Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-14
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 9 April 2018

Open Access Earth System Science Data Discussions

Title: Mapping the Vegetation of Lake Tana Basin in Ethiopia Based on Google Earth Images

Running title: Vegetation Map of Lake Tana Basin

Authors: Song Chuangye[a], Lisanework Nigatu[b], Yibrah Beneye[c], Abdurezak Abdulahi[b], Zhang Lin[a] , Wu Dongxiu[a]

Email of Authors:

Song chuangye: songcy@ibcas.ac.cn

Lisanework Nigatu: lisaneworkn@yahoo.com

Yibrah Beneye: yibrah_beyene@yahoo.com

Abdurezak Abdulahi: arezak6@gmail.com

Zhang Lin: zhanglin@ibcas.ac.cn

Wu Dongxiu: wudx@ibcas.ac.cn

Author's institutional affiliations: [a]State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences, Beijing, China; [b]School of Natural Resource and Environmental Sciences, Haramaya University, Dire Dawa, Ethiopia; [c]College of Plant and Horticultural Sciences, Hawasa University, Hawasa, Ethiopia

Abstracts Lake Tana basin is one of the most important watersheds of Nile basin. It is of great importance for the economy and politics of Ethiopia. In past decades, natural vegetation of Lake Tana basin was heavily destroyed for continuous expansion of cropland. Vegetation conservation and restoration have to be performed in order to protect natural environment and maintain the biodiversity in Lake Tana basin. To provide detailed information of actual vegetation for planning of vegetation conservation and restoration, in this research we mapped the vegetation of Lake Tana basin based on high spatial resolution images provided by Google earth and field survey data, through the approach of visual interpretation. A total of 31972 polygons were generated to represent the vegetation patches of Lake Tana basin on the map, and the validation based on surveyed vegetation plots indicated that 90.6 % patches

were correctly identified. The statistics of vegetation map indicated that natural vegetation (natural forest, woodland, bush land, grassland and wetland) occupies 14.32 % of the basin area, plantation forest occupies 1.92 % of the basin area, cultivated land occupies 61.8 % of the basin area, water body, village and urban occupy 20.8 %, 0.68 % and 0.46 % of the total area of Lake Tana basin respectively. Doi of the dataset used for map production is http://doi.org/10.4121/uuid:48d45053-36f6-411b-96b1-7ae0e22d56d0. We expected that this vegetation map could benefit vegetation conservation and restoration in Lake Tana basin.

Key Words East Africa; Blue Nile; The Abbay River; Nile basin; Land cover; Visual Interpretation

1 Introduction

Lake Tana, located in highlands of North-West Ethiopia, is the largest fresh water lake of Ethiopia, and the third largest lake of Nile Basin. Lake Tana is the source of Blue Nile with the basin being one of the most important catchments of Nile Basin. It has rich natural resources and great potential for the development of irrigation, hydroelectric power, high value crops, aquatic products, livestock products and ecological tourism (Bijan and Shimelis, 2011). Lake Tana basin is of critical national significance in economy and politics of Ethiopia. It also has great influences on livelihoods of tens of millions of people in lower Nile basin.

Historically, large area of afromontane forest and many indigenous plant species existed in Lake Tana basin. 172 woody species were observed in Lake Tana basin, and many of them were indigenous species (IFAD, 2007a). There are also large areas of wetlands and seasonally flooded plains in Lake Tana basin. They are the source of multiple services for local community and the home of many endemic bird species (Ayalew, 2010; Bijan and Shimelis, 2011).

The population density of Lake Tana basin is very heavy and the rate of population growth is very high. More than two million people reside in this basin, and

Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-14
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 9 April 2018

the population density is greater than 150 per square kilometer (Yimenu, 2005).The great population and high rate of population growth lead to the increase of food demand. Large area of forest, grassland and wetland were destroyed and transformed into cropland, and more livestock were raised on the grassland. Deforestation and overgrazing resulted in massive destruction of natural vegetation, decline in biodiversity and forest stand density, desertification and soil erosion (Alelign et al., 2007). In order to protect natural environment and maintain biodiversity, vegetation restoration and conservation have to be performed in Lake Tana basin (Bishaw, 2001). Since 1990s, many conservation efforts were undertaken to conserve and restore the natural vegetation of Lake Tana basin (Bishaw, 2001; Teketay, 2001). However, degradation and decline of natural vegetation in Lake Tana basin is still a major problem (IFAD, 2007b).

