



# Mapping the supply and demand of Enset crop to improve food security in Southern Ethiopia

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Accepted: 20 December 2017 / Published online: 22 January 2018  
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## Abstract

Food security is a worldwide key issue in the context of climate change, requiring to plan local agriculture and make decisions. In order to proceed, it is essential to understand the value of ecosystem services provided by agricultural landscapes. Here, we quantified and mapped the supply and demand of an indigenous food, kocho (i.e., a bread made from starch derived from the Enset plant), in the Wabe River catchment of Gurage Mountains in Southern Ethiopia. To proceed, we measured the pseudostem and plant heights within 100 m<sup>2</sup> sample plots of Enset farms. Enset home garden spatial features were extracted from satellite imagery, and a household questionnaire survey was administered along with population census data. We used suitable models to quantify the yield and demand of kocho, and the data were interpolated, analyzed, and mapped with the ArcGIS software. The results show that the average catchment-wide squeezed (moisture-removed) kocho yield is 16.2 kg/plant, which is equivalent to 417 tons/ha. The annual yield is 6500 kg/ha, and 4.5 million tons of kocho are available as standing stock. However, the spatial distribution of Enset production and its yield are not uniform in the catchment, and the largest stock is found in tepid moist and tepid humid agroecologies. The average demand of kocho per person is fulfilled by 16 Enset plants (i.e., 289 kg) with only 38% of households able to satisfy their demand from their own home garden. There is a high per capita kocho demand in warm sub-humid agroecological zones and a low demand in cool moist zones. While the supply-demand budget shows that there is a high supply of kocho in most areas, the demand is greater than the supply in 25% of the catchment. Here, we demonstrate for the first time that through quantification and mapping of the supply to demand of kocho, the Enset crop contributes to food security in the catchment and needs to improve its production as it is spatially not uniform. This study provides a data set for planners and decision-makers to enhance the production of kocho and to satisfy the current supply-demand gap.

**Keywords** Food system · Kocho · Agroecology · Spatial · Supply-demand budgets · Upscaling

## 1 Introduction

Enset (*Ensete ventricosum* (Welw.) Cheesman) is among the main home garden food crops of Ethiopia. As Fig. 1 shows, it looks like a large, thick, single-stemmed banana plant and belongs to the family Musaceae and the genus *Ensete*. It is an herbaceous monocarpic plant with an underground corm, a

bundle of leaf sheaths that form a pseudostem, and large leaves. It is larger than banana plants, with the largest plant reaching up to 10 m tall and with a pseudostem of up to 2 m in diameter (Wesphal 1975). Enset farming systems are rich in landraces diversity, and Yemataw et al. (2014) reported that 2 to 26 (mean of  $8.9 \pm 0.9$ ) clones are cultivated on individual farms in different zones of Southern Ethiopia.

The plant is a multipurpose crop in which all parts are utilized for different purposes (Brandt et al. 1997). Enset production is largely used for human food, animal forage, fiber, construction materials, medicine, and cultural practices. The major foods obtained from Enset are kocho, bulla, and amicho (Ayele and Sahu 2014). Kocho is the main product of Enset (Fig. 1), and it is baked as a flat bread after squeezing and removing the remaining fiber (Shank and Ertiro 1996). Enset contributes to the local environment by improving the nutrient balance in the soil (Elias et al. 1998), providing shadow, thus

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**Fig. 1** Enset plant and its plantation as a home garden with the main food (kocho) and how it is eaten



moderating temperature, and being part of farming systems with high biodiversity (Tesfaye 2008).

The Enset system of cultivation is one of the last remaining sustainable, indigenous agricultural systems found in Africa. Enset occurs in wild forms in East, Central, and South Africa. It became an emergency food during the Second World War in Vietnam (Asia) (Tsegaye and Westphal 2002). But, it is cultivated only in Ethiopia, where the crop was first domesticated possibly around 8000 years ago (Tsegaye and Westphal 2002). In Ethiopia, it grows in the central and northern highlands around Lake Tana, the Simien Mountains, Adigrat, and southern Eritrea (Simoons 1965; Brandt et al. 1997). However, Enset food products have been used as a staple and/or co-staple food for the people who inhabit the country's southern, southwestern, and western parts (Brandt et al. 1997). These regions are among the most densely populated in Ethiopia and are inhabited by more than 11 ethnic groups with a great variation in culture and agricultural practices (Tsegaye and Westphal 2002).

