Estimating Above Ground Biomass and Carbon Stock of Four Natural Forests in Amhara Region, Ethiopia

Master's Thesis

Submitted by

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Abstract

From the terrestrial ecosystem components which nature has awarded us, forests are significant sinks or sponges of carbon. Among the methods developed the use of allometeric equations and those conversion of volume in to biomass or carbon are the fundamental ones. The objectives of this study were (i) to investigate different possible above ground biomass and carbon estimation methods (ii) to analyze and apply the possible obtained biomass and carbon estimation approaches on Amhara region natural forests, and (iii) to compare the approaches utilized for above ground biomass estimation of the region based on the results obtained from each method. The first approach utilized six recommended allometeric equations and the second approach used volume and biomass expansion factors (BEF).These two methods were applied to the tree data of 20 main tree species that grow in the Amhara region. The biomass equation of Chave (2005) and the biomass expansion factor recommended by IPCC (2003) were applied to the plot data of the study sites of the region in order to estimate the above ground biomass. At biomass selection stage the use of tree data with a diameter at breast height (DBH) range up to 40 cm and a height up to 10 m, all six biomass equations and those with biomass expansion factors provided comparable results. However, in the plot data when the one selected biomass equation and those used biomass expansion factors were applied similar results were obtained only up to 30 cm DBH. The above ground biomass and carbon results calculated from the selected biomass equation of Chave (2005) were lower than the_ biomass expansion factor. According to some literature’s biomass equations are better estimators of biomass and subsequently the carbon converted from it will be a more realistic than the biomass expansion factor equation.

Key words: above ground biomass, above ground carbon, carbon sinks, allometeric equation, biomass expansion factor, volume, Amhara region

Zusammenfassung

Von allen Komponenten unseres Landökosystems nehmen Wälder eine wichtige Rolle als Kohlenstoffsenken oder –speicher ein. Um die Bedeutung der Wälder als Kohlenstoffsenken zu bemessen, wurden bereits etliche Methoden zur Schätzung von oberirdischer Biomasse und Kohlenstoffgehalt entwickelt. Ziele dieser Arbeit waren 1. verschiedene mögliche Methoden zur Schätzung der Biomasse und des Kohlenstoffgehalts zu eruieren, 2. diese Methoden auf die Naturwälder der Amhara – Region anzuwenden und deren mögliche Biomassezunahme und Kohlenstoffschätzwerte zu analysieren und 3. die unterschiedlichen Methoden zur Schätzung der Biomasse der Region anhand der gewonnenen Resultate zu vergleichen. Um generelle Trends aufzeigen zu können, wurden zwei unterschiedliche Methoden zur Biomassenschätzung verwendet. Die erste methodische Annäherung erfolgte mittels Anwendung von sechs empfohlenen allometrischen Gleichungen und die zweite Methode basiert auf dem Verhältnis von Volumen und Biomassezuwachsfaktoren (BEF). Diese beiden Verfahren wurden auf Daten von 20 in der Amhara – Region hauptsächlich vorkommenden Baumspezies angewendet. Die Biomasse – Gleichung von Chave (2005) und der Biomassezuwachsfaktor, vorgeschlagen bei IPCC (2003) wurden auf die Forschungsflächen in der Region angewendet, um Schätzungen für die oberirdische Biomasse treffen zu können. Oberirdisch gebundener Kohlenstoff wurde aus den gewonnenen Resultaten der Biomasse – Messungen aus beiden oben angeführten Methoden geschätzt. In der Folge wurden die Ergebnisse beider Messmethoden verglichen. Bei einem Auswahlverfahren wurden Baumdaten von Bäumen bis zu 40cm Durchmesser in Brusthöhe (DBH) und einer Höhe bis zu 10m gesammelt. Hier lieferten beide angewendeten Methoden vergleichbare Ergebnisse. Bei der Verwendung der Plotdaten konnten lediglich bis zu einem Durchmesser von 30cm in Brusthöhe ähnliche Resultate festgestellt werden. Bei der Berechnung der oberirdischen Biomasse und der Kohlenstoffwerte nach einer ausgewählten Biomasse – Gleichung von Chave (2005) waren die Ergebniswerte geringer als der Biomassezuwachsfaktor. In Einklang mit entsprechender Literatur zu diesem Thema stellten sich Gleichungen als bessere Methode zur Schätzung von Biomasse und des in der Folge darin gebundenen Kohlenstoffs heraus.

Schlüsselwörter: Oberirdische Biomasse, Kohlenstoff, Kohlenstoffsenken, allometrische Gleichungen, Biomassezuwachsfaktor, Volumen, Amhara – Region.

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1. Introduction

Ethiopia is gifted country in the diversity of biological resources due to an amazing variability of landscape, soil and climate, which has resulted in immense diversity of the ecosystems and ecology. Thus the country has a very high floral diversity, which ranges from Afro-alpine to desert vegetation in a highland and lowland areas of the country respectively. Nevertheless, due to a number of factors this highly diverse biological resource including forests is being removed at an unbelievable spatial and temporal measurement rate. Usually the main factors that are responsible for the removal of this natural resource are expansion of agriculture and overexploitation of resources for various purposes like fuelwood and construction material. Most of the time in earlier century's agricultural production has been enhanced through the use of new and highly productive lands instead of improving the productivity of the available arable land:-, commonly these intact and fertile lands established by clearing forested lands. Obviously several diverse biological resources are removed irreversibly due to this bad practice. Some research studies has assured that if the trend of degrading forests is not stopped the natural forest cover will be reduced- to less than 7 million hectares by 2020 from 13.6 million hectares in 1995 (Maile et al., 2001). Most surprisingly, people who were or continue to live in these areas are victims of the consequences and also are either directly or indirectly fully responsible for the issue due to high population increment (Eshetu et al., 2014).

Due to this very rapid devastation of the resource natural forests are located in a fragmented fashion throughout the country, and most of this remnant natural forest are found in the southern and south western parts of the country. Particularly most these small patches of natural forests of the Amhara region are located in a remote areas (mountainous and steep slopes) and sacred places like churches, _monasteries and some mosques. Additionally, trees found in these marginalized areas commercially less significant broadleaved tree species (Wassie et al., 2007). Specifically Amhara Nation Regional State (ANRS) where this study was conducted, agricultural practices were commenced earlier than other parts of the country so this area; has been rigorously offended by the above stated bad trends of deforestation. According to Global Forest Resource Assessment in 2010 the region is made fragmented patch forests which totaled to 84466 ha in 2005. Forests resources both in the country and region can provide several goods and services (timber, non-timber, construction and fuelwood, fodder, etc.). However these benefits from forests will not be achievable in the future unless sustainable management is employed. One of their borderless benefits of forests is its effect on global climate change adaptation and mitigation.

It is of the outmost importance to protect forests from degradation and sustainably manage these vast containers of natural carbon, which has so many adverse effects global climate change both in terrestrial ecosystem and oceans. Among the terrestrial ecosystems which nature has endowed us, forests are the most significant sinks of carbon. As a result forests are the most indispensable components on the earth. Including biomass there are five major carbon pools in terrestrial ecosystem namely, (i) above ground biomass, (ii) below ground biomass, (iii) dead mass of litter, (iv)woody-debris and (v) soil organic matter. Whereas the above ground biomass of trees contain an enormous share of the carbon pool (Penman et al., 2003).

Tree above ground biomass is defined as the oven dried weight of that portion of the tree found from above the ground surface. This includes the stump, stem, bark, branches, and leaves.We quantify biomass and carbon for the purpose of knowing available forest resources, concerns with global warming, and for obtaining information where establishing plantations for bio-energy, firewood and for paper production (Cairns et al., 2003; Rosenschein et al., 1999). Forests have the capacity to store a huge amount of carbon; but while they are cleared this sequestered carbon is released to the atmosphere and transformed to carbon dioxide (Condit et al., 2008). Forest management strongly affects the available above ground biomass and carbon stored.

Including the above stated importance's factors, many other reasons why scientists and re4asearchers are interested in accurate measures to quantify the biomass and carbon stock of forests. Among these interests, insuring sustainable management of forest resources, fuel wood management, different commercial use of wood and immense interest in global C cycle are the main ones that draw attention (Basuki et al., 2009; Henry et al., 2011). In addition to this, the reflectance of vegetation to the current global and local level climate change can straightforwardly be perceived through precise quantification of biomass and carbon assessment. As a result, knowing the amount of carbon held in the forest specially for developing countries where high amounts of deforestation and forest degradation is common problem gives a an opportunity for the governmental and nongovernmental organizations to plan and to be successful in afforestation, Reducing Emissions from Deforestation and forest Degradation (REDD) and carbon trade programs, to mitigate climate change. In developing countries especially in Ethiopia where this study was conducted, many of these programs are failing because of low awareness of local famers about these forest resources and their ecological contribution. It is also important for quick assessment of the impact of land use/land cover change or deforestation on carbon balance. Particularly above ground biomass estimation is one of the important parts of studies of carbon stock to create awareness of local farmers and better perception of effect of deforestation and sequestration in global carbon balance (Brown et al., 1989).

For this study the Carbo-part research project team (masters and PhD students) had collected inventory data such as diameter at breast height, height of median tree and crown width in the four forest sites (Injibara, Gelawudewose, Metema and Tara Gedam) for the purpose of quantifying above ground carbon of Amhara region in north Ethiopia. In addition for 20 main tree species (five species in each sites) other was collected. The other measurement were DBH, and diameter at 2m intervals from stump height till its diameter become ≤ 7cm to the tip of tree and total height of the tree (achieved by climbing the trees) for the development of form factor. From the available indirect biomass estimation methods two most widely used methods are going to be tested, using developed allometric equations and biomass expansion factors (BEF) (Vashum et al., 2012). The accuracy of these methods will be compared by the output that they will provide for above ground biomass estimation. Computations will be continued after using an appropriate biomass estimating method and its corresponding equation is distinguished. As a result, in this study will be the identification of a good AGB estimating method that could be used for Amhara region natural forest or nation wise (Ethiopia) with the given available inventory data.

Since, allometric equations use the easily measurable parameters like diameter at breast height, height, basal area, circumference etc. our collected inventory data will support us for this particular above ground biomass estimation method (Brown et al., 2002; Chave et al., 2005). So far, Ethiopia had very limited number of developed allometric equations(one volume equation for *Eucalyptus globules* and 63 biomass allometric equations, a total of 64 equations) for *Eucalyptus globulus, Eucalyptus camadulensis, Euclea shimperi, Otostegia integrifolia, Grewia* *bicolor* and *Dichrostachys cinerea* tree species only (Henry et al., 2011). Nevertheless it is always advisable to use site specific allometric equations, different authors attempted to develop general allometric equations that can be applied everywhere irrespective of site in order to apply them in areas where no site specific equations are available. But unluckily existing general allometric equations developed so far did not include data from Africa (Djomo et al., 2010). Even though they are used by default their validity to African forests is in question. Therefore, doubt the use of single or multi species allometric equations for sub-Saharan Africa and specifically to Ethiopia will be solved in this study. Hence, to overcome this limitation of equations different multispecies allometric equations that have been broadly developed for tropical countries for different forest types will be employed and compared with each other to select the best fitting equation to the data collected. Particularly the most recommended and tested pan tropical allometric equations developed by Chave (2005) will be tested using the collected inventory data at the above stated forest sites (Djomo et al., 2010).

The reason for neglecting development of single or multi species site specific allometric equations, in this study for better estimation is due to long time requirements, expenses and large labor prerequisites for destructively harvesting large number of trees. Several studies had shown that site specific single and or multi species allometric equations are suggested to enhance the accuracy of biomass estimation. Also, tropical forests are highly diverse in species (>300), but there are so many studies that support using published allometric equations to generate reliable estimate of forest biomass and carbon stocks especially for larger area estimation. Specifically those pan tropical allometric equations whose validity was tested by different researchers can provide nearly the same estimate of biomass with that of site specific equations (Fayolle et al., 2013).

Different studies recommended that grouping of all species together and applying multi species allometric equations classified by broad forest types (broad leaf, deciduous, mixed, etc.) or ecological zones (wet, moist and dry) is highly effective for tropical trees, since DBH alone explains more than 95% of variations in aboveground biomass and carbon stocks. Therefore, DBH is highly pertinent variable in estimating above ground biomass even in highly diverse regions (Brown et al., 2002). In addition the other advantage of these generalized equations is that they were developed based on a larger number of trees that span a wide range of DBH

(Brown et al., 1995; Chave et al., 2005). According to (Brown et al.,1997) biomass is defined as the total amount of above ground living organic matter in trees expressed as oven-dry tons per unit area, also referred as biomass density (tree, hectare region/country). In this study called total AGB includes all components (leaf, branch and trunk) of trees from above ground and thus this definition of AGB will be reviewed and applied.

In this study several available published papers with allometric equations for above ground biomass (AGB) estimation developed for the region (sub-Saharan, tropics, etc.) were studied. An equation with minimum estimation error will be selected and applied at four Amhara region forest sites where inventory data was analyzed. The name the study sites are, in Gelawudewose village Nifara forest, in Injibara zone Katasi forest, in Metema district Mahibere Selassie monastery forest and Tara Gedam monastery forests. Since, choosing of the most accurate allometric equations is not a simple task, assessing the character of available published and recommended equations is a mandatory and prior step before applying them (Henry et al., 2013; Melson et al., 2011).

Subsequently to be confident enough in model selection and to increase their level of accuracy for biomass estimation some basic criterions should be fulfilled (Chave et al., 2014, 2005; Henry et al., 2011; Ketterings et al., 2001; Melson et al., 2011) The models that would be tested will use Diameter at Breast Height (DBH in cm) alone or together with Height (H in meter) and or Wood density (ρ) in ton/m^3) as input variables. DBH and H were collected from the above stated four forest sites of Amhara region. Whereas for wood density an African countries average wood density (0.58 ton/ha) will be utilized (Brown et al., 1997). In addition to these allometric models over bark volume data also converted to biomass using biomass expansion factors (BEF) will be applied. Therefore the above ground biomass values found from the two methods will be compared.

2. Objectives

The study has the following general and specific objectives.

2.1. General objective

- Estimating above ground biomass and carbon stock of four natural forests of Amhara region.

2.2. Specific objectives

- Selecting an equation that will be used to estimate above ground biomass of natural forests of the Amhara region based on standardized data set.
- Applying the selected methods/equation to the plot data of four natural forest sites of the Amhara region.
- Comparing the above ground biomass results of each method both at species and site level.
- Converting the above ground biomass found from each method into above ground carbon of four natural forests of the region.

3. Literature review

Several research studies were conducted to estimate biomass of trees and numerous papers were published using different methods. Since most of the biomass held in the forest its belonged to trees (Brown et al., 1989; Chave et al., 2005; Condit et al., 2008; Henry et al., 2011); The focus of the review is on papers published for measuring the above ground portion of trees and this is routinely abbreviated AGB, for above ground biomass. Though the most fundamental methods used to estimate AGB are field measurements, remote sensing and GIS (geographical information system) methods (Vashum et al., 2012), whereas in this particular study the review has been held specifically on methods that are dependent on terrestrial data. Therefore review and detailed critiques of published papers was conducted on these fundamental and widely used categories of methods for AGB estimation.

3.1. Field measurements AGB estimation methods

Among field biomass estimation methods two principal methods are available; the first one is the destructive method. The second approach that can be used to measure tree biomass is the nondestructive method. The details of these two methods regarding their advantages and drawbacks are given below.

From all available AGB estimation methods, the so called harvest method is the direct method for estimating AGB and carbon stocks stored in a forest ecosystem. This method estimates a AGB of trees without felling (Somogyi et al., 2007; Vashum et al., 2012).

3.2. Destructive/harvest method

When using the destructive method the harvesting of trees in the identified area is the first necessary step. Subsequently, measurements of the different components of the trees (tree trunk, branches and leaves) are taken and then the components are weighed after being oven dried. Despite the fact that this method is highly accurate compared to any other AGB estimation method it is very impractical due to a number of impeding factors. Among the limitations that this method has, applying it for a large area of forest or; degraded forests containing threatened species and diverse tree species is not reasonable. Despite the accurate estimations this method was unreasonable in the Amhara region of Ethiopia where the forest is already highly degraded with critically endangered species. Furthermore, the area is endowed with high diversity of tree species and additionally the study area was too much large (Eshetu et al., 2014; Maile et al., 2001; Wassie et al., 2007). In addition it requires large time and resource commitment (destructive and expensive). Correspondingly, this method it is not practical for a large scale analysis (Somogyi et al., 2007; Vashum et al., 2012).

3.3. Indirect /non- destructive AGB estimation method

As stated above high amount of resources are required for direct measurements to large areas and tov the forest with very diverse tree species compositions. Therefore biomass assessment under field conditions is done using two indirect ways. (i) Hence non-destructive method attempts to estimate the biomass of a tree without felling. This biomass estimation method is applicable to those ecosystems with extraordinary or endangered tree species where clearing of such forests is not reasonable. Despite the fact that it is a non-destructive method trees should be felled and weighted for the validation of estimated biomass (Condit et al., 2008; Djomo et al., 2010; Henry et al., 2011; Melson et al., 2011; Sileshi, 2014; Vashum et al., 2012). The first method is using over bark volume data of specific trees or stand from forest inventories and then use this value to multiply it by appropriate biomass expansion factors (BEF) to transform the available volume estimate to the required biomass estimates (Khurshid et al., 2014; Lehtonen et al., 2004; Soares et al., 2012; Somogyi et al., 2007; Tobin et al., 2007). However, in regions where volume, wood density and appropriate biomass expansion or conversion factor data is not accessible the methods applicability will be laborious as well as time; resource and labor consuming.

$$B = V * p * BEF \qquad (1)$$

Where B is the biomass (fresh or dry plant mass, in Kg or tone), V is an available tree stand volume in m^3, ρ is wood density in ton/m^3 and BEF is an appropriate biomass factor.

The second widely used method to estimate biomass is using an appropriate Biomass Equation (BE) that can estimate tree biomass using easily measured parameters from forest inventories like DBH alone or including H together and others. But the first method will only be applied if only the volume of growing stocks by tree species is available, while biomass equations are preferred if one can access at representative sample of tree-wise data (Basuki et al., 2009; Beets et al., 2012; Brown et al., 1997; Chave et al., 2014; Condit et al., 2008; Djomo et al., 2010; Henry et al., 2013, 2011; Mate et al., 2014; Mokria et al., 2015; Montès et al., 2000; Negash et al., 2013; Ngomanda et al., 2014).

$$\mathbf{B = f(P1, P2 \ldots p1, p2)} \qquad (2)$$

Where B is the biomass (fresh or dry plant mass, in Kg or tone), P1, P2, etc. the available tree data (e.g. DBH in cm, H in m) and p1, p2, etc. the parameters of the equation.

However, to date, there is no far no literature that supports their above ground biomass estimation accuracy advantage, to prefer between these two methods, rather pre-existing data determines which method to use. If there is available volume over bark data of an area then you will apply the biomass expansion factors (BEF) otherwise the biomass equations (BE) will be employed (Brown et al., 2002). However the most widely used methods are biomass equations also known as allometric equations (Basuki et al., 2009; Brown et al., 2002, 1989, 1995; Chave et al., 2005; Djomo et al., 2010; Fayolle et al., 2013; Henry et al., 2013, 2011; Ketterings et al., 2001). Several researchers developed generalized and/or site specific multi-species or single-species equations for different forest types. These equations are developed through creating relationships between different parameters of trees like DBH of the stem, total height of the tree, crown diameter etc. whereas the applicability of the equation for single or mixed tree species and for specific or large-scale area depends on the employed data used to construct it (Somogyi et al., 2007). So at the beginning the methods are destructive (felling of sample trees) in order to develop for site/species specific or general equations for forest types. Nonetheless several multi-species and single-species allometric equations were not equally developed and disseminated across regions in the world. For instance species-specific allometric equations are existing for only 1% of tree species in sub-Saharan Africa (SSA) (Henry et al., 2011). In addition to this the other limitation of allometric equations is their uncertainty of in accurately estimating biomass (Henry et al., 2011; Ketterings et al., 2001; Mokria et al., 2015; Sileshi, 2014). Consequently in order to achieve the maximum possible accuracy of these methods, applying the correct BE for the appropriate tree species and/or forest type is very crucial (Henry et al., 2011). Thus based on their agro ecological area of development origin and their recommended range of applicability both in forest type and input data requirement the following published allometric equations were reviewed for further selection and application.

Table 1 list of reviewed multi-species biomass equations that can estimate the total above ground biomass (stem, branches and leaves) of trees.