Detailed data of regional vegetation distribution is the base for vegetation management and conservation. Only when vegetation of the whole basin was well surveyed and mapped, rational and scientific planning of vegetation conservation and restoration could be made for the whole basin. However, vegetation maps related to Lake Tana basin were almost made for Africa, East Africa and Ethiopia with small scales, such as the vegetation map of Eritrea, Ethiopia and Somalia with the scale of 1:5000000 (Pichi Sermolli, 1957), vegetation map of Ethiopia and Eritrea (Breitenbach, 1963), vegetation map of Africa with the scale of 1:5000000 (White 1983), vegetation map of Africa Horn (Friis, 1992), vegetation map of Ethiopia (Sebsebe, 1996; Sebsebe, 2004; Sebsebe and Friis, 2009), potential vegetation map of Ethiopia with the scale of 1:2000000 (Friis et al., 2011).However, vegetation maps compiled by Pichi Sermolli (1957), Breitenbach (1963), White (1983) and Friis (1992) were published many years ago and were all with small scales. They cannot provide detailed information of actual vegetation of Lake Tana basin. Potential vegetation map compiled by Friis et al. (2011) could not reflect the status of actual vegetation of Lake Tana basin either. Another map concerned to the vegetation of Lake Tana basin is that the land cover/use map made by Shimelis et al. (2008) with the scale around 1:1700000. However, only large patches of vegetation were mapped, and many

Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-14
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 9 April 2018

patches of vegetation were merged or omitted on this map. Therefore, shortage of detailed vegetation data in Lake Tana basin limited the effectiveness of planning of vegetation management and biodiversity conservation. Therefore, in this research, based on high spatial resolution satellite images provided by Google earth and field survey data, we made a vegetation map of Lake Tana basin. We hope this map will be helpful for the vegetation and biodiversity conservation in Lake Tana basin.

2 Study Area

Lake Tana is located on highlands of North-West Ethiopia (Figure 1). The average altitude of Lake Tana is around 1800 meters. The area of Lake Tana basin (including water surface area) is 15096 km^2. The water surface area is 3000-3600 km^2 and the maximum depth of water is 14 meters. Gilgel Abay, Ribb, Gumera and Megech are the most important rivers feeding Lake Tana and contribute more than 90% of total inflow.

The zonal vegetation of Lake Tana basin is dry evergreen afromontane forest. However, only small patches of remnant forest exist currently due to heavy deforestation. The biodiversity of Lake Tana basin is rich and many endemic plant species grow in this catchment. There are large areas of wetlands in this basin. These wetlands are the home of many endemic birds.

Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-14
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 9 April 2018

Open Access Earth System Science Data Discussions

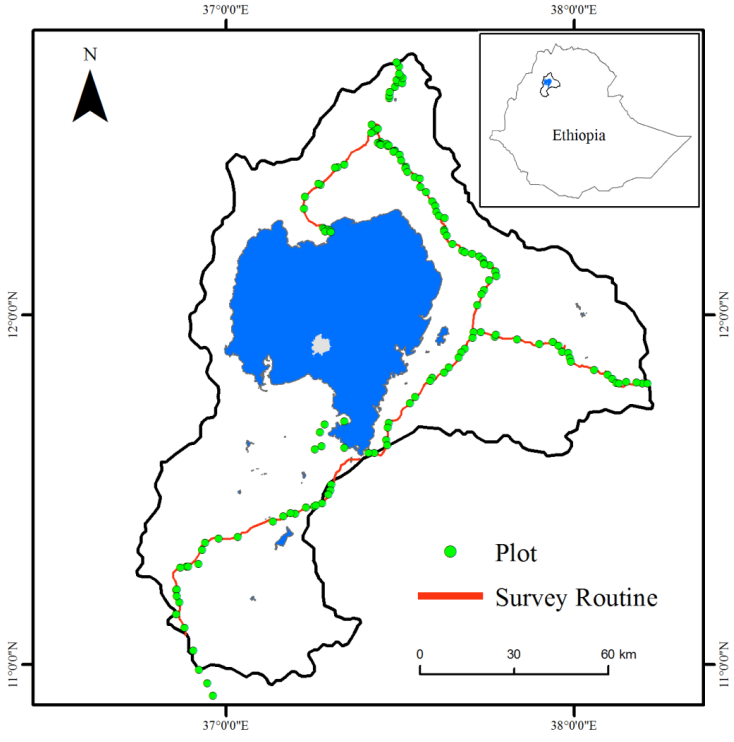

Figure 1 The location of Lake Tana basin, the survey route and plots

3 Data and Method

3.1 Data Sources

Vegetation mapping was based on high spatial resolution satellite images and aerial images provided by Google earth and collected vegetation survey data. Field vegetation surveys were performed in 2015, 2016. Total 156 vegetation plots were investigated (Figure 1) and dominant species were recorded in the field. In addition to this, “Atlas of the Potential Vegetation of Ethiopia” compiled by Friis et al. (2011) was also important references in this research.

