Map 15)	Annual rainfall erosivity based on monthly average rainfall	Source for rainfall: Fick and Hijmans, 2017 (1km resolution)
Soil Erodibility (Map 16)	Erodibility based on soil type	Source for soil type: ISRIC, 2017 (250m resolution)

Map 14 | Digital elevation model



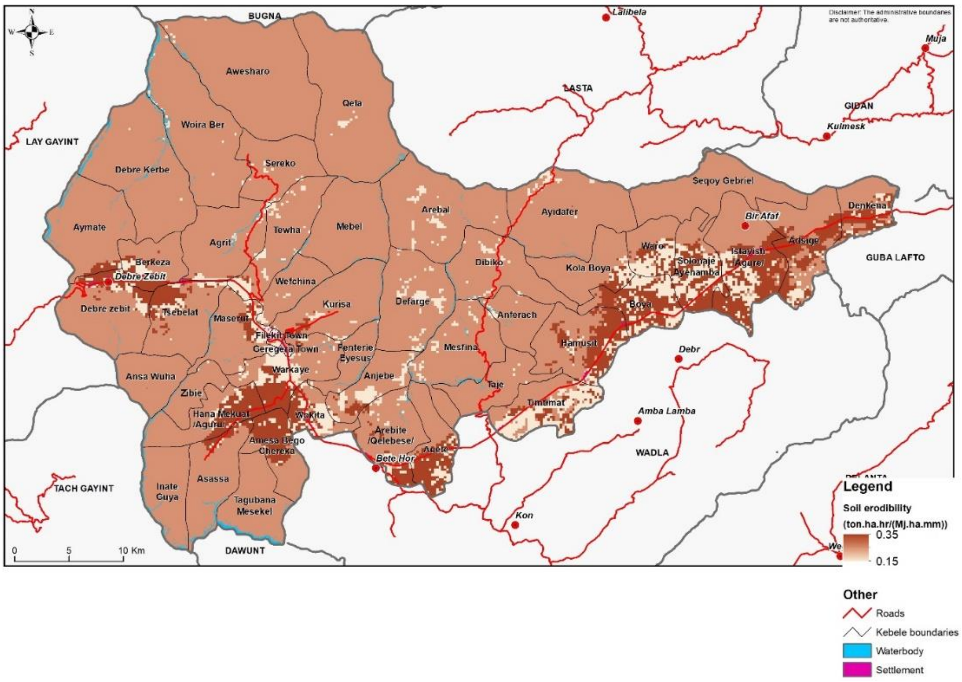
Sources: Digital Elevation Model: based on NASA and METI, 2011. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda census boundaries: adapted from CSA's 2007 census boundaries, 2007.

Map 15 | Rainfall erosivity



Sources: Rainfall erosivity: based on Fick and Hijmans, 2017. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda census boundaries: adapted from CSA's 2007 census boundaries, 2007.

Map 16 | Soil erodibility



Sources: Soil erodibility: based on ISRIC, 2017. Settlement and waterbody: EFCCC, 2019a. Cities: CSA, 2007a. Roads: ERA, 2007. Kebele boundaries: Meket Woreda Office of Agriculture, 2015. Woreda census boundaries: adapted from CSA's 2007 census boundaries, 2007.

9.2 Outputs

The Sediment Delivery Ratio (SDR) model maps overland sediment generation (i.e., soil erosion caused by surface runoff) and delivery to the stream. The model computes:

1- *Amount of annual soil loss* (in tons/ha/year), which is influenced by variables such as the climate (especially rainfall intensity), soil properties, relief and type of land use-land cover (see revised universal soil loss equation (USLE)).

$$USLE = R * K * LS * C * P$$

Where:

- R is the rainfall erosivity (in MJ·mm/(ha·hr))
- K is the soil erodibility factor (in ton·ha·hr/(MJ·ha·mm)) based on Hurni et al., 2015

Soil Group	K value
Haplic Alisols	0.350
Aluandic Andosols	0.150
Haplic Andosols	0.150
Vitric Andosols	0.150
Haplic Cambisols	0.200
Haplic Fluvisols	0.225
Haplic Leptosols	0.200
Lithic Leptosols	0.200
Haplic Luvisols	0.250
Vertic Luvisols	0.250
Haplic Nitisols (Rhodic)	0.250
Haplic Regosols (Eutric)	0.225
Calcic Vertisols	0.150
Haplic Vertisols	0.150
Haplic Vertisols (Eutric)	0.150

- LS is the slope length-gradient factor
- C is the crop-management factor, i.e. the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The higher the value, the higher amount of sediment generated.

LULC class	C factor	Source
Forest	0.001	Hurni, 1985
Shrubland	0.014	Wieshmier and Smith, 1978
Grassland	0.01	Hurni, 1985
Cropland	0.15	Hurni, 1985
Bare land	0.6	Hurni, 1985
Settlement	0.15	Ali and Hagos, 2016
Waterbody	0.0001	Ali and Hagos, 2016

- P is the support practice factor, i.e. the effects of practices that can impact the amount and rate of the water runoff and therefore reduce the amount of erosion. In the absence of information on support practices, 1 was used for P.

Unlike R, K and LS which are associated with local climate and physical attributes and therefore are relatively stable over time, land use-land cover (e.g., restoring secondary forests) and land management practices (e.g., building of bunds/terraces, contour farming, no-till farming) can be modified and substantially affect the amount of sediment running off a catchment by affecting the annual soil loss itself and/or the sediment delivery ratio.

2- *Sediment delivery ratio (SDR)* or proportion of soil loss actually reaching the catchment outlet, which is influenced by the location in the landscape relative to the hydrological network.

Parameter	Value	Source/Reference
Threshold Flow Accumulation	100	Authors
Borselli k Parameter	2	Sharp et al., 2016
Borselli IC_0 Parameter	0.5	Sharp et al., 2016
Max SDR Value	0.8	Sharp et al., 2016

3- *Sediment export* (in tons/ha/year) or the amount of sediment eroded that actually reaches the hydrological network.

$$\text{Sediment export} = \text{USLE} \cdot \text{SDR}$$

Source: Adapted from http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/sdr.html#interpreting-results