Author and place developed	Species /life zone	Region	Equation	DBH (cm)
(Brown et al., 1989) Benin Burkina Faso, Cameroon, Gambia, Ghana, Guinea, Mozambique,	Dry(rain <1500mm/yr. Mexico India)	Tropical trees	$Y= \exp\{-1.996+2.328*\ln(D)\}$ RF>900mm/yr.	May-40
			$Y =10^\wedge\{-0.0535+\log_{10}(BA)\}$ RF<900mm/yr.	May-30
Bolivia, Brazil, Ecuador, French Guyana,	Moist (rain 1500-4000mm/yr.)	Tropical trees	$Y = \exp[-2.289 + 2.649 * \ln (D) - 0.021 * (\ln(D))2]$	5-148
			$Y =\exp\{-2.134+2.53*\ln(D)\}$	
Guatemala, Nicaragua, panama, Peru, Surinam, Venezuela, Bangladesh, Cambodia, India, Malaysia, Myanmar, Philippines, and Sri Lanka)	Wet (>4000mm/yr. rain)	Tropical trees	$Y=21.297-6.953(D)+0.74(D^2)$	4-112
(Brown, 1997)	Dry	Tropics	$Y=\{34.4703-8.0671*D+0.6589*(D^2)\}*1000$	
(for moist Venezuela, Malaysia, Cameroon, French guinea) (for dry and dry transition to moist Sri Lanka)	Moist	Tropics	$Y= 38.4908-11.7883(D)+1.1926D^2$	
			$Y= \exp(-3.1141+(0.9719*\log_{10}((D^2)*H)))$	
			$Y = \exp\{-2.409+09522\ln(D^2H\rho)\}$	
	Wet	Tropics	$Y =13.2579-4.8945(D)+0.6713(D^2)$	
			$Y =\exp\{-3.3012+0.9439\ln(D^2H)\}$	
(Chave et al., 2005) (Australia, Cambodia, Barman, Costa Rica, French guinea, Indicia, India karma, New Guinea, Venezuela, Malaysia)	Tropics	For all forest types	$Y =\exp \{-2.68+1.805\ln(D)+1.038\ln(H)+0.377\ln(\rho)\}$	5-156
			$Y =\exp \{-2.235+0.916\ln(D^2H\rho)\}$	5-156
			$Y =\exp \{-2.843+\ln(D^2H\rho)\}$	5-156
			$Y =\exp \{-1.023+1.821\ln(D)+0.198(\ln(D))^2-0.0272(\ln(D))^3+0.388\ln(\rho)\}$	5-156
			$Y =\exp \{-0.730+1.784\ln(D)+0.207(\ln(D))^2-0.0281(\ln(D))^3+\ln(\rho)\}$	5-156

			$Y = \exp\{-1.083+2.266\ln(D)+\ln(\rho)\}$	5-156
		Moist	$Y = \exp\{-2.994+2.135\ln(D)+0.824\ln(H)+0.809\ln(\rho)\}$	5-156
			$Y=\exp\{-3.08+1.007\ln(D^2H\rho)\}$	5-156
			$Y=\exp\{-3.027+\ln(D^2H\rho)\}$	5-156
			$Y=\exp -1.576+2.179\ln(D)+0.198\ln(D))^2-0.0272(\ln(D))^3+1.036\ln(\rho)\}$	5-156
			$Y=\exp\{-1.562+2.148\ln(D)+0.207(\ln(D))^2-0.0281(\ln(D))^3+\ln(\rho)\}$	5-156
			$Y=\exp\{-1.864+2.608\ln(D)+\ln(\rho)\}$	5-156
		Wet	$Y=\exp\{-2.408+2.04\ln(D)+0.659\ln(H)+0.746\ln(\rho)\}$	5-156
			$Y=\exp\{-2.605+0.94\ln(D^2H\rho)\}$	5-156
			$Y=\exp\{-3.024+\ln(D^2H\rho)\}$	5-156
			$Y=\exp\{-1.362+2.013\ln(D)+0.198\ln(D))^2-0.0272\ln(D))^3+0.956\ln(\rho)\}$	5-156
			$Y=\exp\{-1.302+1.98\ln(D)+0.207(\ln(D))^2-0.028(\ln(D))^3+\ln(\rho)\}$	5-156
			$Y=\exp\{-1.554+2.42\ln(D)+\ln(\rho)\}$	5-156
		All types forest trees	$Y= \exp\{-2.801+2.115\ln(D)+0.78\ln(H)+0.809\ln(\rho)\}$	5-156
			$Y=\exp\{-2.922+0.99\ln(D^2H\rho)\}$	5-156
			$Y=\exp\{-2.994+\ln(D^2H\rho)\}$	5-156
			$Y=\exp\{-1.602+2.66\ln(D)+0.136(\ln(D))2-0.0206(\ln(D))3+0.809\ln(\rho)\}$	5-156
			$Y=\exp\{-1.589+2.284\ln(D)+0.129(\ln(D))^2-0.0197(\ln(D))^3+\ln(\rho)\}$	5-156
			$Y=\exp\{-1.667+2.51\ln(D)+\ln(\rho)\}$	5-156
(Djomo et al., 2010) Cameroon, Para Brazil, Indonesia, Cambodia, data from South America , Asia and Africa	Pan moist tropical forests	General equations for tropical moist forests Multi	$Y=\exp(-2.3778+0.2893(\ln D)^2-0.0372(\ln D)^3+0.7415\ln(D^2H)+0.2843\ln(\rho))$	5-138
			$Y=\exp(-3.1268+0.9885\ln(D^2H))$	5-138
			$Y=\exp(-1.2665+1.3919\ln(D)+0.5477(\ln D)^2 -0.0725(\ln D)^3+0.3529 \ln(\rho))$	5-138

	species equations	$Y=exp(-2.0815+2.5624ln(D))$	5-138
		$Y=exp\{-2.1801+2.5624ln(D)\}$	1-148
		$Y=exp\{-3.2249+0.9885ln(D^2H)\}$	1-138
		$Y=exp\{-2.4733+0.2893(ln(D))^2-0.372(ln(D))^3+0.7415ln(D^2H)+0.2843ln(\rho)\}$	1-138

Where D=diameter at breast height in cm, H=total height in meter, Y= oven dried above ground biomass in kg Where RF is rainfall Y denotes for total above ground biomass (includes leaves, branches and trunk) in Kg, D represents for diameter at breast height (at 1.30m) in cm, ρ is for wood density in ton/m^3, exp. is the power of…and BA denotes for basal area in m^2.

4. Data

4.1. Description of the study area

4.1.1. Amhara region

The study was carried out at Amhara National Regional State (ANRS) in four representative study sites of Gelawudewose village Nifara forest, Injibara zone Katasi forest, Metema district Mahibere Selassie monastery forest and Tara Gedam monastery forests. Amhara region is one of the 14 regions of Ethiopia that is situated in the northern and northwestern part of the country. The region extends from 9 to 14^0 N and 36 to 40^0E, covers an area of 159,173 accounts for 11% of the total area of the country and has a moderately compacted shape (figure 1). The region has 11 administrative zones and 105 districts called woreda. This region is broadly viewed as being the most diverse and complex compared to other regions of the country in terms of geography. From a topographic point of view the Amhara region is classified into highlands, great semen mountains in the north and massive mountain ranges in the east and west, lowlands in the northwest including the low lying Nile River. It is the highly elevated part of the country which is characterized by rugged mountains, extensive plateau and scattered plains detached by deeply cut gorges, steep slopes and faces. The region has been experiencing relatively heavy rainfall and erosion due to highly steep slopes and vast clearance of vegetation as a result of growing population and a long period of human occupation (Tiruneh et al., 2008).

Similar to the rest of the country the region is located within the boundary of the tropics. Therefore there is no significant variations in day length and angle of the sun (macro climate). The region has extraordinary average temperature but with low variations. The altitudinal range of the region extends from 800 to over 4,000m above sea level. The area has bimodal precipitation mainly occurring between March to April and June to September ranges from 300 to 2,000mm per year and the mean annual temperature is between 15^0c and 20^0c conversely more than 27^0c temperature is recorded in valleys and marginal areas. However in north and north east of the region there is a reduction in intensity and duration of rain fall.

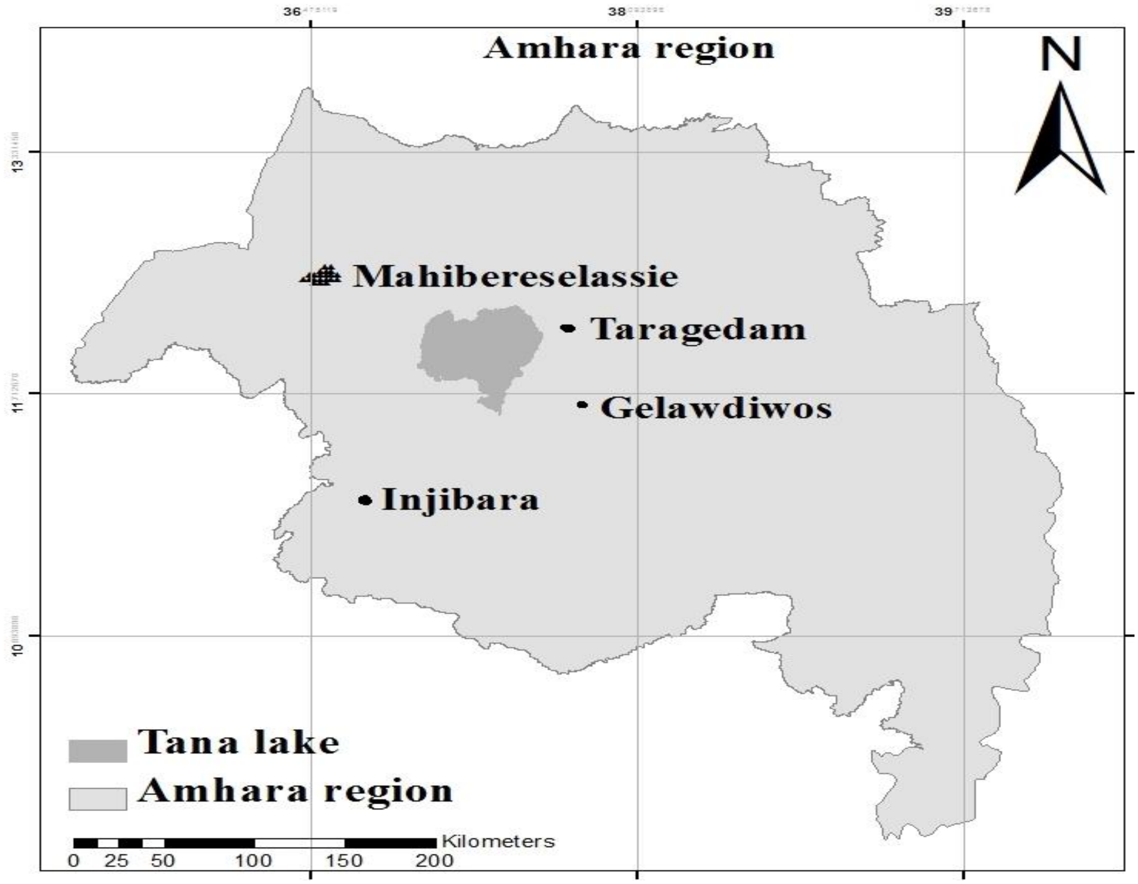

Figure 1 Map of Amhara Nation Regional State and position/location of the four study sites.

4.1.2. Geographical location of the study areas

This study was undertaken at four representative natural forest sites of the region based on their climatic agro-ecology. Two forest sites Gelawudewose and Tara Gedam monastery forests are situated in South Gondar administrative zone and are adjacent to each other. Mahibere Selassie monastery forest is near to the country of Sudan. Mahibere Selassie monastery forest and Katasi forest are located in North Gondar and Injibara administrative zones respectively. Nearby towns for Katasi, Gelawudewose and Tara Gedam monastery forest are Injibara, Hamusit, and Libo kemkem and are located along Addis Ababa- Gondar main road 442.7, 591.9 and 640.6 km from Addis Ababa and 114.8, 34.5 and 83.1 km from Bahir Dar capital of the region respectively. Whereas Mahibere Selassie monastery forest districts capital Metema is located 904.7 km away from Addis Ababa and 347.3 km from Bahir Dar.

Table 2 Geographical location, climate and soil types of study sites.

Study site	Location		Altitude (m a.s.l)		Rainfall (mm)		Temperature (°C)		Forest area (ha)
	Latitude	longitude	Min	Max	Min	Max	Min	Max	
Gelawudewose	10.950°N	36.93°E	2200	2260	1250	1200	18	25	61
Injibara	10.950°N	3.69°E	1800	2200	2000	2953	11	19	482
Metema	12.39°N	36.17°E	550	1608	514.4	1128	19	36	1800
Tara Gedam	12.08^{0}N	37.44^{0}E	2062	2496	900	1200	11	28	231

Sources (Wale etal., 2012; Wassie et al., 2007; Yismaw, 2014; Zegeye et al., 2011)

4.1.3. Vegetation structure of each study site

In order to have some information about the vegetation structure at each study sites relative frequency graphs of the most dominating tree or shrub species by occurrence starting from height ≥ 1.5m was done. The figures below are constructed based the inventory data collected during this study at each study sites. According to (Zegeye et al., 2011) relative frequency was computed as follows.

$$\text{Relative frequency} = \frac{\text{Frequency of one species}}{\text{Total frequency}} * 100 \quad (3)$$

4.1.3.1. Gelawudewose/ nifra forest

Gelawudewose is a village that belonged among 32 of smallest administrative units called Keeble of Dera district south Gondar a part of Amhara National Regional State. Some previous studies confirmed that the kebele has 3,7444ha total area coverage, of which 2,821ha is used for agricultural crop production, 135 ha for grazing and 650ha of forest land (Iones and Onstruc, 2008). Therefore Nifra forest, on the study sites) is among the main forested land of the kebele. The vegetation structure of this forest site was generated from our inventory data that was collected in the area. Thus in order to know which species is dominating in the forest by frequently occurring in the area, the following figures below are constructed based on the relative frequency of each species compared to the total.

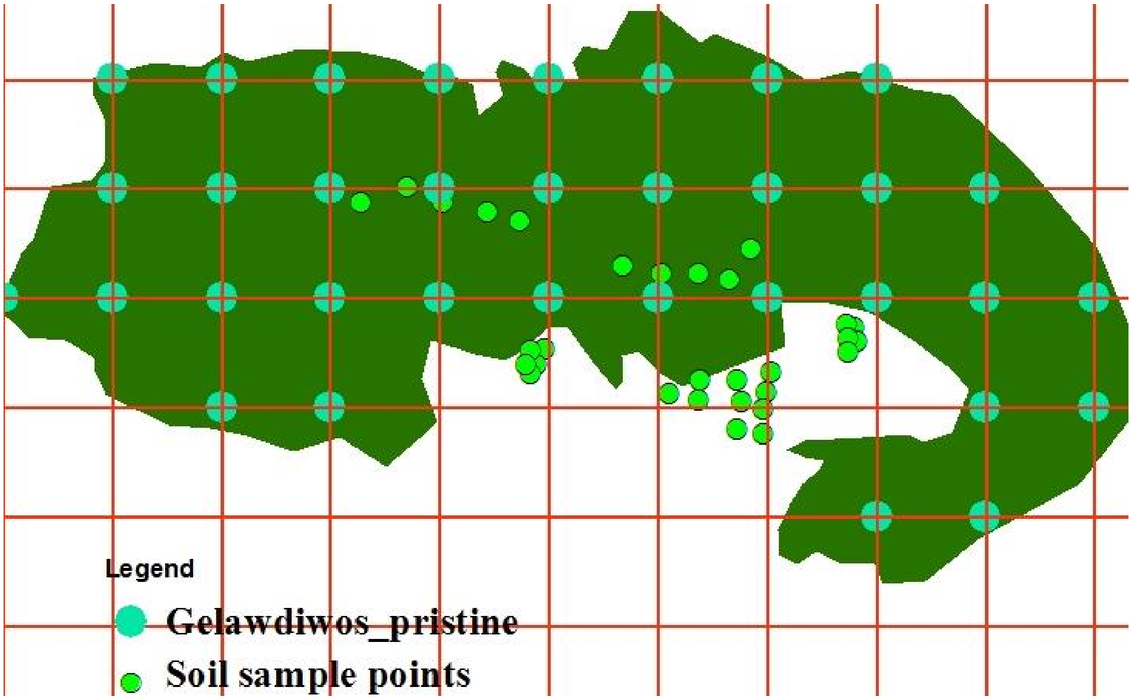

Figure 2 Sample plots of Gelawudewose pristine with 150*150 m grid distance.

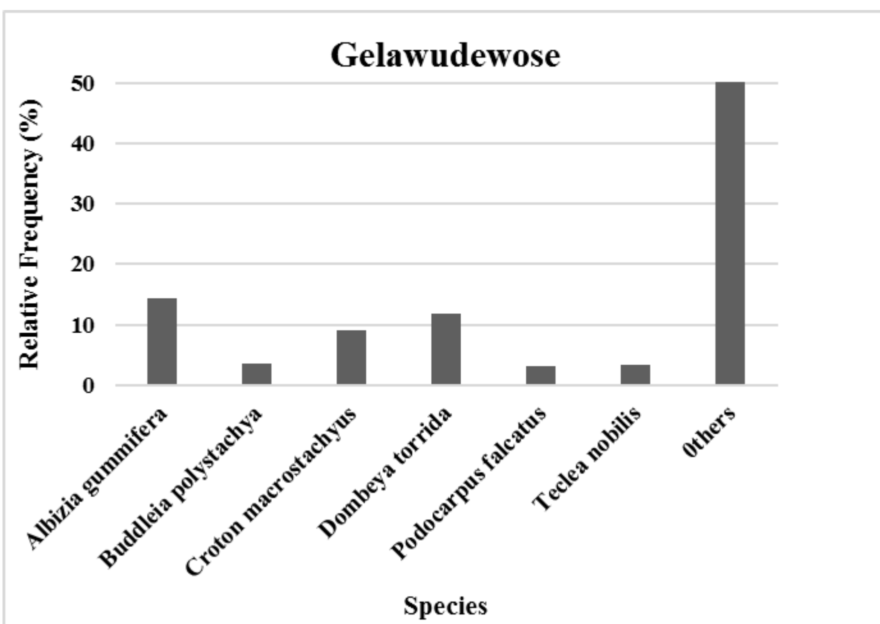

Figure 3 Share of the more frequent tree or shrub species (DBH≥10cm) at Gelawudewose study site.

Figure 4 Picture of Gelawudewose/Nifra forest during data collection 2014.

4.1.3.2. Injibara /katasi forest

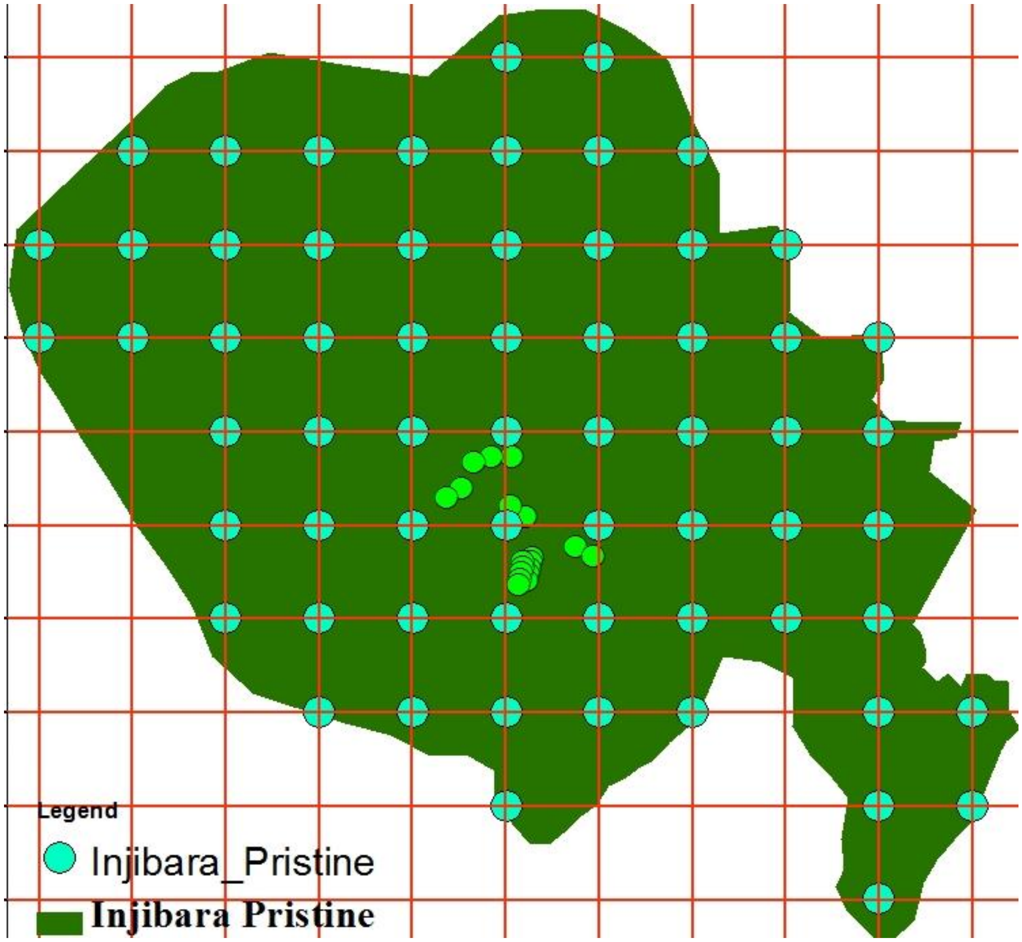

Figure 5 Sample plots of Injibara pristine with 300*300 m grid distance.

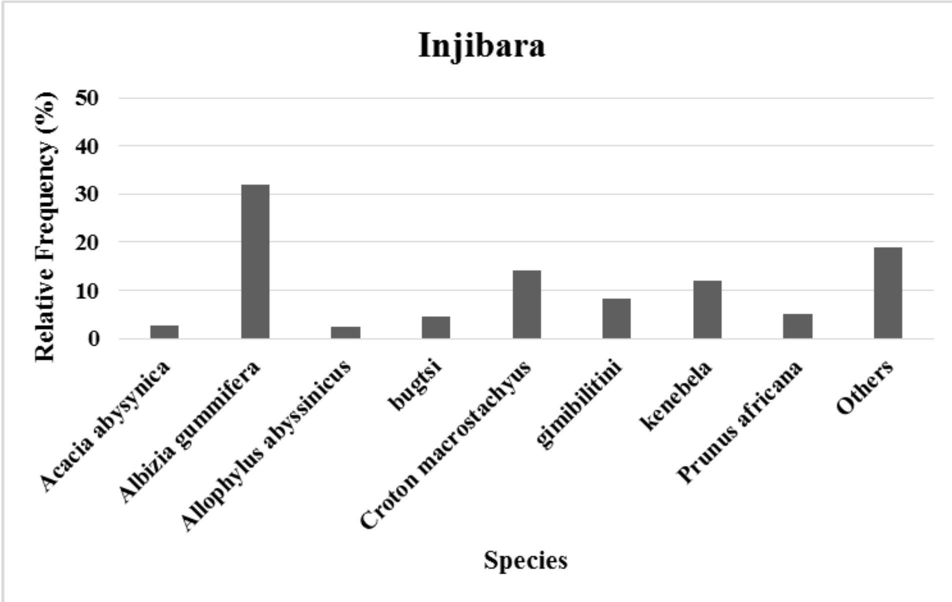

Figure 6 Share of the more frequent tree or shrub species (DBH≥10cm) at Injibara study site.

Figure 7 Picture of Injibara/Katasi forest during data collection 2014.

4.1.3.3. Metema /Mahibere Selassie monastery forest

Mahibere Selassie monastery forest is one of the remnant natural forests which is found in Metema woreda North Gondar administration zone in northwest of Amhara national Regional State. Other monasteries and churches have positive impact on conserving the natural forest of the country and Mahibere Selassie monastery is no expectation as it has a very crucial role in protecting this forest (Wale etal., 2012). The most frequent tree species in the forest are shown in the figure below based on the inventory data collected from the site.

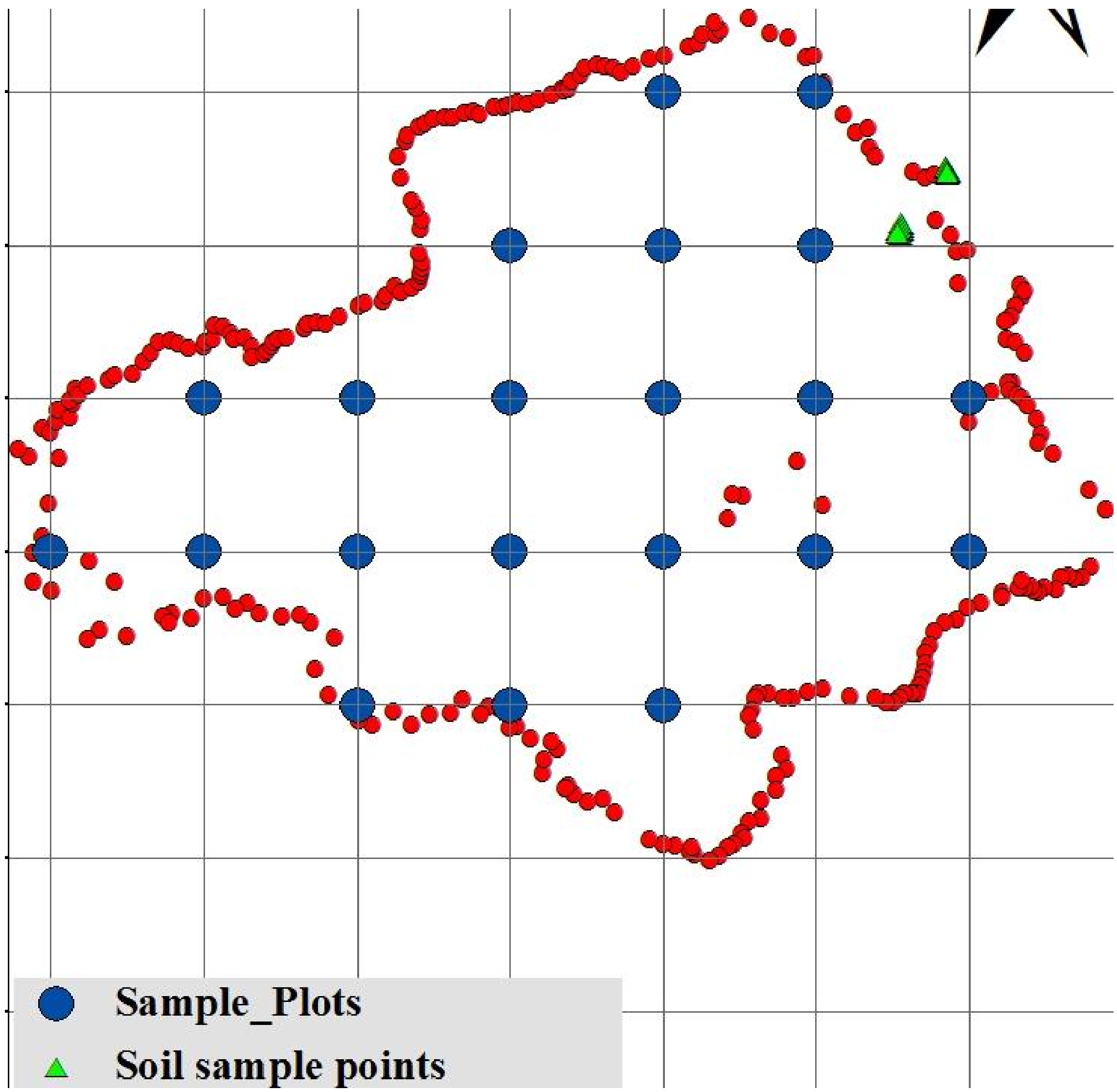

Figure 8 Sample plots of Mahibere Selassie pristine with 3*3 km grid distance.