3.2 Vegetation Classification System

Based on vegetation classification system adopted by Shimelis et al. (2008) and suggestions from geobotanists of Ethiopia, vegetation of Lake Tana basin was categorized into seven groups: natural forest, woodland, plantation forest, bushland, grassland, wetland, and cultivated land. Three types of non-vegetation cover, waterbody, village and urban, were also mapped in this research. There are sub-types

Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-14
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 9 April 2018

of these vegetation groups exist for variation of dominant species. However, we did not differentiate these sub-types for the limitation of spatial resolution of satellite images.

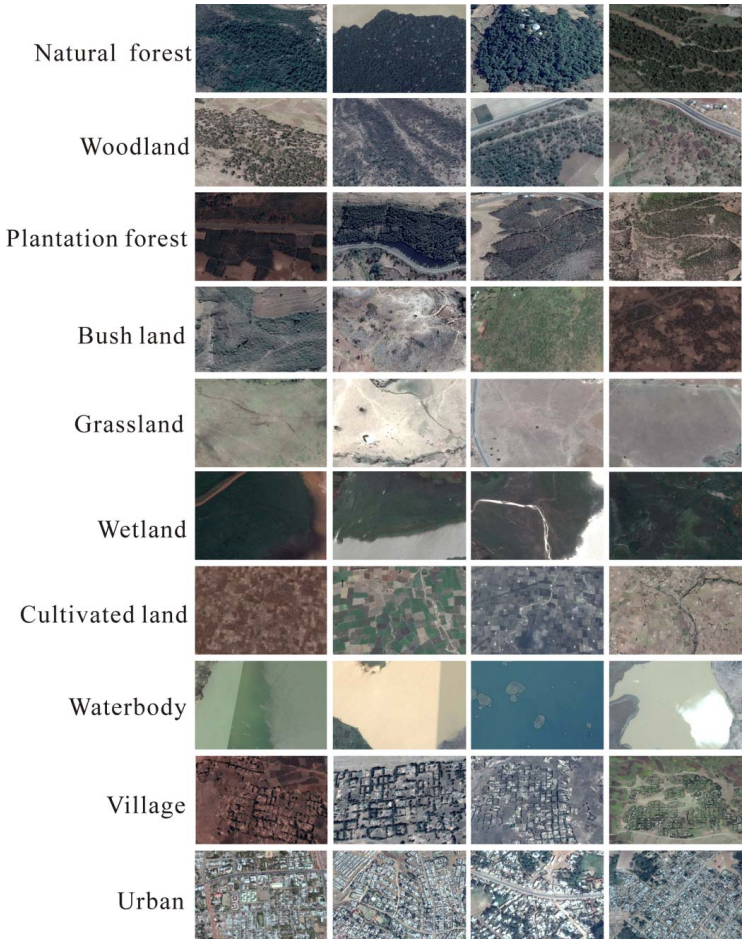

Figure 2 Interpretation marks based on the Google earth images

3.3 Method

Coordinates of vegetation plots were recorded and then transformed into kml files, which could be read by Google earth.

One-third of surveyed plots were randomly selected to establish interpretation marks. Open these kml files in Google earth, and established interpretation marks according to characteristics of color and texture of vegetation reflected on satellite images (Figure 2).The other two-third surveyed plots were used to validate

interpretation results.

On Google earth, visual interpretation was employed to identify vegetation based on established interpretation marks. The tool “Add polygon” was used to vectorise vegetation patches around the scale of 1:5000. The whole process lasted more than one and a half year, and 31972 polygons were generated to represent vegetation patches of Lake Tana basin on the map.

In order to improve the accuracy of vegetation interpretation, advices and suggestions of Ethiopian geobotanist were often consulted to determine vegetation type. The validation based on surveyed vegetation plots indicated that 90.6 % patches were correctly identified.

Kml files of all vegetation were imported into Global Mapper software (v16.0), and then transformed into shp files which could be read by ArcGIS (v9.3, ESRI). In ArcGIS, vegetation type of each polygon was marked in attributes table and all shp files were merged into one shp file. Finally, vegetation map was designed and exported for printing on A1 (at the scale about 1:310000) (Figure 3).

3.4 Projected Coordinate System and Geographic Coordinate System

Projected Coordinate System:WGS_1984_UTM_Zone_37N; Projection: Transverse_Mercator; False_Easting:500000.00000000; False_Northing:0.00000000; Central_Meridian:39.00000000; Scale_Factor:0.99960000; Latitude_Of_Origin:0.00000000; Linear Unit: Meter.

Geographic Coordinate System: GCS_WGS_1984; Datum: D_WGS_1984; Prime Meridian: Greenwich; Angular Unit: Degree.