The Gurage ethnic group of Ethiopia is typically dependent on Enset as their main staple. They identify themselves as "people of Enset" (Shank and Ertiro 1996). In the Gurage Mountains, Enset is extensively cultivated and plays a vital role in the community's economic and social life. Its intensive cultivation enables the concentration of large communities into compact and permanent villages. Well-planned techniques of cultivation and systematic storage of Enset food make it possible for the Gurage to live well above the subsistence level. In addition, they have added cash crops such as coffee and khat (*Catha edulis*), which are grown between Enset plants, without significantly changing the traditional pattern of horticulture.

Spatial quantification and mapping of ecosystem services have been recognized as important tools for scientists and

decision-makers to assess and communicate ecosystem conditions and ecosystem services provided at various scales. Mapping the areal extent and spatial configuration of landscape features has been used as a tool to determine both the type and the value of ecosystem services provided (Morse-Jones et al. 2011). Previous spatially explicit and quantitative analyses are very limited with regard to the differences between what services potentially can be provided in a given piece of land, what services are available and used by different beneficiaries, and what type of services are demanded. Assessing the supply and demand for ecosystem services helps to understand not only how much and where the service is produced, needed, and consumed but also the gap between the supply and demand (Troy and Wilson 2006; Swetnam et al. 2010).

Several researchers have developed models to estimate the yield of Enset in Ethiopia. In order to reduce confusion around the yield and production estimate, Shank and Ertiro (1996) developed a linear model for predicting Enset plant yield and assessing kocho production in Ethiopia. At the Areka Agricultural Research Center in Southern Ethiopia, Tsegaye and Struik (2001) investigated the kocho yield of Enset in terms of weight and energy under different crop establishment methods. By considering different clones and using multiple regression models, Yeshitela (2014) further developed Shank and Ertiro's (1996) simple linear models and investigated fermented unsqueezed kocho as a function of Enset plant height and pseudostem circumference measurements.

Studies on the spatial quantification and mapping of the supply and demand of Enset crop are not available in Ethiopia. Due to the lack of spatial information on the Wabe River catchment's kocho food supply and the community's desire or need, it is challenging to fully understand the

catchment's food security status. This makes it difficult for decision-makers to understand where and to what extent interventions should be made. Thus, studies on all these aspects are needed to develop tools to quantify and map both the potential and the demand so that decision-makers can enhance Enset food production. This study, therefore, quantifies and maps the supply and demand of kocho for management of Enset crop in the Wabe River catchment of the Gurage Mountain landscape in Ethiopia. Furthermore, it demonstrates the Enset crop's contribution to food security and provides a tool for agricultural planners and policy decision-makers to enhance the Enset and kocho sustainable production.

## 2 Materials and methods

### 2.1 Study area

The Wabe River catchment is among the Omo-Gibe basin's major sub-basins in the southwestern and central part of Ethiopia. It is located between 08° 21' 30" and 08° 30' 00" N and 38° 05' 40" and 37° 49' 00" E. The Gurage Mountains, with a maximum altitude of 3611 m above sea level, make up the highest area in the sub-basin and the lowest altitude of 1014 m is found in the Gibe River (Fig. 2). The catchment includes six *woredas* (districts) from the Gurage administrative zone of the Southern Nations, Nationalities, and Peoples region (SNNP) and two from the Oromia region's Southwest Shewa zone. The catchment covers a drainage area of about 1860 km<sup>2</sup>. The five agroecological zones existing in the catchment according to the Ministry of Agriculture are the cool moist mid-highlands, the cool sub-humid mid-highlands, the tepid moist mid-highlands, the tepid sub-humid mid-highlands, and the warm sub-humid lowlands (Fig. 2). The Wabe catchment's maximum temperature ranges from 20 °C (in the wet season) to 39 °C (in the dry season), while the minimum temperature is in the range of 0–19 °C. The average temperature is 18 °C. The mean annual rainfall ranges from 1200 to 1320 mm. Pellic vertisols are the dominant soil type according to the FAO soil classification. Enset plants grow between the altitudes of 1500 and 3400 m in the catchment.