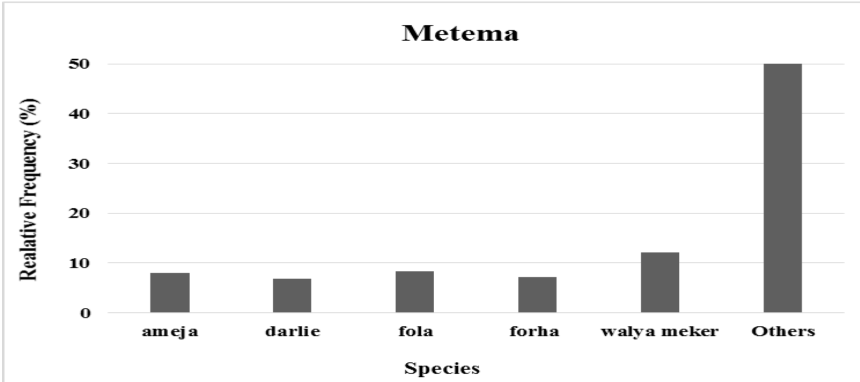

Figure 9 Share of the more frequent tree or shrub species (DBH≥10cm) at Mahibere Selassie.

Figure 10 Picture of Metema/Mahiberes Selassie monastery forest during data collection 2015.

4.1.3.4. Tara Gedam monastery forest

It is one of the remnant natural forests it is partly managed and owned by the monastery whereas the rest is managed by Addis Zemen Agricultural and Rural Development Office. As stated above it is a dry montane forest type of 324ha of forest area. The altitudinal range of the forest is from 2062 to 2496m above sea level.

According to some recent research studies there was a continuous coverage of vegetation surrounding the area of Tara Gedam monastery forest even in recent times. Nevertheless due to high demand and interventions of human and livestock's much of the vegetation coverage was reduced at an alarming rate. The different possible factors that were responsible for the reduction of the resources are expansion of agriculture excessive exploitation for wood products and human settlement (Zegeye et al., 2011). Still there have been attempts to protect the forest from cattle and human interference. However, even with the use of forest guards it was impossible to get a satisfying regeneration of tree or shrub seedlings during this study. It was also possible to speak loudly even in the time of this study because so many illegal cuttings of mature trees and cattle trampling damages of regenerating seedlings was occurring. Due to unstoppable resource damage nowadays this area remains with bushy and patchy forest resources.

According to the Ethiopian climate zone classification system Tara Gedam monastery forest and the surrounding area belongs to "moist woyinadega" (mid-highland). This study site has a total of 324 ha of forest area and the vegetation of the area is belongs to the dry ever green montane forest type consisting of forests, shrub lands and enrichment plantation. The soil of Tara Gedam forest is designated to be one of higher clay content (Workneh, 2008).

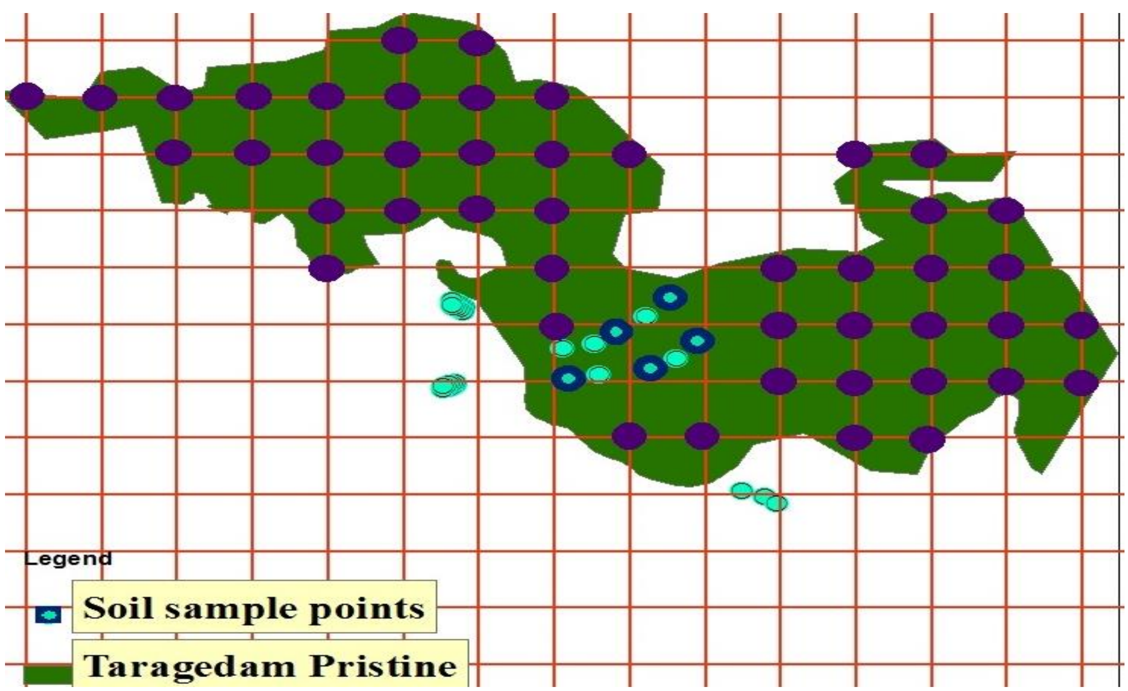

Figure 11 Sample plots of Tara Gedam pristine forest with 250*250 m grid distance.

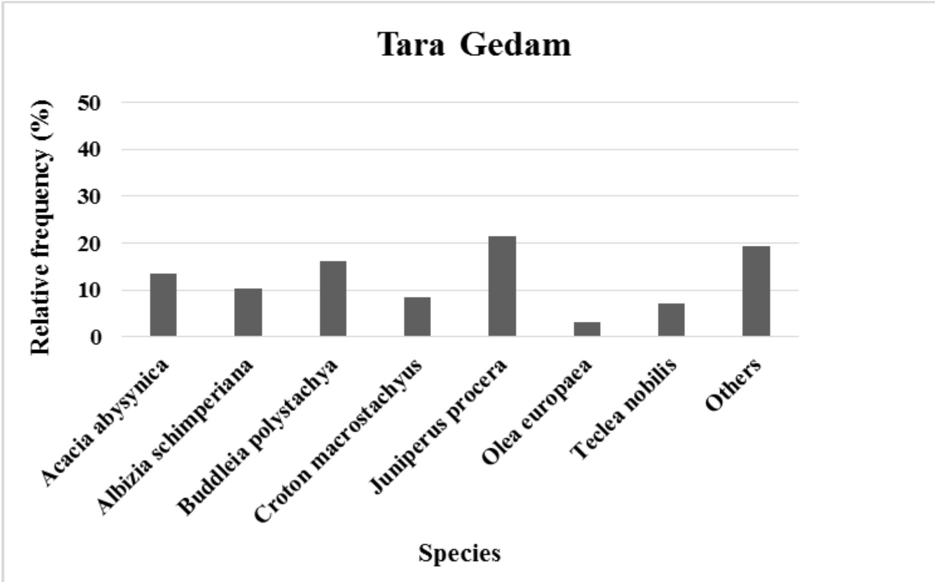

Figure 12 Share of the more frequent tree or shrub species (DBH≥10cm) at Tara Gedam study site.

Figure 13 Picture of Tara Gedam monastery forest during data collection at the peak of the site 2014.

4.2. Tree Data

The data for this study comes from a forest inventory, which was established at the four study sites. It was conducted for the purpose of form factor development. Diameter at breast height and height was measured for a total of 20 species with a replication of 20, five most frequent and main trees in each site (400 trees). The DBH range of each species is fulfilled for the requirement of intended equations of (Brown et al. 1997) and (Chave et al., 2005) which needs 5-148cmand 5-156cm DBH ranges respectively for better estimation of AGB. Therefore the DBH range of each species fit within the equation's DBH range requirements. In addition to the allometric equations the over bark volume, which was also calculated from this data using developed form factor values for these species, will be converted to above ground biomass through biomass expansion factors (BEFs). The two biomass estimation methods will be compared. This data assists in analyzing the estimation accuracy differences of each allometeric equation to the observed values biomass values. DBH of each species was measured using a centimeter graduated caliper at breast height from the ground. Whereas total tree height was measured with meter tape by climbing to the trees through ladder

Table 3 DBH and height of 20 different tree species used in this study. Figures show mean, standard deviation (SD), minimum (min) and maximum (max) of each species.

Species	Parameter	Number of trees	Arithmetic mean	SD	Min	Max
Acacia abyssinica	DBH	20	31.9	10.0	20.0	55.0
	H	20	11.9	2.5	9.3	20.0
Albizia shimperina	DBH	20	19.1	3.1	15.0	28.0
	H	20	10.1	0.8	8.2	11.5
Croton macrostachyus	DBH	20	18.7	5.3	11.0	28.0
	H	20	10.1	2.2	6.0	15.5
Juniperes procera	DBH	20	30.7	6.1	16.0	39.0
	H	20	12.9	1.8	9.8	16.5
Olea europea	DBH	20	25.8	5.2	15.0	33.0
	H	20	8.1	1.5	4.0	10.2
Albizia gummifera	DBH	20	20.2	6.5	10.0	36.0
	H	20	11.0	1.8	8.5	14.9
Podocarpus falcatus	DBH	20	20.8	4.7	12.0	27.0
	H	20	13.1	1.6	9.9	16.1
	DBH	20	21.6	11.1	8.7	44.0

Teclea nobilis	H	20	9.6	1.5	7.7	14.4
	DBH	20	16.5	2.8	13.0	24.0
Buddleia polystachya	H	20	8.8	1.4	5.7	11.3
	DBH	20	46.6	11.7	32.0	79.0
Chionanthus mildbraedii	H	20	14.8	3.8	7.8	21.3
	DBH	20	18.3	4.5	11.5	28.5
kenebela	H	20	9.5	1.0	8.0	11.3
	DBH	20	20.4	5.1	13.4	33.8
bugtsi	H	20	10.9	1.6	8.0	14.0
	DBH	20	25.7	5.8	17.0	37.0
gimblitini	H	20	10.9	1.6	8.0	13.0
	DBH	20	35.8	15.5	14.0	73.0
Prunus africana	H	20	16.6	3.7	10.7	22.7
	DBH	20	9.6	11.9	13.3	54.5
Allophylus abyssinicus	H	20	14.4	3.3	9.8	19.9
	DBH	20	19.2	3.8	14.4	27.6
forha	H	20	9.4	1.3	7.2	11.6
	DBH	20	22.8	4.6	17.1	35.0
Boswellia papyrifera	H	20	9.1	1.1	7.3	11.0
	DBH	20	18.2	4.2	13.5	29.0
Ameja	H	20	8.3	1.3	6.1	10.5
	DBH	20	26.8	2.7	22.6	30.6
Sterculea setigera	H	20	8.3	0.8	6.6	10.1
	DBH	20	18.8	3.9	12.0	30.0
Fola	H	20	7.6	1.8	4.7	11.8

5. Methods

5.1. Site selection

For this study the above stated four sites (Injibara, Mahibere Selassie, Gelawudewose, Tara Gedam) were selected, based on their representativeness of the three agro ecologies of the Amhara region (Lowland, Midland and Highland). Thus according to their altitude Gelawudewose represents the highlands, Injibara and Tara Gedam represents the mid lands and Metema/Mahibere Selassie the lowlands. During site selection the available natural forest cover has been also taken into account. Surveys have been conducted to select these study sites and to collect some basic information this was completed by the BOKU university instructors from different disciplines and Ethiopian PhD students of Carbon part project.

5.2. Sampling design, plot allocation and measurements

In this study two above ground biomass estimation methods were employed for the above stated four forest sites of Amhara region. (i) The first method was applying a biomass equation by selecting one from the list of reviewed biomass equations (see Table 1). From these available and reviewed equations six most recommended biomass equations that were developed by Chave (2005) for all types of tropical forests (dry, moist and wet) and irrespective of species difference were chosen. (ii) The second method was the biomass conversion and expansion factors suggested by IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC, 2003) to convert and expand the over bark volume which is found from inventory data to above ground biomass.

Fixed area plot was employed and the plots were allocated with grid distance in all of the four sites. During field data collection each plot was searched using GPS and then the center of a plot was established by the use of wooden stick. After the establishment of the sample plot, trees were given numbers with a piece of chalk by starting from the nearest tree to the center within the radius of the plot circle, so that we can find them again during DBH and H measurement. Though these plots were allocated in all forest sites, the distance between plots in each site and the area of a plot in some sites were different due to the variability in disturbance level of forests and in order to achieve the minimum number of trees per plot and number of plots per site. Therefore, accordingly the distance between plots used for natural forest data collection was

150m in Gelawudewose, 300m in Injibara, 3km in Mahibere Selassie and 250m in Tara Gedam, Likewise the size of the sample plots were 314.16 m^2 for Gelawudewose and Tara Gedam whereas and for Mahibere Selassie and Injibara they were 706.86m^2.

Similar type of data was collected at each sample plot and forest site; in the plots all trees with diameter at breast height or at 1.3m from the ground (DBH ≥10 cm) DBH was measured by caliper and or meter tape for larger trees and height of a median tree (H) by DBH per species was measured using Blume-Leiss.

DBH height relationship and form factor equations for 20 main tree species for the region and others species together were developed by Tesfaye (2015). Then each trees above ground biomass was calculated using the two methods (one selected biomass equation and biomass expansion factor). The biomass expansion factor and wood densities values were found from literature and they are 3.40 and 0.58 ton/m^3 respectively. These average values of wood density and biomass expansion factors are recommended for any African and broad leafe tree species in areas where species specific values are not available (Brown et al., 1997).

A decision on the number of sample plots and allocating them for each study site forests was done based one the google earth pictures. Thus collecting the data was planned on a total of 169 number of fixed area sample plots with 19836.014 ha total area of natural forest in all study sites. Whereas during fieldwork among these total number of plots 24 of them are located either on farmlands or highways where forests are not available, so due to these vacant spaces, the total number of plots decreases to 145. Likewise the total natural forest area decreases to 18775.187 ha. The data was collected with the following sampling design.

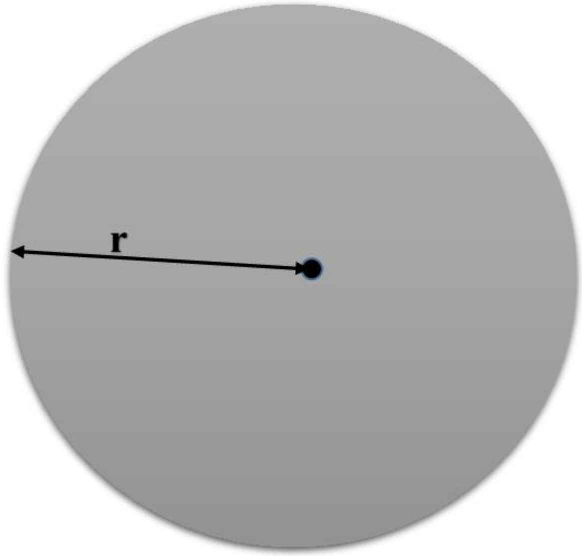

Figure 14 Diagrammatic illustration of sampling design for above ground biomass estimation data collection at each forest site, where r is the radius of sample plot.

5.3.Model selection for AGB calculation

The two above ground biomass estimation methods that were engaged to estimate Amhara region natural forest are employed as follows.

In order to compute AGB of these forest sites methods and/models that can estimate accurately should be chosen. The first method that is used widely throughout the world is Allometric equations. Previously single and or multi-species allometric equations were not developed for Ethiopian tress and or forest types except *Eucalyptus globulus, Eucalyptus camadulensis, Euclea shimperi, Otostegia integrifolia, Grewia bicolor* and *Dichrostachys cinerea tree species.*(Henry et al., 2011). Reviewing and testing developed multi-species allometric equations for broader ecological zones (Wet, Dry and Moist) and forest types (tropics and sub-Saharan Africa) was extremely important. As a result, review of published allometric equations for tropical region trees that could estimate biomass irrespective of species and site was conducted. So these types of different candidate allometric equations were collected for further testing (Table1). Whereas among these several reviewed candidate allometric equations, those which are recommended mostly by different studies and are well known in their high estimation of accuracy (low estimation error) were tested to choose the best one. Therefore the following six equations of (Chave et al., 2005) are nominated and tested to undergo a further selection process. These biomass equations were chosen based on the recommendation of studies conducted in Cameron ((Djomo et al., 2010). Where they were compared with general equations that were developed for the site and showed a better estimate of biomass.

$$Y= \exp\{-2.801+2.115*\ln(D) +0.78\ln(H) +0.809*\ln(\rho)\} \quad (A)$$

$$Y=\exp\{-2.922+0.99*\ln(D^2H\rho)\} \quad (B)$$

$$Y=\exp\{-2.994+\ln(D^2H\rho)\} \quad (C)$$

$$Y=\exp\{-1.602+2.266*\ln(D) +0.136*(\ln(D))^2-0.0206*(\ln(D))^3+0.809*\ln(\rho)\} \quad (D)$$

$$Y=\exp\{-1.589+2.284*\ln(D) +0.129*(\ln(D))^2-0.0197*(\ln(D))^3+\ln(\rho)\} \quad (E)$$

$$Y=\exp\{-1.667+2.51*\ln(D) +\ln(\rho)\} \quad (F)$$

Therefore from these six allometric equations one was selected based on the behavior of the graph it exhibited and the equation parameters it has. The second method that has been used to estimate AGB was biomass expansion factor (BEF). Utilizing the suggestion of the IPCC Good Practice Guidance for Land Use and Land-Use Change and Forestry biomass expansion factor value (3.40), the African trees average wood density values (0.58 ton/m^3) (Brown et al., 1997) and the over bark volume which is computed from our inventory data, the total above ground biomass was calculated (including stem, branches and leaves) (IPCC, 2003). Since Ethiopian species-specific wood density and biomass expansion factor values were not available these default recommended values were chosen from literature.

Therefore estimation of biomass was conducted for the following main tree species in each site

Table 4 List of main tree species at each study site

Study site	Gelawudewose	Injibara	Metema	Tara Gedam
Tree species	*Albizia gummifera* *Buddleia polystachya*	*Acacia abyssinica* *Albiza gummifera*	*Fola,* *Sterculea setigera,*	*Acacia abyssinica* *Albizia shimperina*

Croton macrostachyus	*Allophylus abyssinicus*	*Ameja*	*Buddleia polystachya*
Chionanthus mildbradii	*Bugtsi*	*Boswellia papyrifera*	*Croton macrostachyus*
Podocarpus falcatus	*Croton macrostachyus*	*Sterculea setigera*	*Juniperes procera*
Teclea nobilis	*Gimbltini*	*Forha*	*Olea europea*
Others	*Kenebela*	*Fola*	*Teclea nobilis*
	Prunus africana	*Others*	*Others*
	Others		

5.4. Above Ground Biomass (AGB) estimation

Therefore using the above stated methods and their corresponding equations above ground biomass of Amhara National Regional State (ANRS) natural forest was estimated. Then above ground biomass was calculated with the following procedure using both the selected allometric equation and VBEF methods.

1. Calculating above ground biomass of each tree with DBH ≥ 10cm of all study sites using the two estimation methods (AGB/kg) and converting to AGB/ton.
2. Computing the representative above ground biomass of each tree species by multiplying blowing factor of each study sites. Blooming factor of each site was computed as 10000/area of a sample plot of a site.
3. Summing up each representative tree AGB (ton) within a plot to get above ground biomass per plot in hectare basis of each site
4. Then, in a location where there was no tree, a 0 was set to this spot, this was done for the rest of the plots and then the site parameters were calculated: AGB (ton/ha) sum, average, standard deviation, standard error, coefficient of variance (%),and Confidence interval (95%) per species and plot were done for both methods.
5. Observing the trend of the graph of each main tree species in each site DBH (cm) against and AGB (ton) with both methods, comparing the two methods both by the individual tree

AGB/ton/ha within a study site and by total AGB/ton/ha of the site was done with R Statistical package version 3.1.0 and Microsoft excel 2013.

6. The average and total above ground biomass (ton/ha) of the four sites and Amhara region natural forest was calculated.

5.5. Carbon estimation

1. From the computed above ground biomass above in step 4 above ground carbon stock was calculated by multiplying each AGB values by 0.5. Carbon is 50% of the oven dried biomass (Petrokofsky et al., 2012; West, 2009).
2. Comparison of each study site by carbon (ton/ha) was conducted using boxplots.
3. Eventually average above ground biomass and carbon stock (ton/ha) that has been held by the natural forest was quantified from the two methods.

6. Analysis and Results

In this part of the study the biomass and carbon quantified from the two estimation methods are presented. In the first part the process of selecting one equation from the recommended nominated six allometeric equations of Chave (2005) and BEF were selected are shown. In the second part these selected methods (equations) were applied to estimate above ground biomass and trend of the graphs (AGB (ton) versus DBH (cm)) of each equation for every main tree species was plotted. The table of the calculated above ground biomass per plot and per species with plot sum, mean, standard deviation, standard error, coefficient of variance (%) and confident interval (α=0.05) of each site has been presented in this part. In the third part comparison between the two biomass estimating methods was done based on each species and site above ground biomass contribution including a summary table. In the fourth part of this chapter the converted above ground biomass into carbon from the two methods was presented both in the table and boxplots.