4 Results

4.1 Natural Forest

1320 patches of natural forest were identified and vectorised, and the total area is 122.2 km^2, which occupy 0.82% of the area of Lake Tana basin. The area of maximum and minimum patch is 12.6 km^2 and 0.00075 km^2, respectively. The mean area of natural forest patches is 0.093 km^2.

Two types of natural forest exist in this basin: dry evergreen afromontane forest

Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-14
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 9 April 2018

and riverine forest (Friis et al., 2011). The altitude where dry evergreen afromontane forests occur ranges from 1500 m to 2700 m. The mean annual temperature is 14-25 °C and the mean rainfall is 700-1100 mm (Friis, 1992). High amplitude of altitude and rainfall result in complex habitats and species composition. Characteristic species of arborous layer are *Podocarpus falcatus* and *Juniperus procera*. Dominant species of understory are *Croton macrostachyus*, *Ficus* spp., *Oleaeuropaea* subsp. cuspidata, *Trema orientalisand* and *Maesa lanceolata*.

Riverine forest is predominantly located near lake and river. Dominant species are *Diospyros mespiliformis*, *Mimusops kummel* and *Syzygium guineense*.

Due to continual expansion of cropland, natural forest was gradually destroyed in past decades. Only small patches of remnant forests can be found in two main forms in this region: protected state forests and church forest.

4.2 Woodland

1613 patches of woodland were identified and vectorised, and the total area is 236.1 km^2, which occupy 1.58 % of the area of Lake Tana basin. The area of maximum and minimum patch is 5.6 km^2 and 0.0023 km^2 respectively. The mean area of woodland patches is 0.15 km^2.

There are two kinds of woodland in Lake Tana basin: *Combretum-Terminalia* woodland and *Acacia-Commiphora* woodland (IBC, 2005; Friis et al., 2011).

Combretum-Terminalia woodlands occupy the area with altitude of 500–1900 m. They are usually located in humid areas of lowlands or on valley of rivers. Characteristic species of *Combretum-Terminalia* woodland are *Combretum* spp., *Terminalia* spp., *Oxytenanthera abyssinica*, *Boswellia papyrifera*, *Anogeissus lieocarpa*, *Sterospermem kuntianum*, *Pterocarpus lucens*, *Lonchocarpus laxiflorus*, *Lannea* spp., *Albizia malacophylla* and *Enatada africana*. Most of them are small trees with large deciduous leaves. They often grow together with *Oxytenanthera abyssinica*. The understory is a mixture of herbs and grasses. Dominant herbal species include *Justecia* spp., *Barleria* spp., *Eulophia* spp., *chlorophytum* spp., *Hossolunda opposita* and *Ledeburia* spp..

Acacia-Commiphora woodlands usually occupy dry slope with the altitude of

Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-14
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 9 April 2018

1000-1900 m (WBISPP, 2004). Habitats are characterized with quite large variations of soil and topography and diverse biotic and ecological elements. Most of these plant species in *Acacia-Commiphora* woodland haves mall deciduous leaves or leathery evergreen leaves.

There is a large variation of stand density for *Acacia-Commiphora* woodlands. *Acacia-Commiphora* woodlands could be observed with three kinds of formation: dense forest with close canopy, scattered individuals, even wooded grassland. *Acacia-Commiphora* woodlands are also famous for some *Acacica*, *Boswellia* and *Commiphora* species. They could be used to produce gum and resin.

4.3 Plantation Forest

11390 patches of plantation forest were identified and vectorised, and the total area is 287.1 km^2, which occupy 1.92 % of the area of Lake Tana basin. The area of maximum and minimum patch is 1.73 km^2 and 0.00064 km^2 respectively. The mean area of plantation forest patches is 0.025 km^2.

Eucalyptus species are the main species of plantation forest. *Cupressus lusitanica* and Pine species were also planted in some areas. In addition to this, *Acacia mearnsii* was also found to be planted in the southern area of Lake Tana basin.

There are around 600 *Eucalyptus* species in the world and more than 120 species were found in Ethiopia (Alemayehu, 2017). *Eucalyptus globuls* and *Eucalyptus camaldulensis* are the most common and widely planted species in Ethiopia. *Eucalyptus globulus* was usually planted in the area with altitude over 2200 m, and *Eucalyptus camaldlunesis* was planted in the region with altitude of 1700-2400 m.

The plantation of *Eucalyptus* species was widely criticized from the suppression effects of growth of associated indigenous species and heavy use of underground water. However, plantation area of *Eucalyptus* forest increased rapidly in past fifteen years (Birru et al., 2003).

4.4 Bushland

12023 patches of bushland were identified and vectorised, and the total area is 792.3 km^2, which occupy 5.3 % of the area of Lake Tana basin. The area of maximum and minimum patch is 16.9 km^2 and 0.0004 km^2 respectively. The mean area of

bushland patch is 0.066 km^2.