### 2.2 Data collection

In order to quantify kocho supply and demand in the catchment, household surveys and field measurements were undertaken at different sampling sites within the study site's different agroecological areas. Using the ArcGIS 10.2 software, eight transects ranging from 11 to 80 km long from the lower to the higher altitude and located 5 km apart were identified (Fig. 2). The distance between sample plots was 2.5 km. While conducting sampling surveys, some of the sample plots' locations deviated from the transect line in order to

include Enset crop fields, when possible. The maximum deviation was 1 km. To estimate the existing stock of kocho, sample plots of 10 × 10 m were laid at each sampling site. This sample area's size was derived from preliminary surveys that determined which representative corms, ages, and sizes of Enset could be explored. A total of 120 sample plots were investigated. In order to investigate the demand of household kocho, household questionnaire surveys were administered to the selected Enset crop fields' owners in the six districts of the catchment.

## 2.3 Assessment of ecosystem services

### 2.3.1 Food (kocho) supply

The pseudostem circumference, height, and leaf length of all Enset plants were measured within the sample plot using a tape meter. Because the Enset crop farm is distinct from other crops and land use, it is possible to extract the Enset crop area using high-resolution satellite imagery and Google Earth imagery (Fig. 2). In order to estimate the area of production, all Enset crop fields were digitized from Google Earth imagery from 2016 due to the lack of high-resolution imagery. Ground verification was undertaken to check the accuracy of the spatial data of the Enset crop farms.

In order to estimate the Enset plant's kocho yield, the linear equation developed by Yeshitela (2014) was used. This equation (Eq. 1) can estimate the fermented squeezed (moisture removed) kocho yield for each Enset plant.

$$FSQK = -19.91 + 3.35 PH + 17.1PSC \quad (1)$$

where FSQK is the fermented squeezed kocho yield (in kg), PH is the plant height (m) (pseudostem height and leaf height), and PSC is the pseudostem circumference (m) (measured at the middle height).

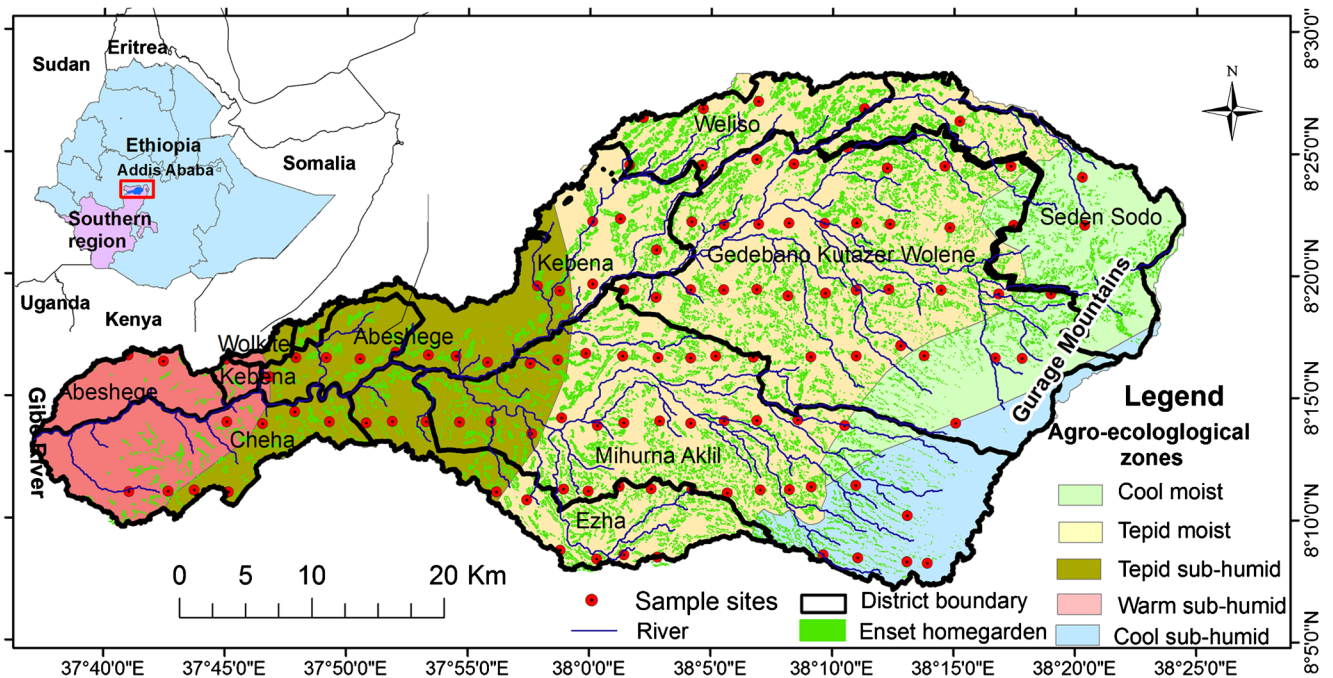
To determine kocho yield/plot, the estimated yield of each plant was summed up within a plot. Then, the average kocho yield was classified into agroecological zones. The measured kocho yield/plot was converted to hectare/year using Eq. 2 given by Singh and Chaudhury (2014).