6.1. Equation selection

Above ground biomass of each individual tree was calculated (using the six biomass equations and biomass expansion factor methods) and plotted against the DBH (cm) and height (m), Figure 10 and 11 respectively. The numbers showed that both of the methods were applied for 20 main tree, the exhibited results that were similar with each other until the DBH and height reaches 40 cm and 10 m respectively. The deviation between the results of each method got higher with an increasing DBH or height except for BE B and C. The spread was much higher for the equation that used biomass expansion factors (VBEF) than any other six biomass equations and relatively in biomass equations (A, B and C,) there is higher spread than for (D, E and F) equations (see figure 10). The VBEF equation has shown much higher results than any of the six biomass equations, whereas the results of D, E and biomass equations overlapped over the whole DBH range.

Furthermore Figure 10 shows that, if the DBH was 65 cm or more only three of biomass equations (A, B and C) had shown the estimation of above ground biomass, but equation A has bigger results than B and C in higher DBH ranges. For a tree with 70-80cm DBH ranges the results of A, B and C biomass equations ranged between 3200 to 4200 kg above ground biomass.

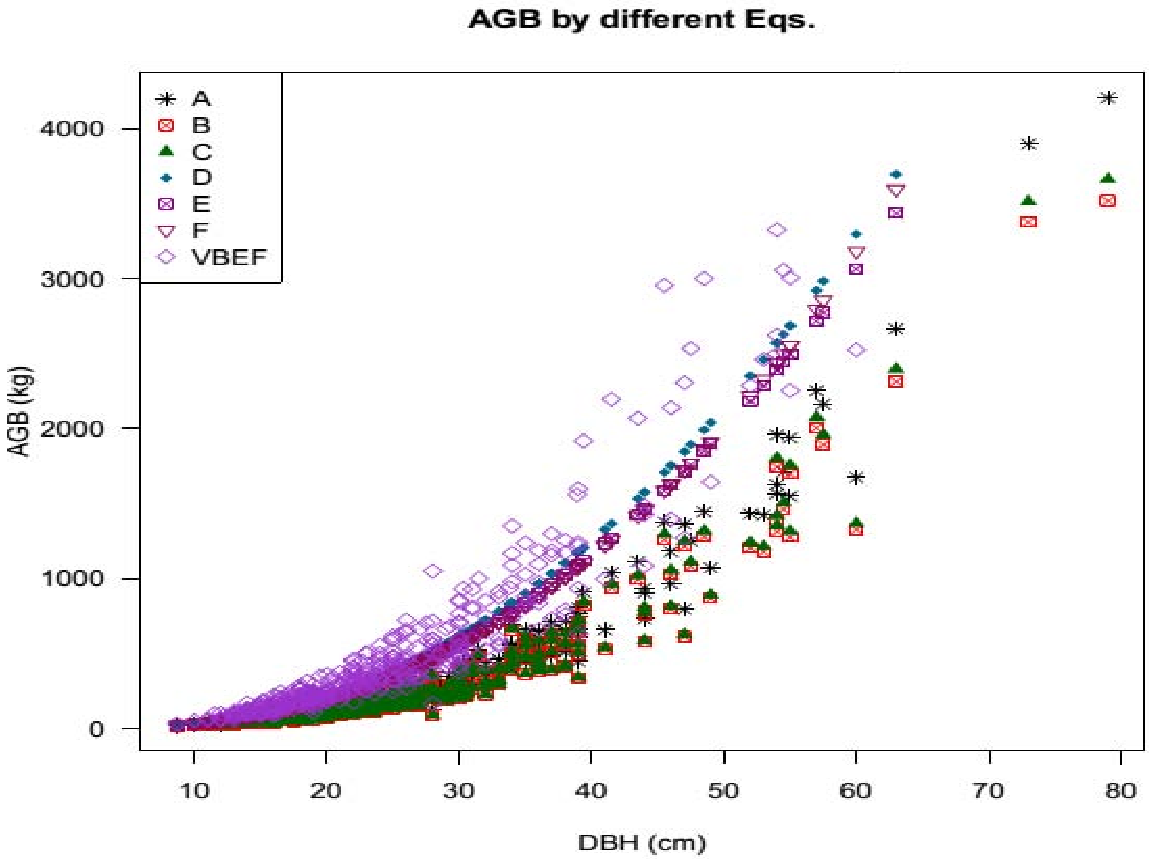

Figure 15 Above ground biomass estimation for the standardized 20 main tree species data set using six different allometric equations (A, B, C, D, E and F) and Biomass expansion factors (VBEF) against diameter at breast height (DBH).

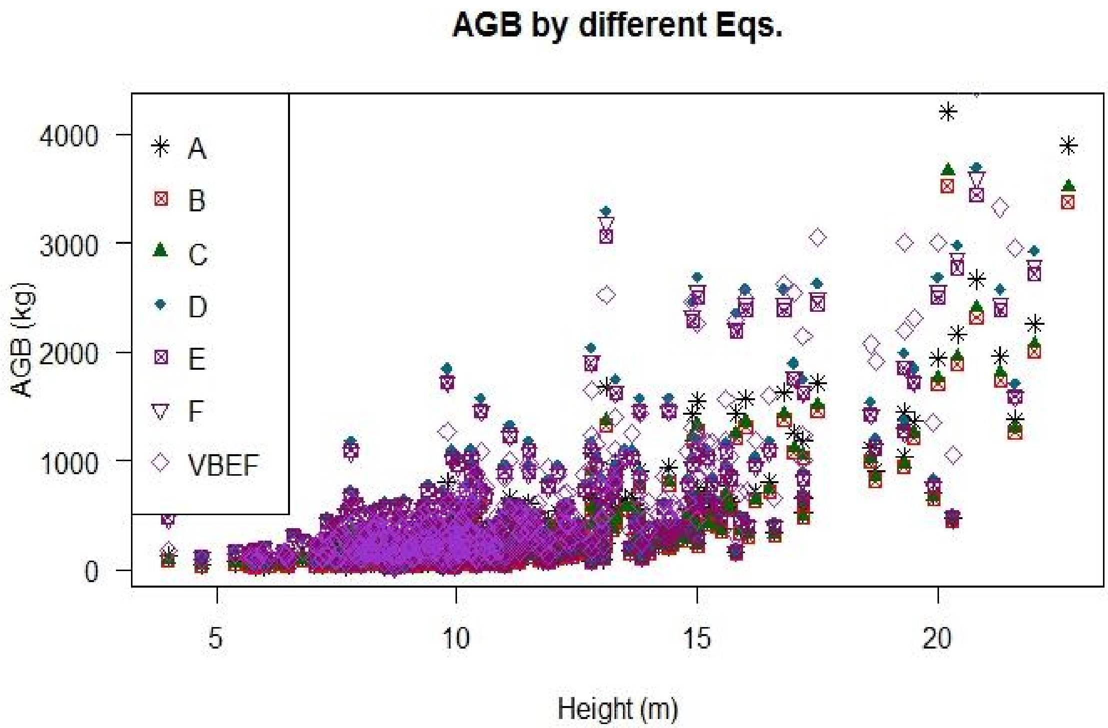

Figure 16 Above ground biomass estimation for the standardized 20 main tree species data set using six different allometric equations (A, B, C, D, E and F) and Biomass expansion factors (VBEF) against height (m).

Thus from the six biomass equations B was selected for the reason that it integrates DBH and height and can estimate for higher DBH ranges**.** In addition to biomass equation B, VBEF was also decided to be used for the whole sites above ground biomass estimation of Amhara region natural forest**.**

6.2. Application of the selected equations

The biomass equation B and VBEF were selected for calculation of the above ground biomass of all study sites (Gelawudewose, Injibara, Metema and Tara Gedam). So the trend of the graph showing above ground biomass against DBH for each main tree species were plotted in the Figures below from 12 to 16 using two methods.

As it is possible to observe the trend of graphs of each tree species of Gelawudewose by the two methods Figure 12, there is little deviation between biomass equation B and VBEF until the

DBH of tree reaches 20 cm almost for all trees. Whereas when the DBH is range 20 cm DBH for each tree species, there is a much bigger deviation between the two methods. Generally higher above ground biomass results were estimated for each tree species by the equation VBEF than biomass equation B, which uses a biomass expansion factor and wood density to convert volume of a tree to biomass. So at higher DBH ranges the there is always much bigger biomass with equation VBEF.

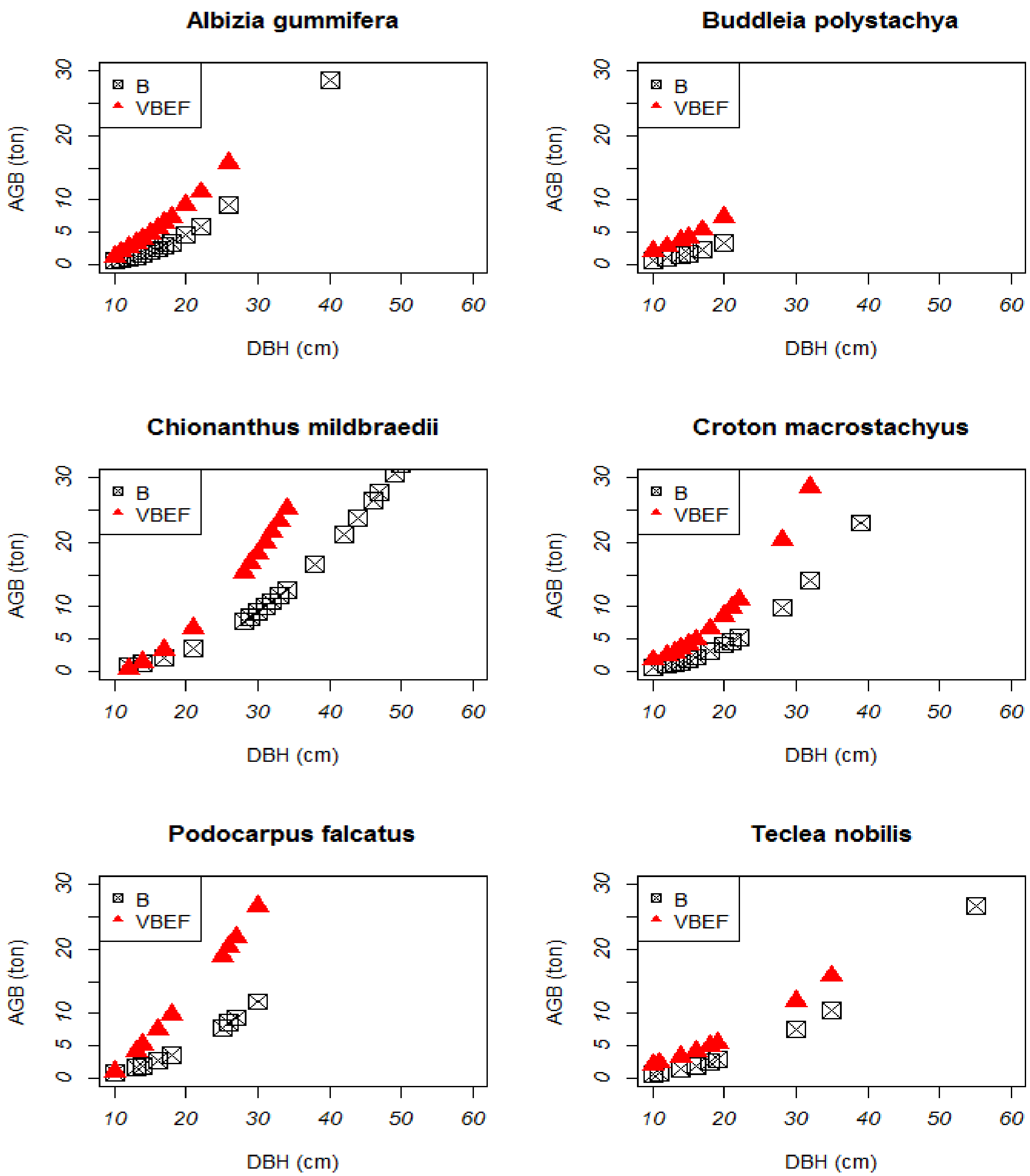

Figure 17 Gelawudewose main tree species group above ground biomass against diameter at breast height (DBH) in ton.

In Injibara main tree species in Figure 13 below the same trends of above ground biomass against DBH graph was seen as that of Gelawudewose except for *Albizia gummifera* tree species which has a much narrower deviation between the two methods even at higher DBH ranges which is a very exceptional case.

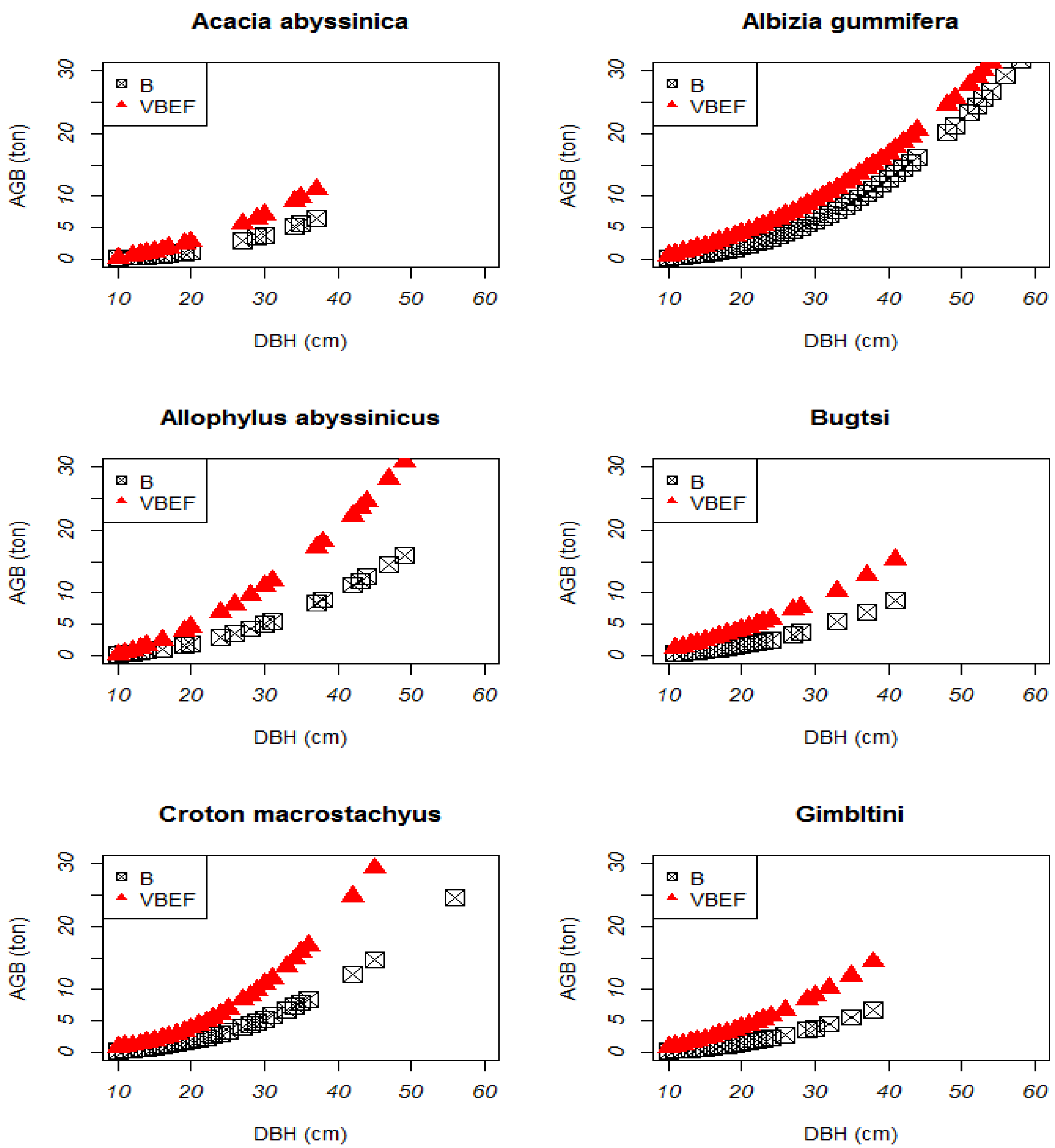

Figure 18 Injibara main tree species group above ground biomass against diameter at breast height (DBH) in ton

Here in Metema with the main tree species the usual trend of above ground biomass against DBH graphs are seen (insignificant deviation of the two methods until DBH≤ 20cm). Nonetheless in some tree species *Boswellia papyrifera* and some other species, the deviation between the two methods was narrower for longer, up until the DBH reached 25 cm.

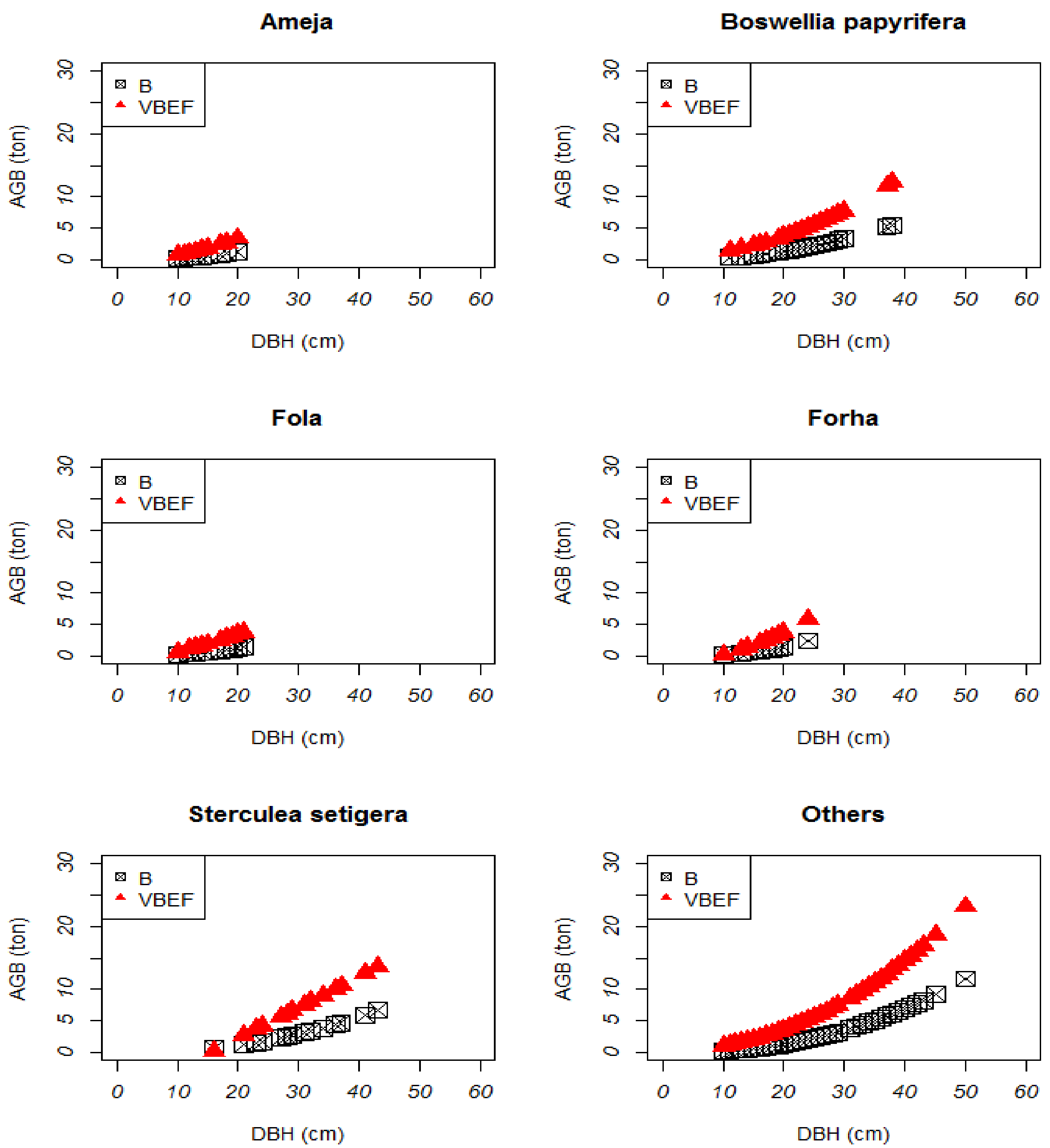

Figure 19 Metema/ Mahibere Selassie main tree species group above ground biomass against diameter at breast height (DBH) in ton.

In Figure 15 Tara Gedam main tree species showed the majority of tree species have narrow deviation between the two methods until the DBH reaches 20cm as majority of tree species in other sites had exhibited. Whereas in *Juniperus procera* there is a very high deviation of the two methods starting from the very small DBH range (≥10 cm) and much bigger deviation as DBH increases was observed. In addition *Albizia schimperiana* tree species had relatively little deviation even at higher DBH ranges (≥ 20cm).

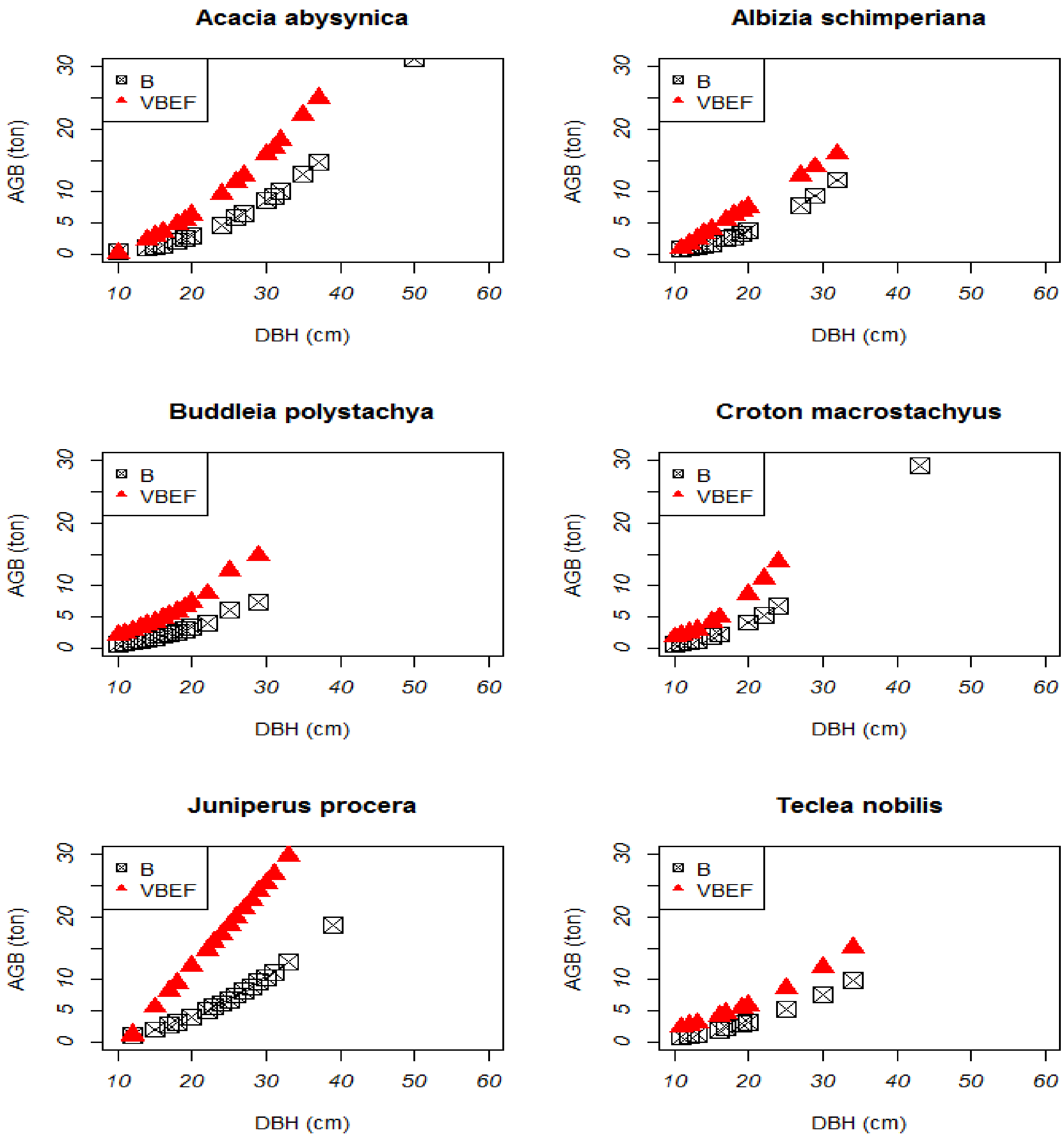

Figure 20 Tara Gedam monastery forest main tree species group above ground biomass against diameter at breast height (DBH) in ton.