Bushland often occurs in the area with shallow soil and steep slope, such as hills, escarpments, mountains and gorge slopes. There is usually grassland on the bottom of bushland. This forms bush-grass complex. The dominant woody species of bushland are *Maytenus senegalensis*, *Carissa spinarum*, *Clausene anista*, *Clerodendrum myricoides*, *Grewia ferruginea*, *Caesalpinia decapetala*, *Ficus verruculosa*, *Calpurnia aurea*, *Erica arborea*, *Hypericum rebolutum*, *Vernonia* spp., *Senna* spp., *Cordia* spp., *Acacia* spp., *Commiphora Africana* and *Indigofera* spp..

4.5 Grassland

4083 patches of grassland were identified and vectorised, and the total area is 595.8 km^2, which occupy 3.99 % of the area of Lake Tana basin. The area of maximum and minimum patch is 7.29 km^2 and 0.0016 km^2 respectively. The mean area of grassland patches is 0.15 km^2.

Grasslands mainly distribute along rivers, around villages, on mountain and hill tops, on slopes and on highlands with stony and shallow soils. Common species are *Eragrostis* spp., *Pennisetum* spp., *Panicum* spp., *Echinochloa* spp., *Setaria* spp., *Hyparrhenia* spp., *Cymbopogon* spp., and *Sorghum* spp.. Scattered shrubs could be observed on the grassland, such as *Senna* spp., *Maytenus senegalensis*.

4.6 Wetland

1030 patches of wetland were identified and vectorised, and the total area is 393.5 km^2, which occupy 2.63 % of the area of Lake Tana basin. The area of maximum and minimum patch is 9.41 km^2 and 0.0015 km^2 respectively. The mean area of wetland patches is 0.38 km^2.

Wetlands are distributed around the Lake and along tributaries of the lake. *Hygrophila auriculata*, *Cyprus papyrus*, *Typha latifolia*, *Phragmites australis*, *Nymphaea caerulea*, *Juncus dregeanus*, *Floscopa glomerata*, *Eriocaulon* spp., *Xyris capensis* are the main species of wetlands.

Wetlands have rich biodiversity and diverse ecological functions. The lake and its tributaries are the home of 28 fish species, of which15 are endemic species to Ethiopia. More than 300 species of birds have been observed and recorded in Lake

Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-14
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 9 April 2018

Tana basin, which was defined as an international bird site by BirdLife International (BLI) (Shimelis, 2013).

4.7 Cultivated Land

The area of cultivated land is 9239.6 km^2, which occupies 61.8% of the total area of Lake Tana basin. Teff, sorgum, chickpea, rice, maize and sesame are widely planted in Lake Tana basin. These crops are often planted mixed with endemic or exotic arbor species, such as *Croton macrostachyus*, several *Acacia* species, *Albizia gummifera*, *Cordia africana*, *Juniperus procera*, *Grevillea robusta* and *Sesbania sesban*, which formed complex agroforestry system.

Many kinds of fruits are planted in agroforestry, like *Mangifera indica*, *Persea americana*, *Carica papaya*, *Citrus sinensis*, *Citrus aurantifolia*, *Rhamnus prinoides*, *Mimusops kummel*and *Syzygium guineense*.

4.8 Waterbody

37 patches of waterbody were identified and vectorised, and the total area is 3112.4 km^2, which occupy 20.8 % of the area of Lake Tana basin. The area of maximum and minimum patch is 3080.8 km^2 and 0.0017 km^2 respectively. The mean area of waterbody patch is 84.1 km^2.

Lake Tana is the biggest waterbody in this watershed. The total area of Lake Tana is 3080.8 km^2, which occupy 98.98% of total water surface area.

4.9 Village

476 patches of village were identified and vectorised, and the total area is 100.97 km^2, which occupy 0.68 % of the area of Lake Tana basin. The area of maximum and minimum patch is 2.24 km^2 and 0.002 km^2 respectively. The mean area of village patch is 0.21 km^2.

In Lake Tana basin, the size of many villages is very small. These small villages distribute sparsely in the landscape. It is difficult to vectorise all the village patches. Therefore, only large villages were identified and vectorised in this research.

4.10 Urban

There are two big cities in Lake Tana basin: Gondar and Bahir Dar. The total area of urban is 69.04 km^2, which occupy 0.46 % of Lake Tana basin.