*Kocho yield per ha/year*

$$= \frac{\text{Kocho yield per plant (kg)} \times 10000}{\text{Number of year of maturity} \times \text{plot area (m}^2\text{)}} \quad (2)$$

The catchment's total kocho yield was determined by multiplying the total Enset crop production area by the average kocho yield of each agroecological zone. The coverage area was calculated from the digitized spatial features of each household's home garden Enset field through ArcGIS 10.2 software. To determine the effects of altitude on yield, the





**Fig. 2** Location map of the Wabe River catchment with sample collection sites, agroecological zones, and *woredas* (districts). The blue color within Ethiopia shows where the catchment found in East Africa

samples were classified into five groups using agroecological zones of Ethiopia.

### 2.3.2 Food (kocho) demand

Data on the current use and future needs of households were collected by local development agent experts (after having taken a training on how to conduct interviews) through interviews with each of the 120 households (Fig. 2). One person, representing the household, determined their current demand by considering the current production of kocho, buying of kocho, or other food items, number of family members, and other crop types they were growing. Similarly, their future demand for the next 10 years was determined by considering the family's expected population size and income conditions. Data on the number of Enset plants harvested per year were collected from each farmer. These data substitute the consumption of kocho in unit measurements. Farmers can remember the amount of Enset harvested by counting the number of pits replaced by a new seedling. The amount of Enset harvested per year was then converted to kocho yield by multiplying with the average yield per Enset using the estimate given in Eq. 3.

The current demand was estimated using a simple linear equation (Eq. 3).

$$\text{Household demand} = \text{own production} + \text{purchased-sold} \quad (3)$$

The current demand of kocho per person per household was determined by dividing the total consumption by the

number of people in each household. The average current consumption of kocho per person in the catchment was then determined by dividing the sum of all averaged consumed kocho by the number of sampled households in the catchment.

The current total consumption of kocho in the catchment was determined by multiplying the average consumption of kocho per person by the total population in the catchment projected for 2016 from the CSA 2007 census data (assuming a growth rate of 2.9%). The major urban population in the catchment was not considered because they did not consume kocho as a staple food.

### 2.3.3 Mapping the supply, demand, and budget of kocho

The use of land cover data for spatial extrapolation of primary data is a relatively frequently used method especially for mapping cultural, provisioning, and regulating ecosystem services. This relatively simple and quick approach relies on several sources of information that are adjusted to the particularities and sites of the studied ecosystem services. In this study, primary data gathered from satellite imagery and household surveys were used to accurately estimate and map the household-level supply, demand, and budget of food (kocho) ecosystem services. An interpolation technique was used to determine the supply, demand, and budget status. The ArcGIS inverse distance-weighted technique enables the interpolation and extrapolation of spatial yield estimates to the whole landscape. The estimated kocho yield in each crop field was used to interpolate the yield in the whole catchment using the quantified average yield/hectare/year results from the sample field

survey. The resulting map shows which areas have higher, medium, and lower yields. Similarly, the current demand of kocho was mapped by interpolating the quantified demand results of the sample survey households and the total projected *kebele* (sub-district) population by 2016.

The kocho net budget map was then produced by subtracting the kocho supply map from the kocho demand map using the mapping software algebra tools in ArcGIS 10.2.

### 3 Results and discussion

#### 3.1 Quantifying the supply of food (kocho)

A total of 3855 individual Enset plants were measured from sample area of 12,000 m<sup>2</sup> with an average of 32 Enset plants per plot. The minimum and maximum plants per plot were 25 and 40, respectively. In most plots, the number of Enset plants was between 30 and 35. This means an average spacing between Enset plants of 1.8 × 1.8 m. We estimated the average number of Enset plants per hectare to be 1024 ± 89.