In Figure 16 *Prunus africana*, Injibara other and Tara Gedam other tree species showed relatively larger deviation between the two methods, more than 20 cm DBH ranges.

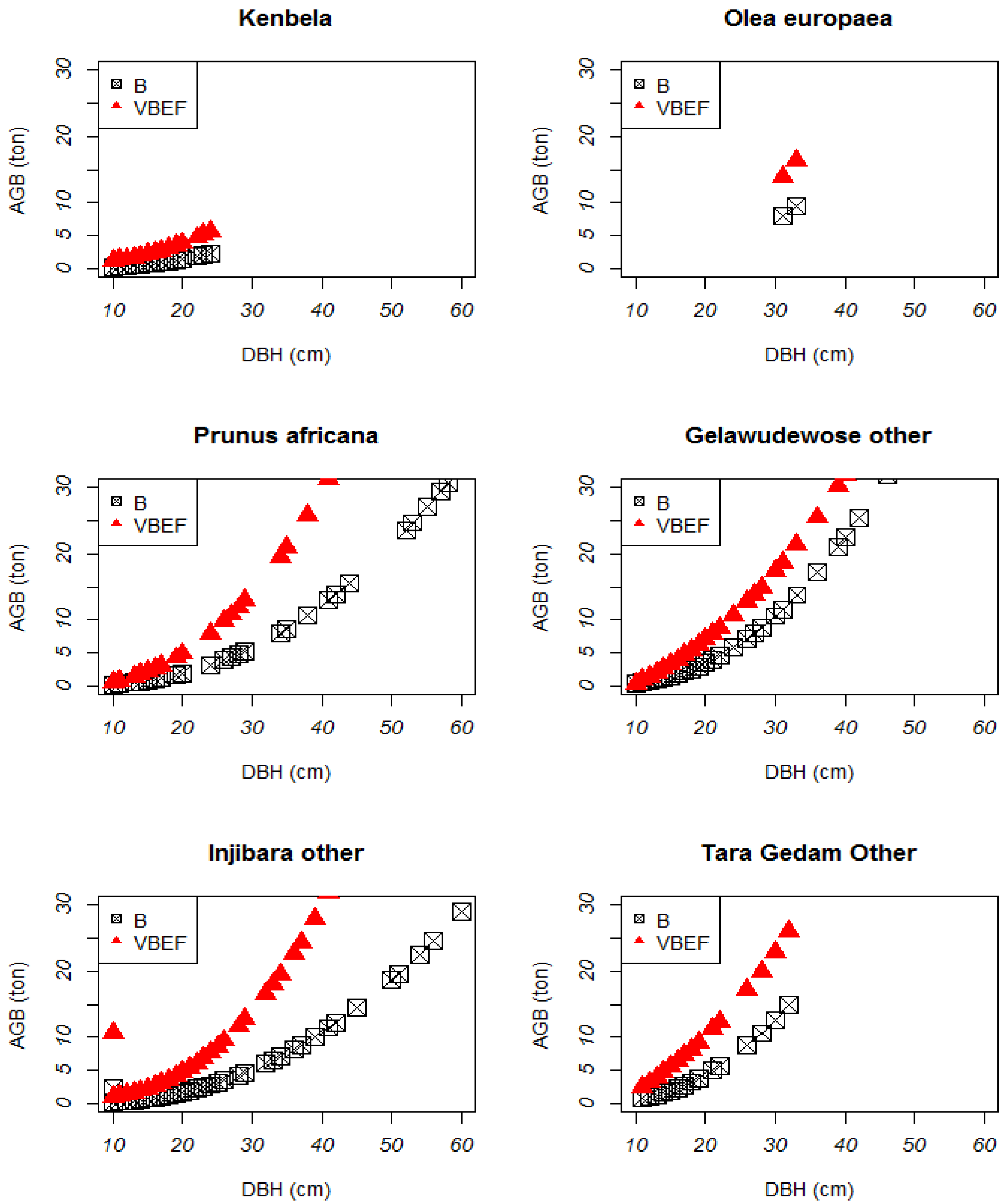

Figure 21 Main tree species group and other species from Gelawudewose, Injibara and Tara Gedam study sites above ground biomass against diameter at breast height (DBH) in ton.

Applying the two methods calculation of above ground biomass of each tree species per each site in a plot was done. Thus the tables in the appendix were calculated using the two methods with the following four steps (see in the appendix from Table B1 to VBEF4).

1st Estimating above ground biomass of each tree species (kg).

2nd Converting above ground biomass in kg to tone and multiplying it by its site specific representative number of tress (blooming factor) in order to get each tree representative above ground biomass (ton).

3rd Then the individual tree values in step 2 of each tree species in the same plot are summed up. If the tree does not appear in plots where other trees are found its value will be 0.

4th Eventually calculation of mean, standard deviation, standard error, coefficient of variance (%) and confident interval (95%) of each plot were done for both approaches. These parameters were calculated to see how the central tendency and dispersion of our data look likes.

Therefore tables from B1 to VBEF4 in the appendix were constructed based on these four procedures in both of biomass calculation methods. The first four tables of each sites (Gelawudewose, Injibara, Metema and Tara Gedam) in the tables (from table B1 to B4) in the appendix were computed using biomass equation B. whereas the next four tables (from table VBEF1 to VBEF4) of these sites again were calculated using VBEF.

Above ground biomass (ton/ha) of each study site main tree species per plot using biomass equation B in the appendix (from Table B1 to B4).

Gelawudewose (see Table B1 in the appendix)

The results of Gelawudewose study site using biomass equation B was done for the main tree species group in the site. And the figures in the table the above ground biomass (ton/ha) of each tree species per each plot. From this table we can understand that specie categorized as other species of the site showed a bigger total and mean above ground biomass (ton/ha) and standard deviation but lowest coefficient of variance (%). Whereas species *Buddleia polystachya* has shown a very small total and mean above ground biomass (ton/ha) and standard deviation but higher coefficient of variance (%) in the site. Likewise plot number 18 has shown a very small total and mean above ground biomass (ton/ha), standard deviation, standard error and confident interval rather plot number 18 has much bigger total and mean above ground biomass, standard deviation, standard error and confident interval. In coefficient of variance (%) parameter plot 3 was the least while plot numbers 8, 9, 17, 19, 28 and 32 showed relatively much bigger coefficient of variance (%) than other plots.

Injibara (see Table B2 in the appendix)

In this study site the following tree species and plots showed highest and lowest results *Albizia gummifera* has showed maximum total and mean above ground biomass (ton/ha) and standard deviation. *Acacia abyssinica* showed smallest total and mean above ground biomass (ton/ha). Kenbela tree species showed lowest standard deviation. Tree species *Albizia gummifera* and Bugtsi showed the smallest and the highest coefficient of variance (%) respectively. Similarly plot number 38 has shown a smallest total and mean above ground biomass (ton/ha), standard deviation standard error and confidence interval (95%). While plot number 53 showed a highest mean and total above ground biomass (ton/ha), standard deviation, standard error and confident interval (95%). Plot numbers 6, 38, 44 and 45 shown an equal but the highest coefficient of variance (%) but plot number 31 was the smallest in coefficient of variance (%).

Metema (see Table B2 in the appendix)

In this study site tree species *Ameja* shown the smallest total and mean above ground biomass (ton/ha) and standar5d error but species categorized in other species has showed a maximum total and mean above ground biomass (ton/ha) and standard deviation. Tree species *Forha* and others showed the maximum and the minimum coefficient of variance (%). Plot number 1 and 17 showed the maximum and the minimum total and mean above ground biomass (ton/ha), standard deviation, standard error coefficient of variance (%) and confident interval (95%).

Tara Gedam (see Table B3 in the appendix)

In this study site tree species *Olea europea, Albizia schimperiana and Buddleia polystachya* showed the minimum species total and mean above ground biomass (ton/ha), standard deviation and coefficient of variance (%). While species categorized as others showed the maximum total and mean above ground biomass (ton/ha), standard deviation and coefficient of variance (%).

Unlike other study sites about 9 plots (7,13, 17, 21, 28, 40 ,47, 50 and 51) provided null/zero, since these plots are inside the forest and they were occupied with trees and shrub species with DBH <10 cm. As a result these values add great effect on the plot minimum, mean, above ground biomass, standard deviation, standard error, coefficient of variance and confident intervals. By excluding these null plots the following minimum values of plots are detected from the calculated biomass and are shown in the table. Thus plot numbers 3 and 11 showed the minimum total and mean above ground biomass (ton/ha), standard deviation, standard error and confident interval (95%). While plot number 29 has shown the maximum total and mean above ground biomass (ton/ha), standard deviation, standard error and confident interval (95%). Plot 36 and 12 showed the minimum and the maximum coefficient of variance (%) respectively.

Above ground biomass (ton/ha) of main tree species per plot of each study site using biomass expansion factors VBEF shown in the table VBEF1 to VBEF4 in the appendix.

Gelawudewose (see Table VBEF1 in the appendix)

With this equation this study site has shown the minimum and maximum species and plots. *Buddleia polystachya* tree species has shown the minimum total and mean above ground biomass (ton/ha) and standard deviation. Whereas *Chionanthus mildbraedii* tree species has shown the maximum total and mean above ground biomass (ton/ha) and standard deviation. Species categorized as others and *Buddleia polystachya* showed the minimum and maximum coefficient of variance (%) in the site respectively. Plot number 18 and 12 showed the minimum and the maximum total and mean above ground biomass (ton/ha) and standard deviation, standard error and confidence interval (95%). In this study site plot number 3 and 8 showed the minimum and the maximum coefficient of variance (%) respectively.

Injibara (see Table VBEF2 in the appendix)

Using this equation (VBEF) Injibara study site has the following maximum and minimum tree species and plots. *Acacia abyssinica* tree species has showed the minimum total and mean above ground biomass (tone/ha) and standard deviation. While tree species categorized as others showed the maximum total and mean above ground biomass (ton/ha) and standard deviation. Trees species *Albizia gummifera and Bbugtsi* showed the minimum and the maximum coefficient of variance (%) respectively. Plot number 44 and 53 showed the minimum and the maximum total and mean above ground biomass (ton/ha), standard deviation, standard error and confident interval (95%). But plot number 56 and 6 showed the minimum and maximum coefficient of variance (%).

Metema (see Table VBEF3 in the appendix)

Ameja tree species showed the minimum total and mean above ground biomass (ton/ha) and standard deviation. While tree species categorized as others showed the maximum total and mean above ground biomass (ton/ha) and standard deviation. Species categorized as others and *Sterculea setigera* showed the minimum and maximum coefficient of variance (%) respectively. Whereas plot number 11 and 17 showed the minimum and the maximum total above ground biomass (ton/ha), standard deviation, standard error and confident interval (95%). Plot number 5 and 12 showed the minimum and maximum coefficient of variance (%) respectively. Plot number 11 and 8 showed the minimum and maximum mean above ground biomass (ton/ha) respectively.

Tara Gedam (see Table VBEF4 in the appendix)

With this method the study site has showed the following results. Tree species *Teclea nobilis* and those species categorized as others showed the minimum and the maximum total and mean above ground biomass (ton/ha). Tree species *Albizia schimperiana* has showed the minimum standard deviation and standard error. But *Teclea nobilis andspecies* categorized as others showed the maximum standard deviation and standard error. By excluding null plots as the previous plot 3and 11 showed an equal minimum total and mean above ground biomass (ton/ha), standard deviation, standard error, and confidence interval (95%) ,on the other hand plot number 29 showed maximum. Plot number 1,3, 5,11,12,15,16,23,26,32 and 41 showed the maximum and an equal coefficient of variance (%) . while plot 222 has the minimum coefficient of variance (%).

6.3.Comparison of results

A comparison of biomass equation B with biomass expansion factor VBEF was conducted based on each main tree species above ground biomass contribution (within a site) and the site average above ground biomass (ton/ha) between sites. For each main tree species of the four study sites above ground biomass was calculated by summing up each plot data (see tables B1 to VBEF4 in the appendix) using the two approaches. Whereas the average above ground biomass of each study site (see table 15) was computed by dividing sum of plot data to the total number of plots in the site.

B= Y=exp {-2.922+0.99*ln ($D^2H\rho$)} and VBEF= V*p*BEF

Gelawudewose

The box plot in Figures 17 showed that from 7 main tree species of the site 3 species have a very huge amount of above ground biomass. This result is totally incomparable with the rest of tree species in both methods. When the two biomass estimation methods (biomass Equation B and VBEF) were compared there was a great difference in biomass estimation. Almost all VBEF estimated trees had a greater biomass than biomass equation B. *Podocarpus falcatus* was dominant in biomass equation B whereas in equation VBEF *Chionanthus mildbraedii* was the dominant tree species.

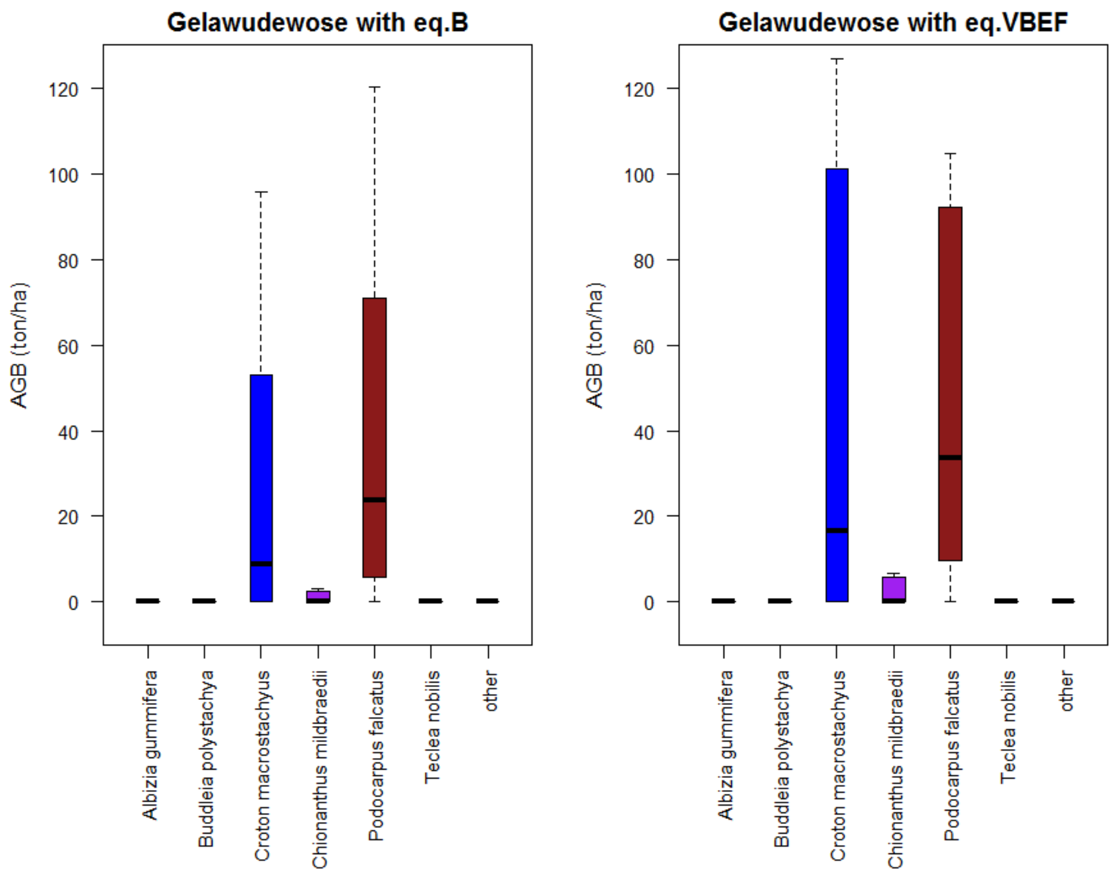

Figure 22 Comparison of the two estimation methods based on main tree species AGB (ton/ha) contribution of Gelawudewose

Injibara

In Figure 18 bellow Injibara forest has a bit higher number of main tree species than any of the forest sites due to the common species found in other sites. From 9 main tree species 6 of them dominated by their biomass in both methods. As the graphs showed there was over estimation of equation VBEF than biomass equation B or the other way round in all of tree species of the site. The same dominant tree species *Albizia gummifera* was seen in both methods.

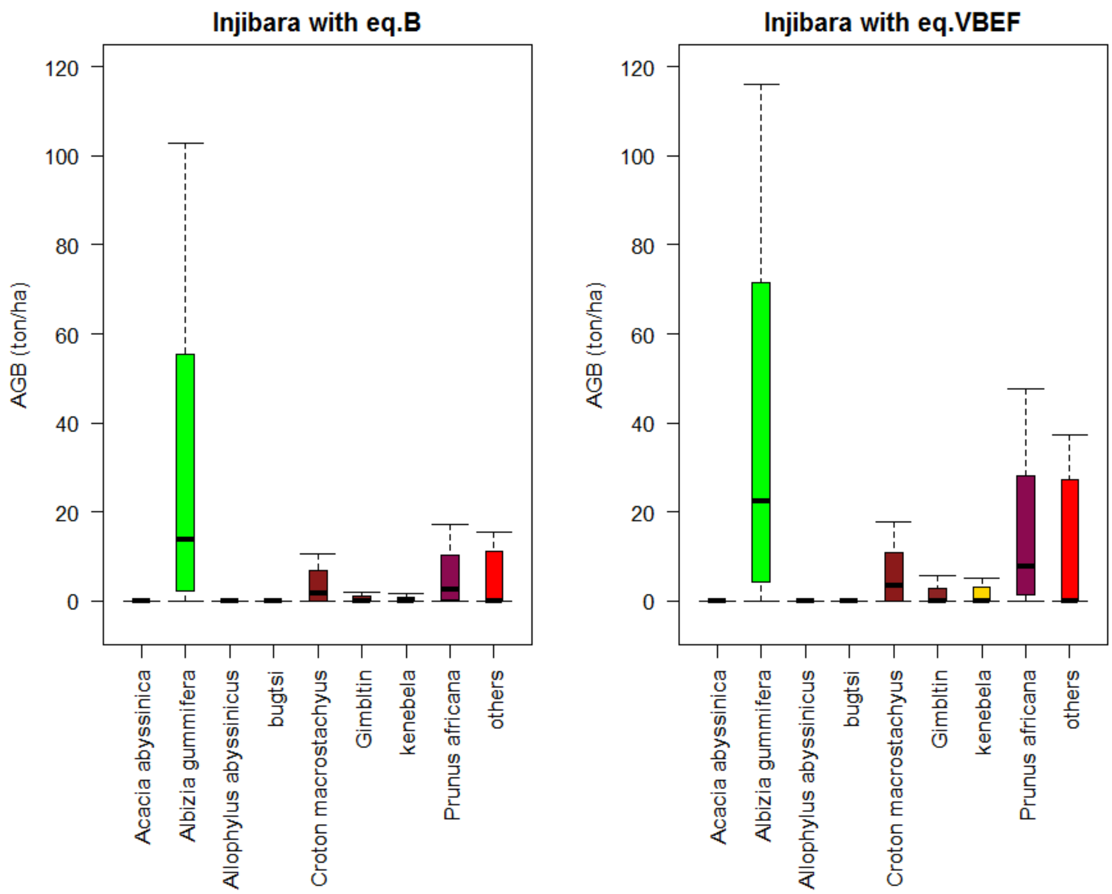

Figure 23 Comparison of the two estimation methods based on main tree species AGB (ton/ha) contribution of Injibara

Metema

This study site has much bigger area and vegetation type in the study site was somehow similar than other forest sites in this study. But the number of tree per hectare was much lower than the rest of the study site forests. Unlike other study sites tree species available in this study site were not found in other forests sites as the agro-ecology of the site was quite different (lowland area). In the figure using the two biomass estimation methods the biomass of each tree species was not that much different (exhibited almost similar trend in AGB). But in relative cases the tree species Forha was dominant in the site for both methods.

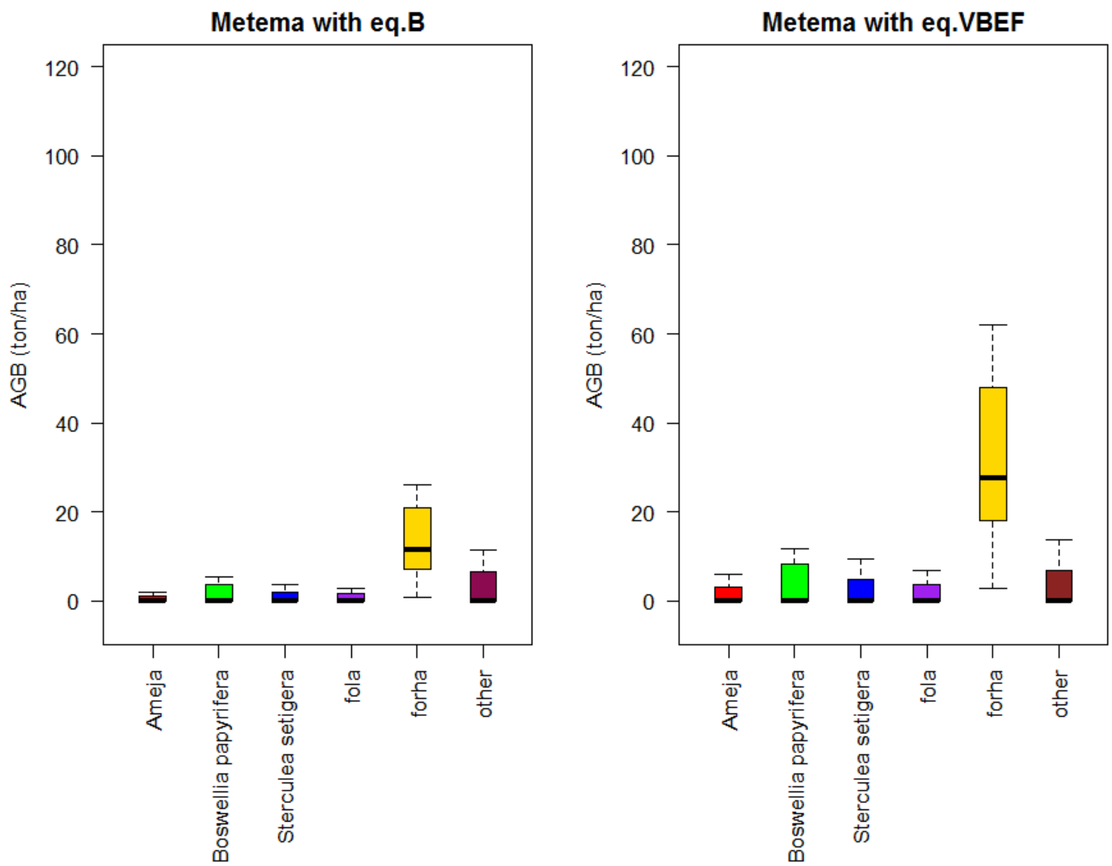

Figure 24 Comparison of the two estimation methods based on main tree species AGB (ton/ha) contribution of Metema/Mahiber Selassie.