Earth Syst. Sci. Data Discuss., https://doi.org/10.5194/essd-2018-14
Manuscript under review for journal Earth Syst. Sci. Data
Discussion started: 9 April 2018

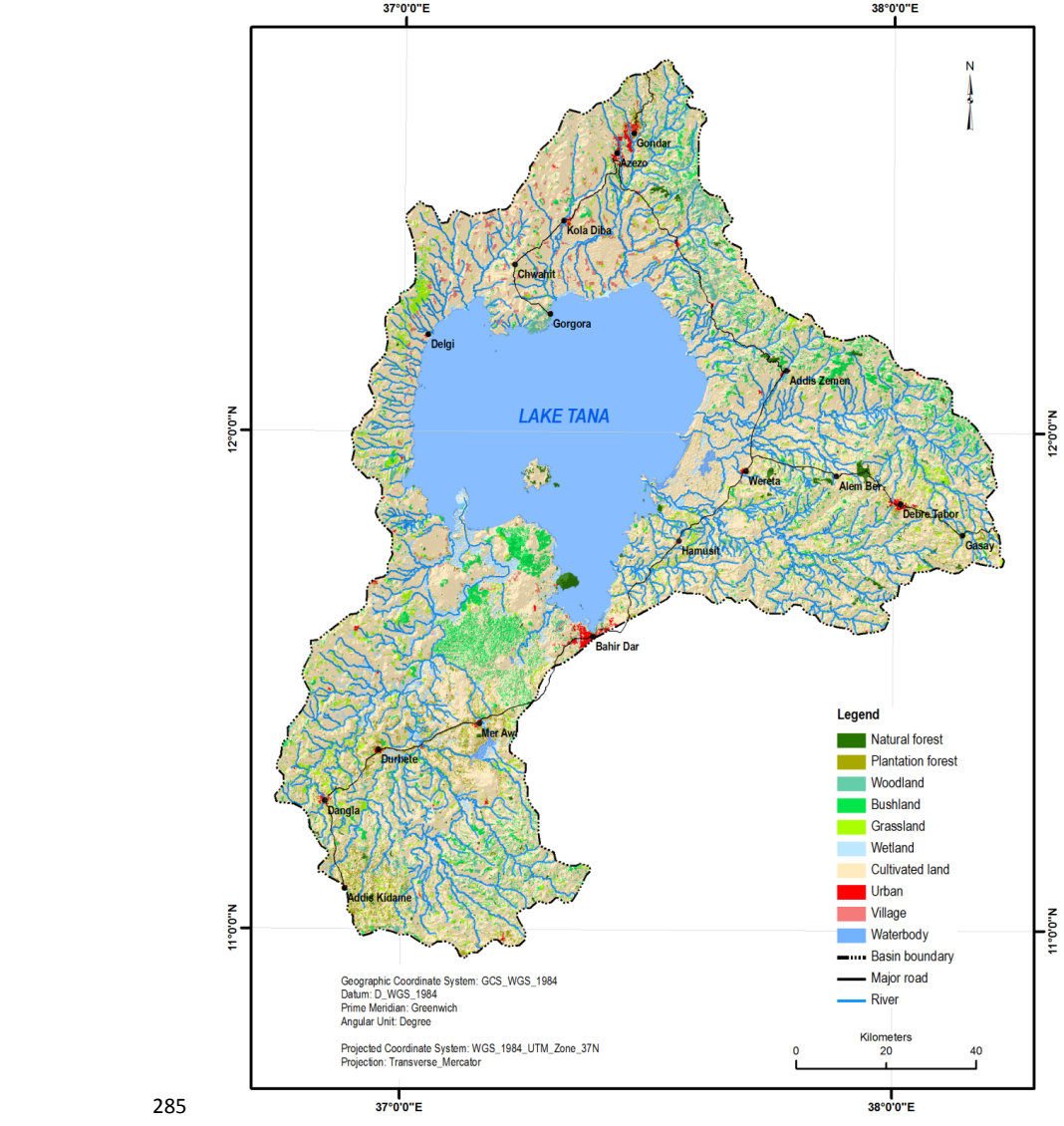

Figure 3 Vegetation map of Lake Tana basin, Ethiopia

5 Discussions and Conclusions

Satellite images and aerial images provided by Google earth offered us valuable and free information for vegetation mapping. The high spatial resolution makes it possible for us to identify small patches of vegetation by visual interpretation. In this research, the validation indicated that most of vegetation patches were correctly identified. We believe this vegetation map could offer reliable information for

293 vegetation conservation in Lake Tana basin.

294 The potential vegetation of Lake Tana basin is dry evergreen afromontane forest
295 and grassland complex (Friis et al., 2011), which should cover most area of this basin.
296 However, based on this vegetation map, we found that natural vegetation only
297 occupies 14.32 % of the basin area. Among natural vegetation, the percentage of
298 natural forest is below 40 %, and bush lands, most of them being secondary
299 vegetation, share 37 % of the total area of natural vegetation. This reflected the
300 seriousness of vegetation degradation in Lake Tana basin.