Using the digitized data, it was estimated that 8251 ha (4.5%) of the Wabe River catchment area was used for Enset crop cultivation. The largest part of this (6046 ha) occurred in the tepid moist mid-highlands agroecological zone. The cool sub-humid mid-highland and warm sub-humid lowland agroecological zones had the lowest coverage areas of Enset fields. The Enset crop farms were concentrated in the catchment's humid mid-highlands.

In this study, considering all sizes and ages of Enset plants in the sample plots, the amount of squeezed kocho production ranged from 0.06 to 53 kg with an average of 16.2 ± 7 kg/plant. From this, the study area's unsqueezed kocho becomes 0.08 to 78 kg/plant with an average of 23.4 ± 11 kg/plant. As according to Yeshitela (2014), the yields of squeezed (moisture removed) kocho are 0.69 times those of unsqueezed kocho. The average yield of kocho per plot was lower in the cool moist mid-highlands of the Mihurna Aklil and Gedebano Gutazer Wolene *woredas* (districts), where they grow at higher altitudes (above 3000 m) (Table 1). In addition, the warm sub-humid lowlands of the Abesghe and Cheha

districts/*woredas* had lower yields, where they grow at lower altitudes (1500–1900 m). The highest yield per Enset was obtained in the catchment's tepid humid mid-highland zones of the Mihurna Aklil, Gedebano Gutazer Wolene, Ezha, Kebena, and Cheha districts/*woredas*, mainly at altitudes ranging between 2000 and 3000 m.

The Enset yield varies depending on the type of clone, growing area, growth stage, and cultural management practices (Shumbulo et al. 2012). According to Tabogie (1997), farm-level Enset production studies undertaken in the Emdibir, Kambata, and Sidama areas in Southern Ethiopia indicated that the yield of unsqueezed kocho ranged from 8 to 70 kg/plant with an average of 30, 34, and 27 kg/plant for the Emdibir, Kambata, and Sidama areas, respectively. Similarly, according to Shumbulo et al. (2012), in the Wolayita Zone of Ethiopia, the amount of unsqueezed kocho obtained from one Enset plant ranges from 15 to 61 kg. Thus, the average kocho/Enset plant yield of the area under study was less than the production in other areas of the region. However, the yield ranges are similar to those recorded in other studies. The minimum yield calculated in this study was lower because, unlike in other studies, all the sizes and ages of Enset plants in the sample plots were considered.

The average yield per plot for the whole catchment was 523 ± 226 kg (Table 1) and ranged from 27 to 1219 kg. The results of the sample plot data show that there is a yield difference between different agroecological zones (Table 1). The lowest yield occurred in the cool moist mid-highlands zone with a mean of 232 ± 169 kg, while the highest (616 ± 211 kg) occurred in the tepid moist mid-highlands agroecological zone. The tepid sub-humid mid-highlands had the next highest productivity (476 ± 201 kg). The cool sub-humid mid-highland and warm sub-humid lowland zones had medium productivity. Most of the sample plots located above 3000-m altitude had kocho yields of less than 600 kg per plot. Sample plots located at altitudes between 2000 and 3000 m had a diversified yield range from 180 to 950 kg. The yield was lower in plots located at altitudes between 1500 and 2000 m. This indicates that the best production areas for Enset plants were in the humid areas of the catchment. Annual kocho yield per hectare was determined by using an

**Table 1** Kocho yield at agroecological zones of the Wabe River catchment

Agroecological zones	Area (ha)	Average yield/Enset plant (kg)	Average yield/sample plot (kg)	Annual average yield (kg/ha/year)	Total yield (kg) (× 1000)
Cool moist mid-highlands	759	15.9 ± 7	232 ± 169	2900 ± 150	175,988
Cool sub-humid mid-highlands	175	16.1 ± 5	374 ± 87	4671 ± 60	66,112
Tepid moist mid-highlands	6046	16.5 ± 6	616 ± 211	7696 ± 450	3,719,667
Tepid sub-humid mid-highlands	1010	16.3 ± 6	476 ± 201	5954 ± 420	482,352
Warm sub-humid lowlands	263	15.9 ± 1	378 ± 16	4730 ± 115	100,204
Average/total	8251	16.2 ± 7	523 ± 226	6543 ± 284	4,544,323

average 8-year Enset maturity period. The yield was lowest in the cool moist mid-highlands ( $2900 \pm 150$  kg/ha/year) and highest in the tepid moist mid-highlands ( $7696 \pm 450$  kg/ha/year). The annual average yield per hectare was  $6543 \pm 284$  kg (Table 1). In the Wabe River catchment, 4,544,323 t of kocho is available as standing stock, with the largest stock found in the tepid moist mid-highlands. The lowest stock was found in the cool sub-humid mid-highlands.