Tara Gedam

As shown in Figure 20 the main tree species found in this particular site provided very small amount of above ground biomass. The main reason that makes them very small in the box plot as was that 9 plots with trees or shrub species ≤ 10 cm DBH were given null values. One of the parameters that the box plots require is the median and thus in this case the value was zero. So only *Buddleia polystachya* showed a bit higher aboveground biomass in both methods.

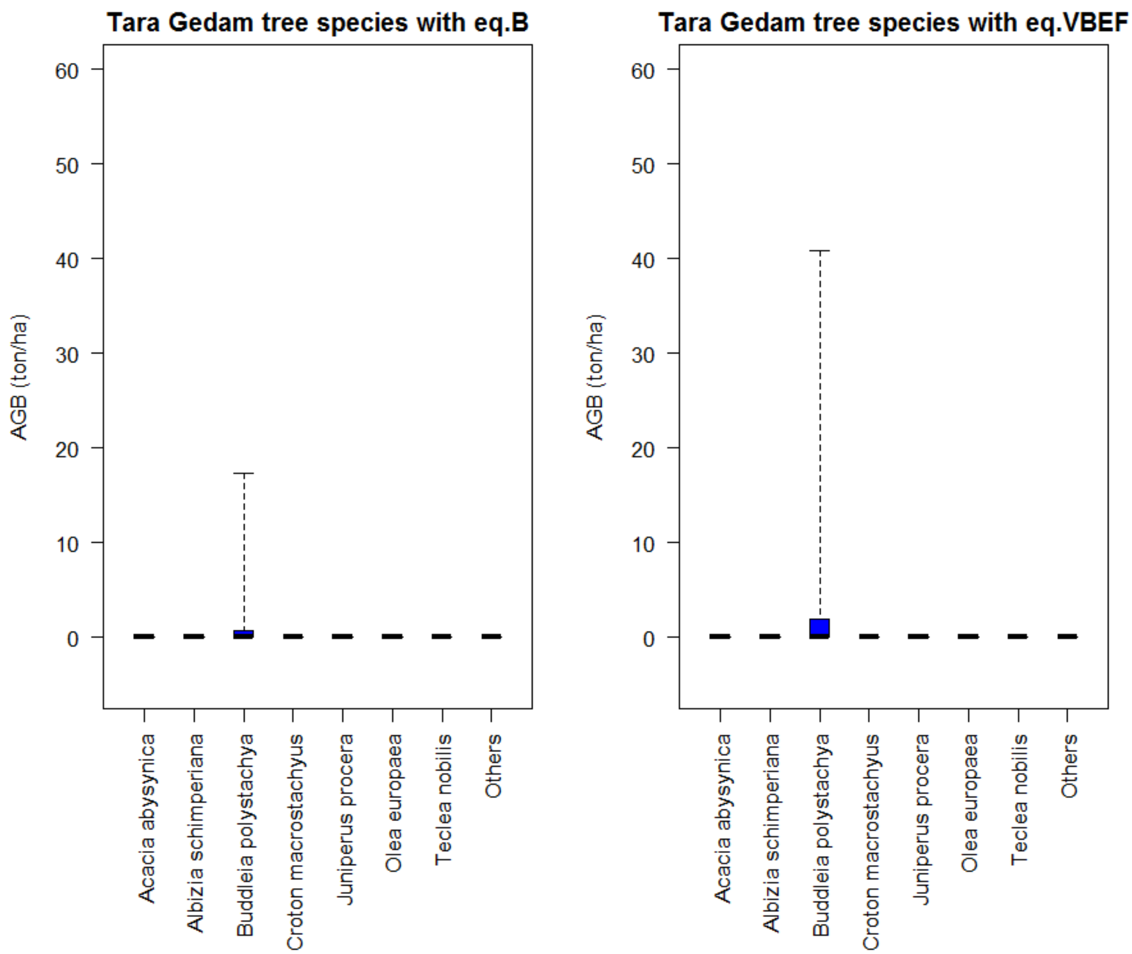

Figure 25 Comparison of the two estimation methods based on main tree species AGB (ton/ha) contribution of Tara Gedam

All study site

In Figure 21 the two biomass estimation methods were compered based on each study site above ground biomass. In all sites the equation that uses biomass expansion factor VBEF has bigger above ground biomass than biomass equation B. Among these forest sites Gelawudewose has great biomass followed by Injibara for both methods. Though Tara Gedam monastery forest has lower contributing main tree species, it has a greater amount of above ground biomass than Metema. Metema/Mahibere Selassie monastery forest has a more vast area of forest than any of other study sites but the site had the lowest above ground biomass (ton/ha) due to sparse population of trees in the site.

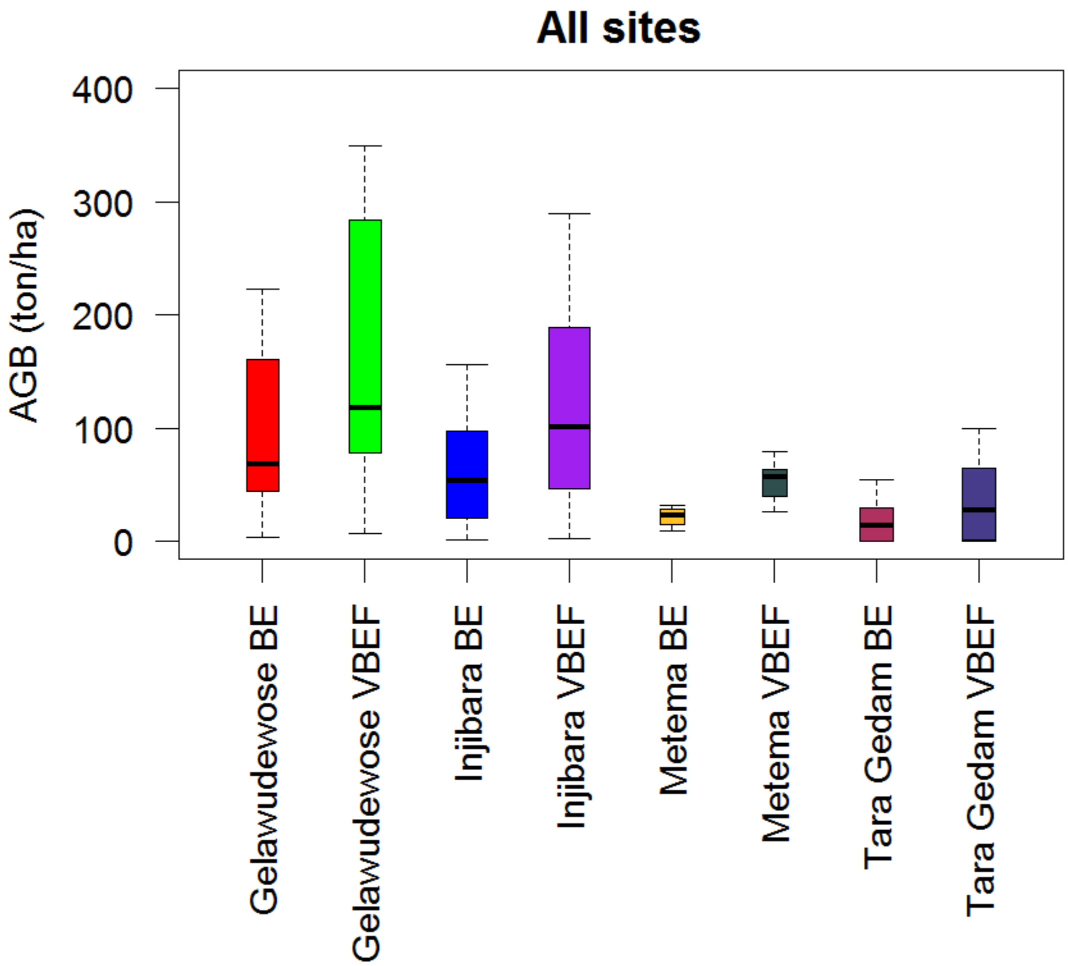

Figure 26 Comparison of the two estimation methods based on the four study sites AGB (ton/ha) contribution

Generally using the two biomass estimation methods the respected study sites with its corresponding area of forest has provided the following total above ground biomass. The estimated above ground biomass found using equation VBEF for Gelawudewose, Injibara, Metema and Tara Gedam study sites was higher by 62.1 % ,50.3 %, 41.7 % and 53.1 % respectively than equation B, and on average it overestimated by 51.8 % greater than the biomass equation.

Table 5 Summary of above ground biomass of each study site and some statistical parameters with the two biomass estimation methods

Study Sites	Gelawud ewose		Injibara		Metema		Tara Gedam	
Methods	B	VBEF	B	VBEF	B	VBEF	B	VBEF
Area /ha	61.1	61.1	482.8	482.8	18000.0	18000.0	231.3	231.3
Total AGB ton	3540.7	5706.5	3554.7	7061.2	451.0	1080.8	1237.8	2334.1
Plot mean (ton/ha)	107.3	172.9	64.6	128.4	22.6	54.0	33.5	63.1
SD	44.2	68.4	18.6	38.8	7.0	16.6	21.8	33.6
SE	2.9	4.4	0.8	1.6	0.6	1.5	1.3	2.0
CV%	288.2	277.1	259.2	272.2	187.3	184.4	520.6	425.7
CI at 95%	5.6	8.7	1.5	3.2	1.3	3.0	2.5	3.8

Where B is a selected Biomass/allometeric equation, VBEF stand for the equation that uses biomass expansion factor and wood density to convert tree volume to above ground biomass. AGB is for above ground biomass. Plot mean is plot arithmetic mean (ton/ha). SD is standard deviation of the data. CV (%) is coefficient of variance in percent for each site. SE is standard error of the data. and CI (95%) stands for confidence interval at 95%.

6.4.Converting above ground biomass in to carbon

The calculated above ground biomass from the two estimation methods (biomass equation B and VBEF) was in dry tones. This dry ton above ground biomass was converted into above ground carbon (C) in tones by multiplying 0.5. Therefore the following table has shown the converted above ground biomass of each site to above ground carbon (ton/ha). Above ground biomass calculated from the two biomass estimation methods was converted in above ground carbon. Likewise their respected above ground biomass each study site has an equitable above ground Carbon (See figure 22 below).

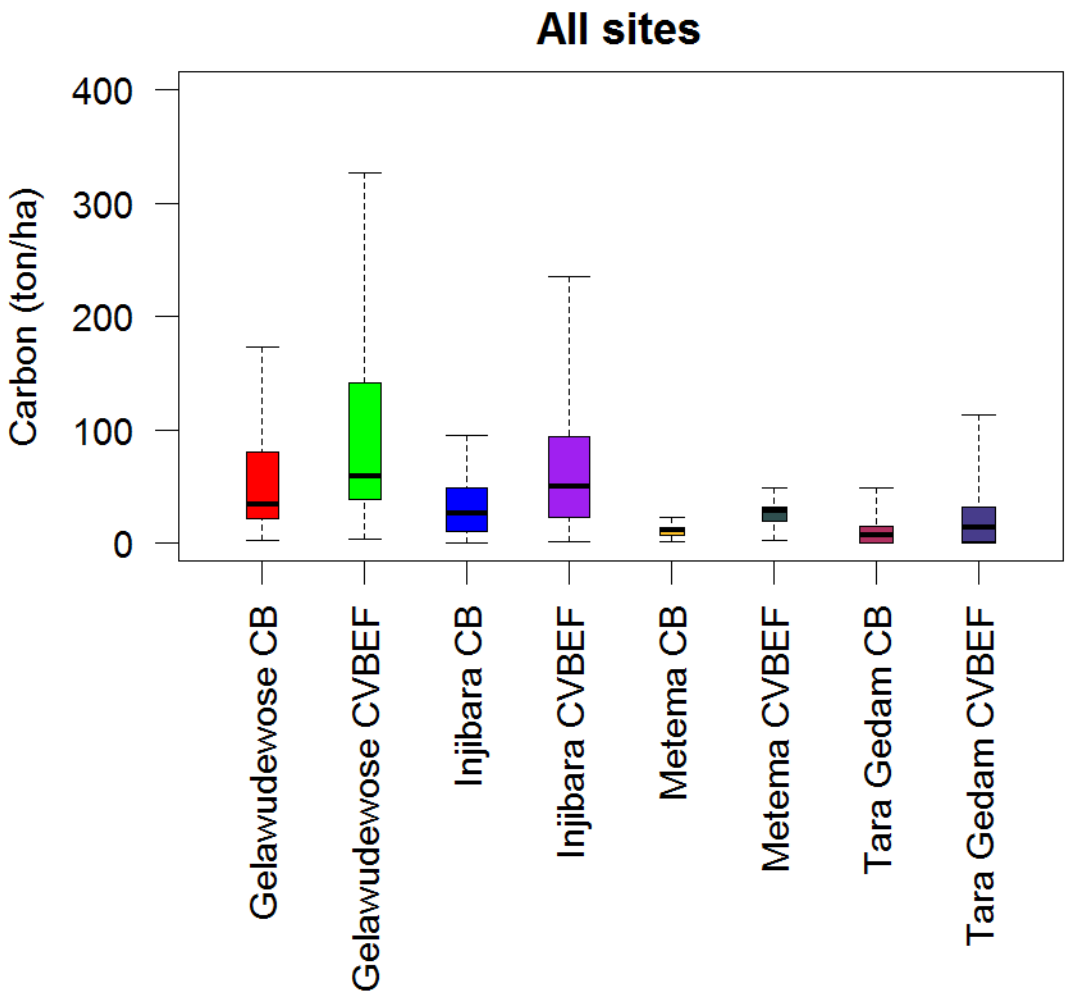

Figure 27 The converted above ground Carbon of each study site from the two biomass estimation methods in comparison where CB stands for above ground Carbon from biomass equation B similarly CVBEF is above ground Carbon from biomass equation VBEF.

From the Table 14 below the calculated carbon from biomass using VBEF equation of Gelawudewose, Injibara, Metema and Tara Gedam study sites was bigger in 1303.82, 3675.806, 347.434 and 548.163 respectively than carbon calculated from biomass equation B. On average the carbon calculated from biomass of VBEF Equation was higher by 5874.785 than carbon found from biomass of equation B.

Table 6 Summary of the converted above ground Carbon from the two biomass estimating approaches for each respective study site.

Sites	Gelawudewose		Injibara		Metema		Tara Gedam	
Method	CB	CVBEF	CB	CVBEF	CB	CVBEF	CB	CVBEF
Area/ha	61.1	61.1	482.8	482.8	18000.0	18000.0	231.3	231.3
Total AGC (ton)	1769.8	3073.2	1777.4	5453.2	192.9	540.4	618.9	1167.1
Plot mean (ton/ha)	53.6	93.1	32.3	99.1	9.6	27.0	16.7	31.5
SD	22.1	38.1	9.3	33.9	3.4	8.3	10.9	16.8
CV (%)	287.8	286.7	259.2	307.8	214.4	184.4	520.6	425.7
SE	1.4	2.5	0.4	1.4	0.3	0.8	0.6	1.0
CI (95%)	2.8	4.8	0.8	2.8	0.6	1.5	1.2	1.9

Where CB stands for above ground carbon from biomass equation B similarly CVBEF is above ground carbon from biomass equation VBEF, AGC is for above ground carbon. Plot mean is plot arithmetic mean (ton/ha). SD is standard deviation of the data, CV (%) is coefficient of variance in percent for each site, SE is standard error of the data and CI (95%) stands for confidence interval at 95%.

7. Discussion

Biomass equation selection

So far several attempts were done to produce general biomass equations for tropical forest above ground biomass estimation (Brown et al., 1989, 1997; Chave et al., 2005; Djomo et al., 2010; Henry et al., 2011). Even though most of tropical forests in Africa had large amount of biomass and carbon, little attention was given to develop species specific or mixed species biomass equation for the region. Most of tropical biomass equations were developed for Asia and Latin America. For instance species-specific allometeric equations are available for only 1% of tree species of SSA (Henry et al., 2011). Though the accuracy of the data has not yet been defined (since these equations were produced based on the data outside Africa) several biomass studies applied broad use of pan moist tropical equations to estimate biomass (Djomo et al., 2010).

Several published allometeric biomass equations were reviewed in this study (see Table1), but in Ethiopia similar to other African countries where this study was conducted there was no site and or species specific general biomass equations. The pan moist tropical six equations developed by Chave (2005) were tested to estimate above ground biomass of Amhara region (Djomo et al., 2010). Since DBH alone can explain more than 95% of above ground biomass and carbon variation of tropical forests even in highly diverse regions applying these general allometeric equation across all sites and species was not that much problematic (Brown et al., 2002; Gibbs et al., 2007). Thus one biomass equation was selected from these six allometeric equations based on its better estimation equation B ($Y=\exp\{-2.922+0.99*\ln(D^2H\rho)\}$) was selected. Therefore using this selected biomass equation and biomass expansion factors with volume data (VBEF=V*p*BEF) (Brown et al., 1997; IPCC, 2003) above ground biomass computation was performed.

Application and comparison of the two approaches

In this part of the study discussion on the two approaches of biomass estimation methods was conducted. The first approach directly estimated biomass using biomass equations. These equations are mathematical functions that relate oven dry biomass of a tree as a function of DBH, height and wood density. The second approach was based on the use of existing measured volume estimates converted to biomass using biomass expansion factors developed by Brown (1997) and wood density (Brown et al., 1989, 1995). There was no literature that can show the statistical accuracy advantage between the two biomass estimation approaches. Therefore the existing data determines which of these approaches to be used. But the first approach has an advantage of estimating biomass without having the estimation of tree volume and biomass expansion factors. While its disadvantage is that it will not work well for all DBH classes of trees, so DBH class limit the application of this approach for all sizes of trees (Brown et al., 1997).

Consequently the two approaches were applied across all forest sites and tree species just for comparative purpose. As we can see in Figure 12, 13, 14, 15, and 16 above both methods in the majority of tree species shown similar trend of graphs. Nevertheless the results from the two methods were quite different both at species and site level above ground biomass (i.e. above ground biomass (ton/ha) from VBEF was much bigger than biomass equation B). And on average the total estimated above ground biomass of all sites together using equation VBEF was greater by 7398.42 than biomass equation B. Specifically Gelawudewose, Injibara, Metema and Tara Gedam have 2165.852, 3506.496, 629.747 and 1096.325 more biomass respectively with equation VBEF than biomass equation B. The higher values of VBEF approach are seen Table 15 at species and site level.

From the table 15 below the maximum and minimum deviation of the two (VBEF-B) methods observed at Gelawudewose forest was *Chionanthus mildbraedii* and *Buddleia* tree species with 1307.513 and 29.076 respectively. At Injibara the maximum and minimum above ground biomass (ton/ha) was 1432.655 and 36.405 at *other* and *Acacia abyssinica* respectively. At Metema Mahibere Selassie monastery forest the minimum and maximum deviation between the two equations (VBEF-B) was 382.193 and 22.983 at *other* and *Ameja* tree species respectively. At Tara Gedam monastery forest the maximum and the minimum deviation (VBEF-B) was *367.004* and *30.317* at *Juniperus procera* and *Teclea nobilis* tree species respectively. Across all study sites the maximum and the minimum deviation (VBEF-B) was at Injibara and Metema/Mahibere Selassie with 3506.496 and 629.747 respectively.

Table 7 Total above ground biomass (tone/ha) of each tree species in at each study site

Gelawudewose tree spess	*Albizia gummifera*	*Buddleia polystachya*	*Croton macrostachyus*	*Chionanthus mildbraedii*	*Podocarpus falcatus*	*Teclea nobilis*	*other*		
B	149.5	19.0	110.8	1441.8	53.8	68.2	1697.5		
VBEF	282.5	48.0	228.2	2749.3	125.2	104.5	2168.9		
Injibara ree speciest	*Acacia abyssinica*	*Albizia gummifera*	*Allophylus abyssinicus*	*Bugtsi*	*Croton macrostachyus*	*Gimbltini*	*kenebela*	*Prunus africana*	*other*
B	43.2	1606.4	112.1	71.6	332.6	69.4	58.0	498.3	763.3
VBEF	79.6	2148.8	227.0	155.7	690.4	185.7	183.6	1194.6	2195.9
Metema treee species	*Ameja*	*Boswellia papyrifera*	*Sterculea setigera*	*fola*	*forha*	*other*			
B	12.5	63.4	65.1	18.1	17.1	274.7			
VBEF	36.2	155.9	140.6	51.1	40.1	656.9			

Tara Gedam tree species	*Acacia abysynica*	*Albizia schimperiana*	*Buddleia polystachya*	*Croton macrostachyus*	*Juniperus procera*	*Olea europaea*	*Teclea nobilis*	*Others*
B	137.9	60.7	49.5	56.4	233.1	249.8	35.7	414.6
VBEF	251.0	104.9	116.6	117.9	600.1	446.8	66.0	630.8

Where B is a biomass/allometeric equation and VBEF is an equation that uses biomass expansion factors to convert tree volume in to above ground biomass.

Compared to the findings of other outers, the biomass equation B developed by (Chave 2005) Y=exp {-2.922+0.99*ln ($D^2H\rho$)}was the best estimator of above ground biomass even across the continent of Africa and it has an average error of 20.3% (Djomo et al., 2010). The equation was developed from 1505 tree species with 5-156 cm DBH range and the data was collected from moist tropical forests of Australia, Cambodia, Barman, Costa Rica, French guinea, Indicia, India karma, New Guinea, Venezuela and Malaysia (see tabe 1)(Chave et al., 2005; Djomo et al., 2010). The results of using this approach in this study showed high consistency across all sites and species. Therefore AGB from equation B is 0.379 whereas VBEF produced 0.648 ton/ha.

Though it is impossible to speak extensively to the results of VBEF equations in this study which uses the same wood density and biomass expansion factor across all tree species, other authors confirmed that general predictions obtained from VBEF equations are less precise than allometeric equations (Joosten et al., 2004).

Carbon estimation

In this study the calculated above ground biomass (ton/ha) of each tree species was converted into above ground C by multiplying the values with 0.5. Accordingly the converted above ground carbon from the two approaches have equivalent differences. The converted above ground carbon from VBEF is always higher than biomass equation B. Therefore the above ground carbon of each tree species per each site was lookalikes the following seen in Figures 23, 24, 25 and 26.

Particularly in Figure 23 at Gelawudewose forest site the main tree species those with high or small amount of carbon were similar from the two approaches. They showed an almost similar trend and the site was dominated by few species (the rest contributed less). Likewise AGC on average from equation B is 0.189 and VBEF estimated 0.324 ton/ha.