301 The number of natural vegetation patches is as high as 20069 with the total area
302 of 2140 km^2. The mean patch area of natural forest, woodland, bush land, grassland
303 and wetland is only 0.07km^2, 0.08 km^2, 0.60km^2, 0.20 $km^2$and 0.05 km^2, respectively.
304 This indicated that natural vegetation was highly fragmented.

305 Vegetation degradation and fragmentation reduced the geographical environment
306 for the survival of biological species and influenced the flow of material and energy
307 balance in the ecosystem. These will definitely impact the maintenance of biodiversity.
308 In addition to this, vegetation degradation also results in soil erosion and
309 desertification. Therefore, more and larger conservation areas are needed to maintain
310 the biodiversity and protect the environment in Lake Tana basin.

311 Plantation forest (dominated by *Eucalyptus* species) occupies 1.9 % of the area
312 of Lake Tana basin. But, plantation of *Eucalyptus* was proved to have negative
313 influences on the maintenance of biodiversity and ecological water balance, for its
314 allelopathy and high consumption of water (Martens, 2002; Cornish and Vertessy,
315 2001). Moreover, we need to realize that allelopathic effect depends on the amount of
316 rain falling in the site and texture of the soil. Not all *Eucalyptus* species release the
317 same concentration of allelochemicals (Pohjonen and Pukkala, 1990; Lisanework and
318 Michelsen, 1993, 1994; Michelsen et al., 1996). Therefore, site-species matching and
319 objectives of plantations should clearly be defined to avoid negative connotations
320 against *Eucalyptus*. These actions will maximize the economic benefits and minimize
321 the ecological risk brought by *Eucalyptus*.

322

Data Access： http://doi.org/10.4121/uuid:48d45053-36f6-411b-96b1-7ae0e22d56d0.

Author contributions: Wu Dongxiu and Song Chuangye designed the research, Song Chuangye, Lisanework Nigatu, Yibrah Beneye, Abdurezak Abdulahi, Zhang Lina, Wu Dongxiu collected the data, and Song Chuangye wrote the manuscript. Wu Dongxiu and Lisanework Nigatu revised the manuscript.

Competing interests: The authors declare that they have no conflict of interest.

Acknowledgments: This study was funded by the Ministry of Sciences and Technology (International Science & Technology Cooperation Program of China 2014DFG32090) and State Key Laboratory of Vegetation and Environmental Change, Institute of Botany, Chinese Academy of Sciences.

References

Alelign, A., Teketay, D., Yemshaw, Y. and Edwards, S.: Diversity and status of regeneration of woody plants on the Peninsula of Zegie, Northwestern Ethiopia. Trop. Ecol., 48(1), 37–49, 2007.

Woody Biomass Inventory and Strategic Planning Project (WBISPP): A strategic plan for sustainable development, conservation and management of the woody biomass resources at national level, Addis Ababa, 2004.

Ayalew, W.: Improving management of shoreline and riparian wetland ecosystems: the case of Lake Tana catchment. Ecohydrology Hydrobiology, 10(2-4), 123-132, http://doi: 10.2478/v10104-011-0017-4, 2010.

Alemayehu, W.: Forest Resources in Amhara: Brief Description, Distribution and Status. In S. Krystyna, G. Goraw and A. Shimelis (Eds.) Social and Ecological System Dynamics-Characteristics, Trends, and Integration in the Lake Tana Basin, Ethiopia (pp 231-243). Springer, 2017.

Bishaw, B.: Deforestation and Land Degradation in the Ethiopian Highlands: A Strategy for Physical Recovery. Northeast African Studies, 8(1), 7–26, http://doi: 10.1353/nas.2005.0014, 2001.

Bijan, D. and Shimelis, G. S.: Combined 3D hydrodynamic and watershed modelling of Lake Tana, Ethiopia. J. Hydrol., 398, 44–64, http://doi:10.1016/j.jhydrol.2010.12.009, 2011.

Birru, Y., Anteneh, A., and Tadele, A.: Expansion of eucalyptus woodlots in the fertile soils of the highlands of Ethiopia: could it be a treat on future cropland use? J. Agric. Sci., 5(8), 97–107, http://doi: 10.5539/jas.v5n8p97, 2003.

Breitenbach, F. von.: The Indigenous Trees of Ethiopia, 2nd revised and enlarged edition. Ethiopia Forestry Association, Addis Abeda.1963.

Cornish, P. M. and Vertessy, R. A.: Forest age-induced changes in evapotranspiration and water yield in a Eucalypt forest. J. Hydrol., 242(1/2), 43–63, http://doi: 10.1016/S0022-1694(00)00384-X, 2001.