According to the CSA (2012) agricultural survey report, the production of Enset crop in Ethiopia is 2335 kg/ha/year, which is much lower than the production found in this study. The supply estimated in this study is much larger than the CSA report that could be the model used for estimation.

### 3.2 Quantifying the demand of kocho

The household survey showed that most of the farmers had large family sizes (between four and eight people). Only 22.5% of the households have a family size of fewer than four people. About 14% of the households have a family size of greater than nine people. The largest family comprised 13 people with an average family size of 6 people.

The survey results showed that almost all farmers were also practicing other agricultural activities. Livestock is the other main agricultural activity practiced along with Enset farming. Livestock provides draught power for traction, manure to fertilize the soil, and milk/meat products to balance the Enset-based diet with proteins. Manure produced from livestock excrements is the main source of fertilization for Enset cultivation rather than using artificial fertilizer. About 50% of the households practiced the production of other crops like teff (*Eragrostis tef*), barley, beans, peas, sorghum, wheat, maize, and other related crops according to agroecological zones of the catchment. Households in the catchment that engaged in vegetable and fruit production other than Enset account for 31% of the total households. Khat (*C. edulis*) is a stimulant crop grown next to or inside an Enset garden in the lower altitudes of the catchment. The household survey indicated that 49% of the farmers practiced the production of this crop.

Even though other food crops are also grown in the catchment, 97.5% of the surveyed households' staple food is from kocho with others acting as complementary food items. Teff (*E. tef*) and potatoes contribute to 2 and 0.5% of the households' supplementary food supply, respectively.

The survey results indicated that only 38.8% of the households met their yearly demand for kocho from their own home garden production. The remaining households needed an additional 20 to 200 Enset plants to fulfill their demands. About 27.5% of the households satisfied the demand by buying kocho from the market and 13.3% of the households covered their need by consuming other crops.

The remaining 20.4% of the households did not satisfy their demands. Yearly, 11% of the households sold 11 to 50 Enset plants and 21.6% of the households occasionally sold their Enset plants or kocho.

The results show that the average current demand of households was  $97 \pm 13$  Enset plants ( $1618 \pm 150$  kg kocho), equivalent to  $16 \pm 2$  Enset plants ( $289 \pm 24$  kg of kocho) per person. The maximum and the minimum demands per household were about 3800 and 266 kg, respectively. According to the survey data,  $939 \pm 87$  kg of kocho per household will be needed on average in the future. Thus, the future demand will be less than the current one. This is due to some household's expected to diversify food crops and for the others decline in their number family size.

The current demand of kocho within different agroecological zones shows that kocho has high demand in warm sub-humid lowland zones ( $461 \pm 207$  kg/year) (Table 2) followed by tepid sub-humid mid-highland zones ( $308 \pm 116$  kg/year). Whereas, the lowest demand zone is in the cool moist mid-highlands ( $208 \pm 97$  kg/year). The low demand in cool moist highland agroecological zones is due to the fact that the cold climatic conditions are not suitable for Enset growth and the farming community cultivates other food sources, such as potatoes and cereal crops, as their food security options. In recent years, there has been a new tendency to introduce Enset to these new agroecological zones and, therefore, the demand is expected to increase as the area of production increases. This may be due to both the catchment becoming warmer as compared to the last 30 years or to the development of new varieties that are suitable for these low-temperature cultivation areas. The long-term weather data records show an average annual maximum temperature increase of  $2^\circ\text{C}$ .

In addition to their high yield (Tsegaye and Westphal 2002), Enset plants can be harvested at different periods of the year, and the kocho product can be stored for longer times without the use of refrigerators, further encouraging farmers to introduce Enset. They use it as a source of income (selling the strong fiber and leaves of the plant) (Brandt et al. 1997), for domestic uses (the leaves become feed for livestock, serving as dishes, and covering pits) (Menbere 2014), for building (to make containers, mats, ropes, bags, and sieves) (Brandt et al. 1997), and to serve as cover (the leaves wrap kocho, honey bee hive, Khat, butter, bread, and crops). In addition, they use Enset for medicinal purposes (Nudego 2016), such as therapeutic practices, to treat fractures and broken bones, problems related to childbirth, an aid to release the placenta, and for abortion as a means of family planning. Even though few studies are available, Enset is highly valued for environmental conservation (soil erosion control and enhancing soil fertility) (Tamire and Argaw 2015) and landscape aesthetics (Olango et al. 2014). Thus, due to its multiple uses, the demand of Enset is high.