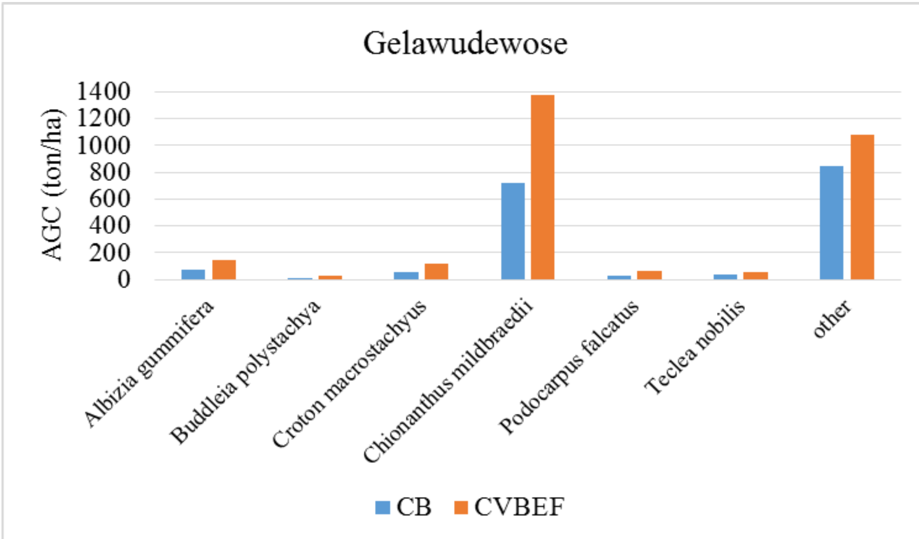

Figure 28 Gelawudewose tree species above ground carbon using the two approaches

Where CB stands for above ground carbon from biomass equation B similarly CVBEF is above ground carbon from biomass equation VBEF.

Injibara forest site has a better distribution of tree species and shows a higher amount of main tree species relative to other study sites. Gelawudewose and Injibara study sites have shown similar trend of graph.

Figure 29 Injibara tree species above ground carbon using the two approaches

Where CB stands for above ground Carbon from biomass equation B similarly CVBEF is above ground Carbon from biomass equation VBEF.

The same is true at Metema/Mahibere Selassie monastery forest main tree species above ground carbon contribution. But unlike any of the other study site here there was no common tree species that is why the site only has six tree species. This was due to the different agro-ecology that the site has.

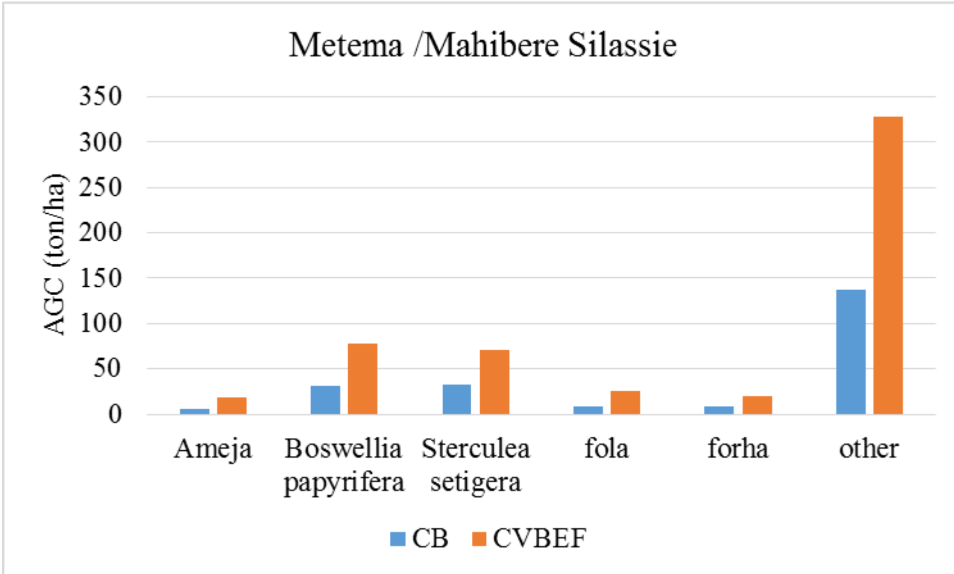

Figure 30 Metema/Mahibere Selassie tree species above ground carbon using the two approaches

Where CB stands for above ground carbon from biomass equation B similarly CVBEF is above ground carbon from biomass equation VBEF.

Tara Gedam monastery forest in Figure 26 below shows that most of the tree species has shown better contribution of above ground carbon equitably. likewise other sites they have similar trends.

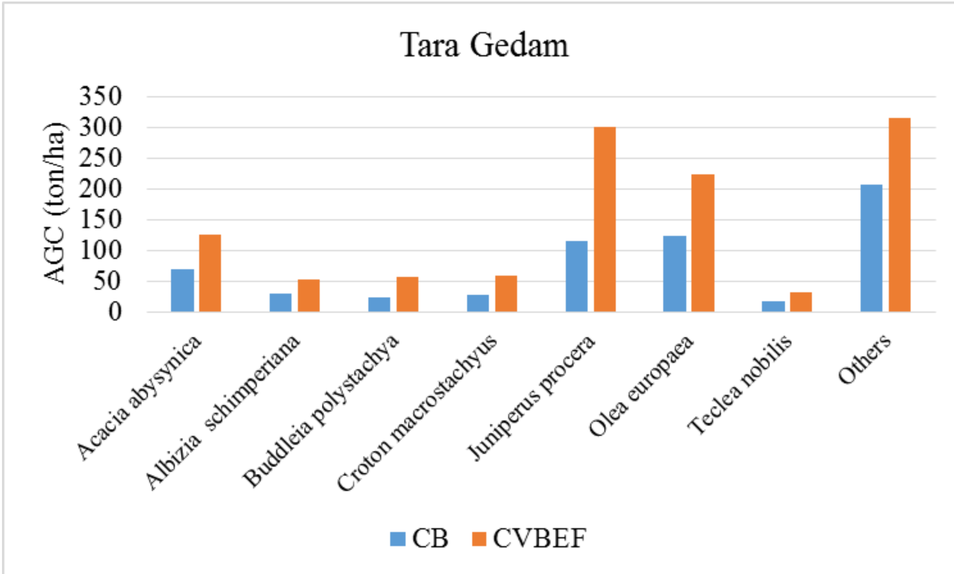

Figure 31 Tara Gedam monastery forest Metema/Mahibere Selassie tree species above ground carbon using the two approaches

Where CB stands for above ground Carbon from biomass equation B similarly CVBEF is above ground Carbon from biomass equation VBEF.

Generally the AGB calculated from the two approaches was quite different or the VBEF equations has much bigger results than biomass equation B. as stated earlier, the VBEF equations calculated biomass from volume using biomass expansion factor and wood density. Though the volume was computed based on our study site data (Tesfaye (2015)), the applied wood density and biomass expansion factors were similar for all tree species 058 ton/m^3 and 3.40 respectively. Though some authors recommend to use these average values when the tree species specific values are not available (Brown et al., 1997) they will differ per tree species age and site (Chave et al., 2005). According to Brown (1997) VBEF approach was developed originally based on the data of closed forests, so trusting the results found from VBEF rather than biomass equation B may lead either to over or under estimation of biomass and inaddtion to that the Chave (2005) biomass equation is best across the continent of Africa (Djomo et al., 2010; Joosten et al., 2004). Likewise the AGC from the two approaches has to be taken into account.

8. Conclusion

From our results it possible to suggest that for trees with a DBH and height range up to 40 cm and 10 m respectively it does not matter which biomass equation is selected. Meanwhile the results were very similar for all tree species within this DBH and height range. As a result one can conclude that the different approaches of how biomass functions work using any of six alllometeric relationships or a biomass expansion factor, provide equivalent results.

After the allometeric equation B and VBEF were selected and applied to plot of each tree species per each study site, most tree species comparable results of above ground biomass were shown only till the DBH range reaches 20-30 cm. Therefore the two approaches provided incomparable above ground biomass for most of the DBH ranges including higher values. Thus similar to other author's recommendations, using the generalized allometeric biomass equation that can work with high DBH range and irrespective of site and tree species is better than that of biomass expansion factors. This study how ever is based on literature wood density value and biomass expansion factor.

The above ground biomass results found from the two approaches both in species level and site level were quite different and always the VBEF equations showed a much larger amount of biomass than biomass equation B. Similarly the converted above ground biomass carbon has shown analogous differences accordingly.

Therefore generating both site and species specific results accurately, biomass equations, biomass expansion factor and wood density is strongly recommended in order to compare and contrast and to get the maximum possible accuracy of the approaches. Nevertheless in this particular study based on the recommendations and suggestions given by (Djomo et al., 2010; Joosten et al., 2004) applying the general biomass equation is better than biomass expansion factors (VBEF).

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10. Acronyms and abbreviations

°c	degree centigrade
a.s.l	above sea level
AGB/Y	above ground biomass
AGC	above ground carbon
ANRS	Amhara nation regional state
B	one of the biomass/allometeric equation
BE	Biomass equation
BEF	Biomass expansion factor
CB	Above ground carbon calculated from biomass equation B
CI	confident interval
Cm	centimeter
CV	Coefficient of variance
CVBEF	above ground carbon calculated from volume biomass expansion factor equation
DBH/D	diameter at breast height
E	east
Eq.	Equation
exp	the power of….
GIS	Geographical information system
GPS	Geographical position system
H	tree height
ha	hectare
IPCC	International panel for climate change
KG	kilo gram
Km	kilo meter

m	meter
max	maximum
min	minimum
mm	millimeter
N	north
ρ	wood density
SD	standard deviation
SE	standard error
SSA	Sub-Saharan Africa
VBEF	volume biomass expansion factor
V	volume

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13. Appendix

Table B1 Gelawudewose main tree species in each plot above ground biomass (ton/ha).

Plot	*Albizia gummifera*	*Buddleia polystachya*	*Croton macrostachyus*	*Chionanthus mildbraedii*	*Podocarpus falcatus*	*Teclea nobilis*	*Others*	*Plot sum*	*Plot mean*	*Plot SD*	*Plot CV%*	*Plot SE*	*Plot CI*
1	29.5	0.0	0.0	158.6	0.0	2.0	80.9	271.1	38.7	60.7	156.7	22.9	56.1
2	0.0	0.0	0.6	53.1	0.0	0.0	23.7	77.4	11.1	20.5	185.6	7.8	19.0
3	0.0	0.0	7.0	21.9	0.0	7.9	9.6	46.5	6.6	7.9	119.3	3.0	7.3
4	12.1	0.0	0.0	0.0	0.0	0.0	34.1	46.3	6.6	13.0	196.0	4.9	12.0
5	0.0	0.0	5.5	0.0	0.0	0.0	7.1	12.6	1.8	3.1	172.9	1.2	2.9
6	0.0	0.0	9.1	0.0	0.0	0.0	18.0	27.0	3.9	7.1	183.3	2.7	6.5
7	0.0	0.0	0.0	42.1	0.0	0.0	181.4	223.4	31.9	67.7	212.2	25.6	62.7
8	0.0	0.0	0.0	0.0	0.0	0.0	44.3	44.3	6.3	16.8	264.6	6.3	15.5
9	0.0	0.0	0.0	0.0	0.0	0.0	326.3	326.3	46.6	123.3	264.6	46.6	114.1
10	0.0	0.0	1.9	48.3	0.0	0.0	17.2	67.4	9.6	18.2	188.9	6.9	16.8
11	0.0	0.0	0.0	8.7	0.0	0.0	12.0	20.7	3.0	5.1	173.7	1.9	4.8
12	0.0	0.0	0.0	337.6	0.0	3.8	4.5	346.0	49.4	127.1	257.2	48.0	117.6
13	0.0	1.1	37.4	0.0	0.0	0.0	66.5	105.0	15.0	26.6	177.4	10.1	24.6
14	0.0	0.0	0.0	66.7	0.0	33.4	24.6	124.8	17.8	25.7	143.9	9.7	23.7
15	0.0	0.0	0.0	0.0	0.0	18.8	49.0	67.8	9.7	18.7	193.1	7.1	17.3
17	0.0	0.0	0.0	0.0	0.0	0.0	120.3	120.3	17.2	45.5	264.6	17.2	42.1
18	0.0	0.0	3.2	0.0	0.0	0.0	1.0	4.2	0.6	1.2	201.4	0.5	1.1
19	0.0	0.0	0.0	0.0	0.0	0.0	5.7	5.7	0.8	2.2	264.6	0.8	2.0
20	0.0	0.0	2.5	95.8	0.0	0.0	0.0	98.3	14.0	36.1	256.8	13.6	33.4
21	0.0	0.0	0.0	21.9	0.0	0.0	46.6	68.5	9.8	18.2	185.6	6.9	16.8
22	0.0	0.0	2.3	92.1	26.9	0.0	71.8	193.1	27.6	38.8	140.7	14.7	35.9
23	0.0	0.0	0.0	161.4	17.2	0.0	0.5	179.1	25.6	60.2	235.4	22.8	55.7
24	0.0	0.0	20.0	81.7	9.7	0.0	92.6	204.0	29.1	40.4	138.7	15.3	37.4

25	0.0	0.0	0.0	46.5	0.0	0.0	5.7	52.2	7.5	17.3	232.8	6.6	16.0
26	0.0	0.0	0.0	28.7	0.0	0.0	258.2	286.9	41.0	96.4	235.1	36.4	89.1
27	0.0	0.0	1.6	0.0	0.0	0.0	30.7	32.2	4.6	11.5	249.8	4.4	10.6
28	27.7	0.0	0.0	0.0	0.0	0.0	0.0	27.7	4.0	10.5	264.6	4.0	9.7
29	0.0	0.0	8.7	144.7	0.0	2.2	5.2	160.8	23.0	53.8	234.0	20.3	49.7
30	2.0	0.0	10.1	31.7	0.0	0.0	3.1	47.0	6.7	11.6	172.8	4.4	10.7
31	19.0	12.7	1.0	0.0	0.0	0.0	12.0	44.7	6.4	8.0	124.9	3.0	7.4
32	0.0	0.0	0.0	0.0	0.0	0.0	71.1	71.1	10.2	26.9	264.6	10.2	24.8
33	48.7	5.2	0.0	0.0	0.0	0.0	1.3	55.2	7.9	18.1	229.5	6.8	16.7
34	10.5	0.0	0.0	0.0	0.0	0.0	72.3	82.8	11.8	27.0	227.9	10.2	24.9
Mean	4.5	0.6	3.4	43.7	1.6	2.1	51.4						
SD	11.1	2.4	7.5	71.6	5.7	6.7	74.8						
CV%	245.3	411.3	223.1	163.8	347.5	321.8	145.5						

$$Y = \exp\{-2.922 + 0.99 * \ln(D2H\rho)\}$$

Where SD is standard deviation, CV% is coefficient of variance in percent, SE is standard error and CI confident interval at 95%.

Table B2 Injibara main tree species in each plot above ground biomass (ton/ha).

Plot	*Acacia abyssinica*	*Albizia gummifera*	*Allophylus abyssinicus*	*Bugtsi*	*Croton macrostachyus*	*Gimbltini*	*kenebela*	*Prunus africana*	*Others*	*Plot sum*	*Plot mean*	*Plot SD*	*Plot CV%*	*Plot SE*	*Plot CI*
3	0.0	62.4	8.4	0.0	0.0	0.5	0.0	0.0	1.3	72.6	8.1	20.6	254.9	6.9	15.8
4	0.0	44.7	0.0	0.0	0.3	0.0	0.0	0.0	0.0	45.0	5.0	14.9	298.1	5.0	11.5
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.7	30.7	3.4	10.2	300.0	3.4	7.9
7	0.0	10.5	0.0	0.0	1.7	0.0	0.0	0.0	0.0	12.2	1.4	3.5	256.0	1.2	2.7
8	13.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	0.6	15.2	1.7	4.3	252.7	1.4	3.3
9	6.6	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.6	9.6	1.1	2.2	207.9	0.7	1.7
10	0.0	102.9	20.2	21.7	0.0	0.0	0.0	0.0	0.0	144.8	16.1	33.8	210.1	11.3	26.0
11	0.0	64.1	0.0	0.0	7.0	0.0	0.0	0.0	0.4	71.5	7.9	21.2	266.5	7.1	16.3
12	0.0	94.1	7.4	0.0	0.0	0.0	0.0	0.0	3.5	104.9	11.7	31.0	265.9	10.3	23.8
13	0.0	37.8	0.0	0.0	0.3	0.0	1.6	0.0	55.2	94.8	10.5	20.9	197.9	7.0	16.0
14	0.0	79.2	0.0	0.0	6.8	0.0	0.0	0.0	0.3	86.3	9.6	26.2	273.2	8.7	20.1
17	0.0	29.8	0.0	0.0	0.0	0.0	0.0	23.5	0.2	53.6	6.0	11.9	199.1	4.0	9.1
18	0.0	8.9	0.0	1.7	1.0	14.8	4.7	15.5	0.3	47.0	5.2	6.3	121.4	2.1	4.9
19	9.7	3.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.7	1.4	3.3	231.6	1.1	2.5
20	0.0	5.8	0.0	11.0	0.0	0.4	0.0	46.3	0.0	63.4	7.0	15.2	215.7	5.1	11.7
21	0.0	6.5	0.0	0.0	4.1	6.7	0.0	0.9	2.6	20.8	2.3	2.8	122.3	0.9	2.2
22	0.0	69.0	0.0	0.0	0.0	5.6	5.2	0.0	53.6	133.4	14.8	26.7	180.3	8.9	20.5
23	0.0	0.5	0.0	0.0	20.6	6.7	1.4	36.1	0.9	66.1	7.3	12.7	172.8	4.2	9.8
24	0.0	0.9	0.0	0.0	24.1	5.5	0.0	1.4	1.8	33.8	3.8	7.8	209.1	2.6	6.0
25	0.0	32.7	0.0	2.9	0.0	0.0	4.1	15.5	69.3	124.4	13.8	23.5	169.8	7.8	18.0
26	0.0	36.1	4.2	0.0	0.0	2.2	0.3	0.0	8.2	51.0	5.7	11.8	207.7	3.9	9.0
27	0.0	13.1	12.5	0.0	0.0	0.0	0.0	84.3	1.9	111.9	12.4	27.5	221.4	9.2	21.1
29	0.0	0.0	0.0	0.0	21.3	0.0	0.0	0.0	17.1	38.3	4.3	8.5	199.9	2.8	6.5
30	0.0	76.5	11.9	0.0	22.4	0.0	1.7	30.7	5.6	148.8	16.5	25.0	151.4	8.3	19.2
31	0.0	15.5	0.0	0.0	10.5	1.8	0.0	13.1	11.5	52.4	5.8	6.6	114.1	2.2	5.1

32	0.0	20.8	0.0	0.0	0.0	7.2	1.8	8.6	38.6	77.0	8.6	13.2	154.1	4.4	10.1
33	0.0	6.0	0.0	0.0	0.7	2.0	5.3	29.5	27.1	70.6	7.8	11.8	150.7	3.9	9.1
34	0.0	1.1	0.0	6.6	3.6	1.3	0.4	99.3	0.4	112.6	12.5	32.6	260.5	10.9	25.1
35	0.0	13.0	0.0	0.0	0.3	2.8	2.3	0.0	121.2	139.4	15.5	39.8	257.2	13.3	30.6
36	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	6.4	0.7	1.5	202.9	0.5	1.1
37	0.0	0.4	0.0	0.0	5.8	0.0	0.0	0.0	8.9	15.0	1.7	3.3	198.2	1.1	2.5
38	0.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	1.5	0.2	0.5	300.0	0.2	0.4
39	0.0	79.4	4.3	0.4	2.9	0.0	0.3	0.0	0.6	88.0	9.8	26.1	267.6	8.7	20.1
40	0.0	84.0	3.0	0.8	1.9	0.6	0.0	0.0	2.5	92.7	10.3	27.6	268.3	9.2	21.3
41	0.0	32.0	0.0	0.0	10.0	3.2	0.0	0.0	6.1	51.3	5.7	10.5	184.1	3.5	8.1
42	0.0	57.4	9.1	0.0	0.0	0.3	3.7	23.5	23.9	118.0	13.1	19.3	147.0	6.4	14.8
43	0.0	55.4	0.0	0.0	6.8	0.0	0.3	13.0	25.8	101.3	11.3	18.7	166.6	6.2	14.4
44	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	1.8	0.2	0.6	300.0	0.2	0.5
45	0.0	21.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.1	2.3	7.0	300.0	2.3	5.4
47	0.0	1.3	0.0	0.0	13.8	0.0	0.0	0.0	0.0	15.1	1.7	4.6	272.5	1.5	3.5
48	0.0	55.2	0.0	0.0	3.2	0.0	0.3	0.9	2.2	61.9	6.9	18.2	264.1	6.1	14.0
49	0.0	3.0	0.0	0.5	7.0	0.4	0.0	0.0	3.2	14.0	1.6	2.4	154.8	0.8	1.8
50	0.0	13.8	0.0	5.0	0.6	0.0	0.0	0.0	7.2	26.5	2.9	4.9	165.2	1.6	3.7
51	0.0	60.6	0.0	0.0	0.0	0.6	4.9	27.0	0.0	93.1	10.3	20.8	201.3	6.9	16.0
53	0.0	20.7	0.0	0.0	24.7	0.0	3.0	0.0	142.5	190.8	21.2	46.5	219.4	15.5	35.7
54	3.8	1.5	0.0	0.0	2.7	0.0	0.0	0.5	1.1	9.6	1.1	1.4	127.9	0.5	1.0
55	0.0	7.8	0.0	0.0	87.7	0.0	0.0	0.0	4.3	99.8	11.1	28.9	260.3	9.6	22.2
56	0.0	45.6	30.5	21.2	2.3	5.5	0.0	5.2	6.6	116.8	13.0	16.0	123.2	5.3	12.3
57	6.3	17.5	0.0	0.0	4.5	0.0	2.2	0.0	0.0	30.5	3.4	5.8	170.9	1.9	4.5
58	0.0	4.1	0.0	0.0	13.8	0.0	0.0	0.0	0.3	18.2	2.0	4.6	228.5	1.5	3.6
59	0.0	79.7	0.0	0.0	0.0	0.0	0.0	13.8	0.0	93.5	10.4	26.4	254.0	8.8	20.3
60	0.0	0.3	0.6	0.0	0.0	1.6	14.5	9.5	2.9	29.3	3.3	5.2	159.1	1.7	4.0
61	0.0	10.8	0.0	0.0	3.4	0.0	0.0	0.0	3.4	17.6	2.0	3.6	185.5	1.2	2.8
62	0.0	113.3	0.0	0.0	1.6	0.0	0.0	0.0	42.0	156.8	17.4	38.5	221.0	12.8	29.6
63	0.0	6.7	0.0	0.0	8.2	0.0	0.0	0.0	24.3	39.3	4.4	8.2	187.1	2.7	6.3
Mean	0.8	29.2	2.0	1.3	6.0	1.3	1.1	9.1	13.9						

SD	2.5	32.1	5.5	4.4	13.1	2.7	2.4	19.6	28.1
CV%	320.2	110.0	272.2	334.9	216.4	215.6	227.5	216.4	202.6

$$Y = \exp\{-2.922 + 0.99 * \ln(D2H\rho)\}$$

Where SD is standard deviation, CV% is coefficient of variance in percent, SE is standard error and CI confident interval at 95%.