Friis, I.: Forest and forest trees of northeast tropical Africa-their nature habitats and distribution patterns in Ethiopia, Djibouti and Somalia, Kew Bull. Additional Series, No 15 (pp. i-iv & 1-396). London: HMSO, 1992.

Friis, I., Sebsebe, D. and Paulo, van. B.: Atlas of the Potential Vegetation of Ethiopia. Addis Ababa: Addis Ababa University Press & Shama Books, 2011.

Institute of biodiversity conservation (IBC). Ethiopian Biodiversity Strategy and Action Plan, 2005.

International Fund for Agriculture Development (IFAD). Community-based Integrated Natural Resources Management in the Lake Tana Watershed, Ethiopia, on Forestry, Agroforestry, Soil Conservation. Bahir Dar, 2007a.

International Fund for Agriculture Development (IFAD). Community-based Integrated Natural Resources Management Project in Lake Tana Watershed, Ethiopia (3rd draft). Bahir Dar, 2007b.

Lisanework, N. and Michelsen, A.: Allelopathy in Agroforestry systems: the effects of leaf extracts of *Cupressus lusitanica* and three *Eucalyptus spp*. on four Ethiopian crops. Agroforest. Syst., 21: 63–74, http://doi:10.1007/BF00704926,1993.

Lisanework, N. and Michelsen, A.: Litterfall and nutrient release by decomposition in three plantations compared with natural forest in the Ethiopian highland. Forest. Ecol. Managem., 65, 149–164,

http://doi:10.1016/0378-1127(94)90166-X,1994.

Michelsen, A., Lisanework, N., Friis, I., and Holsts, N. Comparisons of understory vegetation and soil fertility in plantations and adjacent natural forests in the Ethiopian highlands. J. Appl. Ecol., 33, 627–642, http://doi: 10.2307/2404991,1996.

Martens, D. A.: Identification of phenolic acid composition of alkali-extracted plants and soils. Soil. Sci. Soc. Am., 66(4), 1240–1248, http://doi: 10.2136/sssaj2002.1240, 2002.

Ministry of Water Resources, Ethiopia (MWR). Ribb ELA report. Design of dams in Lake Tana sub-basin project. Ribb Dam design. WWDSE with sub consultants TAHAL Consulting Engineers, Ministry of Water Resources, Addis Ababa, Ethiopia, 2007.

Pichi Sermolli, R. E. G.: Una carta geobotanica dell's Africa Orientale (Eritrea, Ethiopia, Somalia). Webbia, 13, 15–132 & 1 map, 1957.

Pohjonnen, V. and Pukkala, T.: *Eucalyptus globulus* in Ethiopian Forestry. Forest. Ecol. Managem., 36, 19–31, http://doi: 10.1016/0378-1127(90)90061-F, 1990.

Sebsebe, D., Mengistu, W. and Yilma, D.: Ethiopia's natural resource base. In S. Edwards (ed)., Important Bird Areas of Ethiopia. A First Inventory (pp36-53). Ethiopian Wildlife and Natural History Society, Addis Abeba, 1996.

Sebsebe, D., Cribb, P., and Rasmussen, F.: Field guide to Ethiopia Orchids. Royal Botanic Gardens, Kew, 2004.

Sebsebe, D. and Friis, I.: The vegetation type in Ethiopia. In: Hedberg, I. Friis, I. & Persson, E. (eds.) The Flora of Ethiopia and Eritrea, 8, 27-32. National Herbarium, Addis Abeba & Uppsala University, Uppsala, 2009.

Shimelis, G. S., Ragahavan, S., and Bijan, D.: Hydrological Modelling in the Lake Tana Basin, Ethiopia Using SWAT Model. The Open Hydrology Journal, 2, 49–62, http://doi: 10.2174/1874378100802010049, 2008.

Shimelis, A. Z.: Birds of Lake Tana area, Ethiopia. A photographic field guide. View Graphics and Printers, Addis Ababa, 2013.

Teketay, D.: Deforestation, Wood Famine and Environmental Degradation in

412 Ethiopia's Highland Ecosystems: Urgent Need for Action. Northeast African Studies
413 8(1): 53–76, http://doi: 10.1353/nas.1995.0010, 2001.
414 White, F.: The vegetation of Africa. A descriptive memoir to accompany the
415 Unesco/AETFAT/UNSO vegetation map of Africa, with map in 3 parts + legend. Paris:
416 Unesco, 356 pp, 1983.
417 Yimenu, A.: Characterization of domestic wastewater disposal as point source
418 pollution in southern gulf of Lake Tana, Northwestern Ethiopia. MSc. Thesis,
419 Environmental Science Program, School of Graduate Studies, Addis Ababa University,
420 Addis Ababa, Ethiopia, 2005.