**Table 2** Demand of kocho per year in different agroecological zones of the study area

Agroecological zones	No. of samples	Min (kg/year)	Max (kg/year)	Mean (kg/year)
Cool moist mid-highlands	9	20.75	553.3	208 ± 97
Cool sub-humid mid-highlands	9	49.8	669.5	287 ± 119
Tepid moist mid-highlands	70	55.3	597.6	257 ± 91
Tepid sub-humid mid-highlands	24	83	560.3	308 ± 116
Warm sub-humid lowlands	8	221.3	913	461 ± 207

### 3.3 Mapping the supply and demand of kocho

Based on interpolations of the household-level supply and demand data, 31,025 ha (19.7%) of the catchment area provides kocho yields of 0–50 kg/ha. Areas with kocho yields of 51–100 kg/ha constitute 17% of the total catchment, whereas 59% of the catchment (92,606 ha) has kocho yields of between 101 and 500 kg/ha. Kocho yields above 1000 kg were recorded in 462 ha (0.3%) of the area. The remaining 4% of the area has kocho yields of between 501 and 1000 kg/ha (Fig. 3).

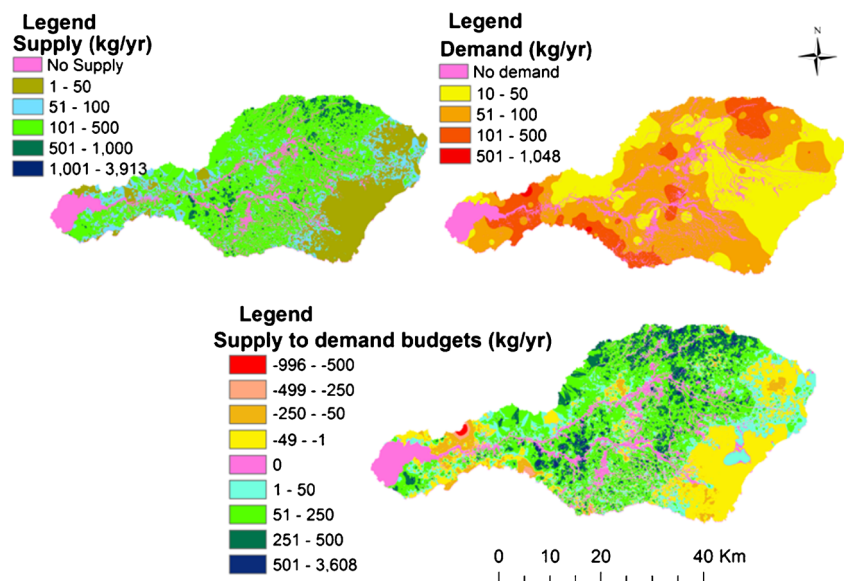
The kocho demand map (Fig. 3) shows that the population living in 38% of the area needs up to 50 kg/year of kocho. The population living in the largest part of the catchment (48%) needs 51–100 kg/year of kocho. Furthermore, 12.7% of the population requires 100 to 500 kg/year of kocho. Only 0.3% of the population living in the catchment area needs above 500 kg/year of kocho.

The supply-demand budget indicates that there is a high supply of kocho in most parts (63%) of the catchment (Fig. 3). A surplus of above 500 kg/year of kocho is found in 2.2% of the catchment area, and a surplus of below 50 kg/year is found in 15.5% of the catchment area. The remaining 47.6% of the catchment area has a surplus of 51 to 500 kg/year. However, 24% of the catchment population needs additional

supplies of between 1 and 996 kg/year of kocho. In 19.7% of the catchment area, the demand for additional kocho supply is between 1 and 49 kg/year. More than 500 kg/year of additional kocho supply is needed in 0.1% of the area. In the remaining 3.9% of the catchment area, 50 to 500 kg/year of additional kocho supply is needed. In 13% of the catchment area, the supply and demand of kocho is balanced.

The area of cultivation, production, and productivity of cereal crops increased in Ethiopia from 2010 to 2015 (CSA 2015). However, the demand for most crops remains higher than its supply. Like other cereal crops, Enset (kocho) demand was found to be higher than the supply in 25% of the Wabe River catchment area. Most of the demand for Enset in the middle altitude catchment is met but in some areas, the supply is greater than the demand. However, in the higher and lower altitude areas and in some parts of the middle altitude areas of the catchment, there is a higher demand for food production from Enset. At the moment, households living in the lower altitude areas are complementing their dietary requirements with the use of other crops like teff (*E. tef*) and maize, and in higher altitude areas, potato and barley act as the main substitute foods. People in higher altitude areas and some in middle and lower altitude areas are buying kocho from local markets, which requires traveling long distances to and from surplus areas on donkey and horseback.

**Fig. 3** Supply, demand, and net budget map of kocho in the Wabe River catchment



Enset farming systems contribute to the long-term sustainability of food production capacity through several mechanisms. Enset can be stored for long periods, can be harvested at any time during the year, can be harvested at any stage over a period of several years, and can survive high-stress years that reduce other food sources. Thus, in order to ensure sustainability of the food supply in the area, the production of kocho should be increased to meet the demands of the catchment people (Brandt et al. 1997).

Productivity can be enhanced in multiple ways: increasing the spacing between Enset plants (Shumbulo et al. 2012), choosing the proper type of corm according to the level of soil fertility and agroecology (Birmeta 2004), undertaking biotechnological studies to discover new varieties that can adapt to the cool climatic conditions, controlling diseases (Yemataw et al. 2016), and using technologies to improve the production process of kocho (Ayele and Sahu 2014).

According to Martínez-Harms and Balvanera (2012), there are several methods for mapping ecosystem services. The inconsistency noted between methods used to quantify and map services poses a challenge for developing robust values of ecosystem services for inclusion in national accounts and broader policy, natural resource management, and decision-making. The authors argue that there is a need for a standard process for quantifying and mapping ecosystem services in order to support robust decision-making, potential trade on markets, and landscape planning. This study demonstrates the ability to improve the quantification and mapping of the supply, demand, and net budget provisioning of food ecosystem services through the collection of different physical and socioeconomic data, and by using appropriate models to estimate yields. Using this approach, both the potential supply and demand of food crops like Enset can be quantified and mapped and used as a tool for decision-making.

## 4 Conclusions

This study, on the quantification and mapping of kocho yield in the Wabe River catchment, showed that even though Enset grows in most parts of the catchment, the areal coverage, the amount of yield per year, and the amount of stock are higher in the humid mid-highlands. The demand of kocho is high throughout the catchment as almost all households' staple food is from Enset, although other agricultural activities are also practiced. The majority of the household demand for kocho is met, as many areas may be suitable for Enset growth. However, communities located in higher and lower altitudes and some parts of mid-altitude areas need more Enset production than currently available from their home garden. This study identified the areas where Enset demand is not satisfied by Enset on-site supply with catchment-wide spatial analysis, which could be utilized by planners to improve the land use

zoning system of the catchment and develop appropriate measures such as improving or expanding production yield of Enset, and improving access to local market. Decision-makers should intervene in enhancement of Enset food production, thereby ensuring the food security of the communities. Enset production and productivity enhancement mechanisms are also important to increase the additional benefits of Enset beyond its food provisioning aspect. Future studies are needed to quantify and map other ecosystem services (regulating, supporting, and cultural services) provided by Enset in order to better inform planning and decision-making. This study's approach and methods to measure and map both supply and demand of provisioning ecosystem services can be applicable to other crops, and future studies need to consider measuring supply and demand of multiple crops as well as other types of ecosystem services such as regulating services.

**Acknowledgments** The study data were collected with the kind cooperation of Gurage zone-, *woreda*- (district), and *kebele*- (sub-district) level agriculture and natural resources departments and their staffs.

**Funding information** Financial and logistic supports were provided by Wolkite and Addis Ababa Universities. The Japan Science and Technology Agency provided a financial support to stay in Tokyo (Japan) and to undertake Intensive Core Courses at United Nations University Institute for the Advanced Study of Sustainability. The International Foundation for Science with grant number D/5915-1 partially financed this study. We greatly acknowledge all these organizations and the financial support rendered to the first author.

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