Table B3 Metema/ Mahibere Selassie main tree species in each plot above ground biomass (ton/ha).

Plot	*Ameja*	*Boswellia papyrifera*	*Sterculea setigera*	*Fola*	*Forha*	*Others*	*Plot sum*	*Plot mean*	*Plot SD*	*Plot CV%*	*plot SE*	*Plot CI*
1	0.0	0.0	0.0	1.1	1.4	1.4	3.9	0.6	0.7	1.1	0.3	0.7
2	0.0	1.7	0.0	0.0	0.0	22.8	24.5	4.1	9.2	2.2	3.7	9.6
3	0.0	0.0	0.0	2.5	3.7	22.2	28.3	4.7	8.7	1.8	3.5	9.1
4	2.0	2.1	11.5	0.0	0.0	7.6	23.3	3.9	4.7	1.2	1.9	4.9
5	0.3	9.2	13.7	0.0	0.0	8.8	31.9	5.3	6.0	1.1	2.4	6.3
6	1.3	17.6	0.0	3.6	2.9	3.3	28.7	4.8	6.4	1.3	2.6	6.8
7	0.9	1.9	0.6	0.4	0.0	10.7	14.4	2.4	4.1	1.7	1.7	4.3
8	3.7	5.3	0.0	3.2	1.7	26.1	40.0	6.7	9.7	1.5	4.0	10.2
9	0.0	0.0	6.8	2.5	5.0	14.0	28.3	4.7	5.3	1.1	2.2	5.6
10	0.0	0.0	8.8	0.0	2.3	11.8	22.9	3.8	5.2	1.4	2.1	5.5
11	0.0	0.0	14.3	0.0	0.0	1.7	16.0	2.7	5.8	2.2	2.3	6.0
12	0.0	0.0	0.0	0.0	0.0	25.9	25.9	4.3	10.6	2.4	4.3	11.1
13	1.8	0.0	0.0	3.4	0.0	12.3	17.5	2.9	4.8	1.6	2.0	5.1
14	0.0	0.0	0.0	0.0	0.0	10.9	10.9	1.8	4.5	2.4	1.8	4.7
15	0.0	8.4	3.2	0.0	0.0	9.9	21.5	3.6	4.5	1.3	1.8	4.7
16	0.0	1.4	6.1	1.0	0.0	0.8	9.3	1.6	2.3	1.5	0.9	2.4
17	0.0	0.0	0.0	0.0	0.0	45.7	45.7	7.6	18.6	2.4	7.6	19.6
18	0.5	15.8	0.0	0.4	0.0	6.6	23.4	3.9	6.4	1.6	2.6	6.7
20	0.0	0.0	0.0	0.0	0.0	12.7	12.7	2.1	5.2	2.4	2.1	5.5
21	2.1	0.0	0.0	0.0	0.2	19.6	21.9	3.7	7.9	2.2	3.2	8.3
Mean	0.6	3.2	3.3	0.9	0.9	13.7						
SD	1.0	5.4	5.1	1.3	1.5	10.8						
CV%	164.1	170.5	155.2	146.4	174.2	78.9						

$$Y = \exp\{-2.922 + 0.99 * \ln(D2H\rho)\}$$

Where SD is standard deviation, CV% is coefficient of variance in percent, SE is standard error and CI confident interval at 95%.

Table B4 Tara Gedam main tree species in each plot above ground biomass (ton/ha).

Plot	*Acacia abysynica*	*Albizia schimperiana*	*Buddleia polystachya*	*Croton macrostachyus*	*Juniperus procera*	*Olea europaea*	*Teclea nobilis*	*Others*	*Plot sum*	*Plot mean*	*Plot SD*	*Plot CV%*	*Plot SE*	*Plot CI*
1	0.0	0.0	0.0	30.3	0.0	0.0	0.0	0.0	30.3	3.8	10.7	282.8	3.8	25.3
3	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.8	0.1	0.3	282.8	0.1	0.7
5	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0	5.5	0.7	1.9	282.8	0.7	4.6
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	1.6	0.0	0.8	0.0	21.7	0.0	0.0	0.0	24.1	3.0	7.6	251.3	2.7	17.9
9	21.1	0.0	3.9	0.0	0.0	0.0	0.0	0.0	25.0	3.1	7.4	236.6	2.6	17.5
10	38.9	0.0	0.0	0.0	0.0	0.0	0.0	16.4	55.3	6.9	14.2	204.7	5.0	33.5
11	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.8	0.1	0.3	282.8	0.1	0.7
12	0.0	0.0	0.0	0.0	54.1	0.0	0.0	0.0	54.1	6.8	19.1	282.8	6.8	45.2
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	6.4	0.0	0.0	0.0	0.0	0.0	6.4	0.8	2.3	282.8	0.8	5.4
16	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.6	1.2	3.4	282.8	1.2	8.1
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	11.5	17.3	0.0	0.0	0.0	0.0	0.0	28.9	3.6	6.9	190.1	2.4	16.2
20	0.0	0.0	0.0	0.0	72.3	0.0	0.0	1.0	73.3	9.2	25.5	278.4	9.0	60.4
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	6.0	11.5	0.0	4.8	0.0	0.0	0.0	4.8	27.1	3.4	4.2	123.2	1.5	9.9
23	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.5	1.3	282.8	0.5	3.2
26	0.0	0.0	0.0	0.0	0.0	17.5	0.0	0.0	17.5	2.2	6.2	282.8	2.2	14.7
27	0.0	0.0	6.4	6.4	0.0	0.0	1.9	15.6	30.3	3.8	5.5	146.2	2.0	13.1
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	103.9	16.4	307.1	427.4	53.4	108.6	203.2	38.4	256.8
30	0.0	0.0	0.0	0.0	0.0	0.0	17.3	0.8	18.2	2.3	6.1	268.3	2.2	14.4
31	0.0	3.4	0.0	3.9	59.1	0.0	0.0	0.0	66.4	8.3	20.6	248.1	7.3	48.7
32	0.0	0.0	0.0	0.0	0.0	128.4	0.0	0.0	128.4	16.1	45.4	282.8	16.1	107.4
33	43.1	0.0	1.9	0.0	0.0	0.0	0.0	53.0	98.0	12.3	22.3	181.7	7.9	52.6

36	3.3	3.6	5.4	2.1	0.0	0.0	0.0	0.0	14.4	1.8	2.1	117.6	0.8	5.0
37	0.0	12.1	0.0	1.8	0.0	0.0	0.0	0.0	13.9	1.7	4.2	244.0	1.5	10.0
38	10.5	0.0	0.0	0.0	25.9	0.0	0.0	0.0	36.4	4.5	9.4	206.3	3.3	22.2
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	0.0	5.2	0.0	0.0	0.0	0.0	0.0	0.0	5.2	0.7	1.8	282.8	0.7	4.4
42	0.0	0.0	0.7	0.0	0.0	0.0	0.0	15.9	16.6	2.1	5.6	269.5	2.0	13.2
43	0.0	1.8	3.4	0.0	0.0	0.0	0.0	0.0	5.2	0.6	1.3	196.2	0.5	3.0
46	0.0	11.6	3.2	0.0	0.0	0.0	0.0	0.0	14.9	1.9	4.1	221.1	1.5	9.7
47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	3.7	1.6	1.3	1.5	6.3	6.8	1.0	11.2						
SD	10.0	3.7	3.3	5.1	17.7	26.8	3.9	50.9						
CV%	267.1	227.5	245.3	336.6	281.5	397.3	401.7	454.1						

$$Y = \exp\{-2.922 + 0.99 * \ln(D2H\rho)\}$$

Where SD is standard deviation, CV% is coefficient of variance in percent, SE is standard error and CI confident interval at 95%.

Table VBEF1 Gelawudewose main tree species in each plot above ground biomass (ton/ha.

Plot	*Albizia gummifera*	*Buddleia polystachya*	*Croton macrostachyus*	*Chionanthus mildbraedii*	*Podocarpus falcatus*	*Teclea nobilis*	*Others*	*Plot sum*	*Plot mean*	*Plot SD*	*Plot CV%*	*Plot SE*	*Plot CI*
1	37.8	0.0	0.0	318.9	0.0	4.1	104.5	465.3	66.5	117.7	177.1	44.5	108.9
2	0.0	0.0	1.7	101.0	0.0	0.0	33.7	136.5	19.5	38.1	195.2	14.4	35.2
3	0.0	0.0	14.9	42.3	0.0	11.9	17.6	86.8	12.4	15.2	122.7	5.8	14.1
4	21.3	3.7	0.0	0.0	0.0	0.0	53.3	78.3	11.2	20.1	180.0	7.6	18.6
5	0.0	0.0	11.0	0.0	0.0	0.0	13.6	24.5	3.5	6.0	172.1	2.3	5.6
6	0.0	0.0	18.3	0.0	0.0	0.0	30.7	49.0	7.0	12.5	178.2	4.7	11.5
7	0.0	0.0	0.0	79.1	0.0	0.0	204.9	284.0	40.6	78.2	192.8	29.6	72.4
8	0.0	0.0	0.0	0.0	0.0	0.0	68.7	68.7	9.8	26.0	264.6	9.8	24.0
9	0.0	0.0	0.0	0.0	0.0	0.0	349.1	349.1	49.9	131.9	264.6	49.9	122.0
10	0.0	0.0	4.7	92.9	0.0	0.0	28.5	126.1	18.0	34.6	192.3	13.1	32.0
11	0.0	0.0	0.0	16.7	0.0	0.0	22.1	38.8	5.5	9.6	173.1	3.6	8.9
12	0.0	0.0	0.0	637.1	0.0	7.7	8.2	653.0	93.3	239.8	257.1	90.6	221.8
13	0.0	2.8	74.2	0.0	0.0	0.0	79.2	156.1	22.3	37.2	166.7	14.1	34.4
14	0.0	0.0	0.0	126.9	0.0	47.6	43.1	217.7	31.1	47.4	152.4	17.9	43.8
15	0.0	0.0	0.0	0.0	0.0	27.7	75.9	103.6	14.8	28.9	194.9	10.9	26.7
17	0.0	0.0	0.0	0.0	0.0	0.0	201.5	201.5	28.8	76.2	264.6	28.8	70.4
18	0.0	0.0	6.6	0.0	0.0	0.0	0.8	7.4	1.1	2.4	231.9	0.9	2.3
19	0.0	0.0	0.0	0.0	0.0	0.0	9.6	9.6	1.4	3.6	264.6	1.4	3.4
20	0.0	0.0	5.9	180.2	0.0	0.0	0.0	186.1	26.6	67.8	255.0	25.6	62.7
21	0.0	0.0	0.0	42.3	0.0	0.0	60.3	102.6	14.7	25.6	174.4	9.7	23.6
22	0.0	0.0	4.9	175.7	62.7	0.0	101.8	345.1	49.3	68.5	139.0	25.9	63.4
23	0.0	0.0	0.0	304.5	40.6	0.0	0.4	345.5	49.4	113.5	230.0	42.9	105.0
24	0.0	0.0	39.5	156.0	21.8	0.0	104.6	322.0	46.0	61.3	133.2	23.2	56.7
25	0.0	0.0	0.0	89.3	0.0	0.0	9.9	99.3	14.2	33.3	235.1	12.6	30.8
26	0.0	0.0	0.0	55.3	0.0	0.0	273.1	328.4	46.9	101.9	217.1	38.5	94.2
27	0.0	0.0	3.5	0.0	0.0	0.0	48.3	51.8	7.4	18.1	244.3	6.8	16.7

28	48.0	0.0	0.0	0.0	0.0	0.0	0.0	48.0	6.9	18.1	264.6	6.9	16.8
29	0.0	0.0	18.7	269.9	0.0	5.4	9.2	303.2	43.3	100.2	231.2	37.9	92.6
30	4.6	0.0	21.9	61.0	0.0	0.0	6.2	93.7	13.4	22.4	167.2	8.5	20.7
31	43.4	30.2	2.5	0.0	0.0	0.0	20.1	96.1	13.7	17.7	129.0	6.7	16.4
32	0.0	0.0	0.0	0.0	0.0	0.0	92.3	92.3	13.2	34.9	264.6	13.2	32.3
33	105.6	11.4	0.0	0.0	0.0	0.0	1.9	118.9	17.0	39.3	231.3	14.9	36.4
34	21.8	0.0	0.0	0.0	0.0	0.0	95.5	117.3	16.8	35.7	212.8	13.5	33.0
Mean	8.6	1.5	6.9	83.3	3.8	3.2	65.7						
SD	21.9	5.6	14.9	136.0	13.2	9.6	82.6						
CV%	255.4	382.4	216.0	163.2	348.3	303.4	125.7						

$$VBEF = V * p * BEF$$

Where SD is standard deviation, CV% is coefficient of variance in percent, SE is standard error and CI confident interval at 95%.

Table VBEF2 Injibara main tree species in each plot above ground biomass (ton/ha).

Plot	*Acacia abyssinica*	*Albizia gummifera*	*Allophylus abyssinicus*	*Bugtsi*	*Croton macrostachyus*	*Gimbltini*	*Kenebela*	*Prunus africana*	*Others*	*Plot sum*	*Plot mean*	*Plot SD*	*Plot CV%*	*Plot SE*	*Plot CI*
3	0.0	74.4	17.1	0.0	0.0	1.5	0.0	0.0	5.1	98.2	10.9	24.5	224.4	8.2	18.8
4	0.0	48.9	0.0	0.0	9.0	0.0	0.0	0.0	0.0	58.0	6.4	16.2	251.7	5.4	12.5
6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	86.4	86.4	9.6	28.8	300.0	9.6	22.1
7	0.0	14.3	0.0	0.0	11.0	0.0	0.0	0.0	0.0	25.3	2.8	5.6	200.7	1.9	4.3
8	24.1	0.0	0.0	0.0	1.8	0.0	0.0	0.0	1.9	27.9	3.1	7.9	255.6	2.6	6.1
9	11.1	0.0	0.0	0.0	0.9	0.0	0.0	0.0	1.9	14.0	1.6	3.6	235.0	1.2	2.8
10	0.0	145.8	40.4	54.6	0.0	0.0	0.0	0.0	0.0	240.8	26.8	49.3	184.2	16.4	37.9
11	0.0	100.6	0.0	0.0	10.9	0.0	0.0	0.0	1.4	113.0	12.6	33.2	264.7	11.1	25.5
12	0.0	107.0	16.0	0.0	0.0	0.0	0.0	0.0	9.5	132.5	14.7	35.1	238.2	11.7	27.0
13	0.0	53.0	0.0	0.0	0.9	0.0	5.1	0.0	155.1	214.2	23.8	52.2	219.4	17.4	40.1
14	0.0	113.6	0.0	0.0	0.8	0.0	0.0	0.0	1.2	115.6	12.8	37.8	294.2	12.6	29.1
17	0.0	40.3	0.0	0.0	0.0	0.0	0.0	56.2	1.1	97.6	10.8	21.6	199.1	7.2	16.6
18	0.0	17.1	0.0	4.2	3.3	36.9	14.0	37.2	1.2	114.0	12.7	15.1	119.2	5.0	11.6
19	19.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.4	2.7	6.4	234.4	2.1	4.9
20	0.0	13.4	0.0	23.4	0.0	1.3	0.0	111.3	0.0	149.4	16.6	36.5	219.7	12.2	28.0
21	0.0	11.5	0.0	0.0	17.7	14.3	0.0	2.1	7.6	53.2	5.9	7.1	119.2	2.4	5.4
22	0.0	92.7	0.0	0.0	0.0	12.1	16.6	0.0	152.4	273.9	30.4	54.7	179.7	18.2	42.0
23	0.0	1.1	0.0	0.0	22.5	18.3	4.7	87.0	3.1	136.8	15.2	28.2	185.6	9.4	21.7
24	0.0	2.1	0.0	0.0	40.6	13.0	0.0	3.6	6.2	65.5	7.3	13.2	181.5	4.4	10.1
25	0.0	52.8	0.0	7.8	0.0	0.0	11.4	37.2	202.4	311.5	34.6	65.7	189.8	21.9	50.5
26	0.0	58.0	9.1	0.0	0.0	6.1	0.0	0.0	22.8	96.0	10.7	19.3	181.0	6.4	14.8
27	0.0	18.6	24.5	0.0	0.0	0.0	0.0	201.2	6.9	251.1	27.9	65.6	235.2	21.9	50.4
29	0.0	0.0	0.0	0.0	52.3	0.0	0.0	0.0	47.7	100.0	11.1	22.1	198.7	7.4	17.0
30	0.0	105.7	23.4	0.0	63.7	0.0	7.9	73.3	15.2	289.2	32.1	39.0	121.3	13.0	30.0
31	0.0	27.0	0.0	0.0	31.7	5.4	0.0	32.1	31.5	127.7	14.2	15.7	110.7	5.2	12.1

32	0.0	30.4	0.0	0.0	0.0	22.2	7.5	20.9	107.9	189.0	21.0	34.6	164.9	11.5	26.6
33	0.0	12.8	0.0	0.0	1.1	5.8	15.8	70.3	76.6	182.4	20.3	30.7	151.7	10.2	23.6
34	0.0	2.5	0.0	16.6	6.8	4.0	1.5	237.5	1.4	270.3	30.0	78.0	259.7	26.0	59.9
35	0.0	22.3	0.0	0.0	2.5	7.9	7.8	0.0	357.6	398.1	44.2	117.7	266.2	39.2	90.5
36	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	14.7	1.6	3.3	198.7	1.1	2.5
37	0.0	0.9	0.0	0.0	5.6	0.0	0.0	0.0	24.6	31.1	3.5	8.1	236.1	2.7	6.3
38	0.0	0.0	0.0	0.0	7.2	0.0	0.0	0.0	0.0	7.2	0.8	2.4	300.0	0.8	1.8
39	0.0	93.2	9.5	1.5	9.0	0.0	1.3	0.0	2.4	117.0	13.0	30.3	233.2	10.1	23.3
40	0.0	99.0	6.8	1.1	2.9	1.8	0.0	0.0	8.3	119.9	13.3	32.3	242.1	10.8	24.8
41	0.0	45.4	0.0	0.0	10.9	10.0	0.0	0.0	16.6	82.9	9.2	15.0	162.3	5.0	11.5
42	0.0	72.7	20.0	0.0	0.0	1.0	12.1	56.2	67.0	229.0	25.4	30.9	121.6	10.3	23.8
43	0.0	70.0	0.0	0.0	14.7	0.0	1.2	31.2	71.6	188.7	21.0	30.1	143.7	10.0	23.2
44	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	2.9	0.3	1.0	300.0	0.3	0.7
45	0.0	25.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.5	2.8	8.5	300.0	2.8	6.5
47	0.0	2.8	0.0	0.0	33.3	0.0	0.0	0.0	0.0	36.2	4.0	11.0	274.4	3.7	8.5
48	0.0	86.0	0.0	0.0	5.1	0.0	1.2	2.2	6.1	100.6	11.2	28.1	251.8	9.4	21.6
49	0.0	6.4	0.0	3.1	10.8	1.3	0.0	0.0	8.5	30.1	3.3	4.2	125.6	1.4	3.2
50	0.0	20.7	0.0	6.3	6.1	0.0	0.0	0.0	20.2	53.3	5.9	8.6	145.9	2.9	6.6
51	0.0	82.8	0.0	0.0	0.0	1.8	14.7	64.4	0.0	163.8	18.2	32.1	176.5	10.7	24.7
53	0.0	34.1	0.0	0.0	11.7	0.0	10.5	0.0	414.8	471.1	52.3	136.4	260.6	45.5	104.8
54	7.3	0.0	0.0	0.0	6.4	0.0	0.0	1.4	3.1	18.1	2.0	2.9	145.3	1.0	2.2
55	0.0	18.1	0.0	0.0	219.4	0.0	0.0	0.0	12.6	250.1	27.8	72.2	259.7	24.1	55.5
56	0.0	53.3	58.9	37.1	2.1	16.3	0.0	12.9	18.0	198.6	22.1	22.5	102.1	7.5	17.3
57	11.1	26.9	0.0	0.0	9.4	0.0	7.6	0.0	0.0	55.0	6.1	9.1	148.2	3.0	7.0
58	0.0	8.4	0.0	0.0	29.7	0.0	0.0	0.0	1.2	39.4	4.4	9.9	226.3	3.3	7.6
59	0.0	82.6	0.0	0.0	0.0	0.0	0.0	33.1	0.0	115.7	12.9	28.4	220.5	9.5	21.8
60	0.0	0.6	1.3	0.0	0.0	4.5	42.7	23.1	8.2	80.4	8.9	14.7	164.5	4.9	11.3
61	0.0	16.9	0.0	0.0	10.0	0.0	0.0	0.0	10.5	37.4	4.2	6.5	157.0	2.2	5.0
62	0.0	115.9	0.0	0.0	4.9	0.0	0.0	0.0	121.0	241.8	26.9	52.0	193.4	17.3	39.9
63	0.0	15.0	0.0	0.0	10.6	0.0	0.0	0.0	69.4	95.0	10.6	22.8	215.8	7.6	17.5
Mean	1.4	39.1	4.1	2.8	12.6	3.4	3.3	21.7	39.9						

SD	4.7	39.8	11.0	9.5	31.4	7.0	7.2	46.9	81.8
CV%	322.4	101.9	265.3	335.5	250.4	208.2	216.6	215.9	204.8

$$VBEF = V * p * BEF$$

Where SD is standard deviation, CV% is coefficient of variance in percent, SE is standard error and CI confident interval at 95%.

Table VBEF3 Metema main tree species in each plot above ground biomass (ton/ha).

Plot	*Ameja*	*Boswellia papyrifera*	*Sterculea setigera*	*Fola*	*Forha*	*Others*	*Plot sum*	*Plot mean*	*Plot SD*	*Plot CV%*	*plot SE*	*Plot CI*
1	0.0	0.0	0.0	3.1	3.3	4.9	11.3	1.9	2.1	114.1	0.9	2.3
2	0.0	4.4	0.0	0.0	0.0	54.4	58.7	9.8	21.9	223.8	8.9	23.0
3	0.0	0.0	0.0	6.8	8.3	47.9	63.0	10.5	18.7	178.1	7.6	19.6
4	5.8	5.1	24.4	0.0	0.0	19.0	54.4	9.1	10.2	113.0	4.2	10.8
5	0.9	22.8	29.3	0.0	0.0	26.9	79.9	13.3	14.4	108.3	5.9	15.1
6	3.8	43.2	0.0	10.1	6.9	8.1	72.1	12.0	15.7	130.4	6.4	16.4
7	2.4	4.7	0.2	1.1	0.0	25.3	33.8	5.6	9.8	174.1	4.0	10.3
8	11.1	11.7	0.0	9.5	4.2	62.1	98.5	16.4	22.8	138.9	9.3	23.9
9	**0.0**	0.0	13.6	6.6	12.1	33.0	65.3	10.9	12.3	112.8	5.0	12.9
10	**0.0**	0.0	19.6	0.0	5.1	28.1	52.7	8.8	12.1	137.9	4.9	12.7
11	**0.0**	0.0	0.0	0.0	0.0	4.3	4.3	0.7	1.8	244.9	0.7	1.8
12	**0.0**	0.0	0.0	0.0	0.0	59.4	59.4	9.9	24.3	244.9	9.9	25.5
13	4.7	0.0	0.0	9.8	0.0	31.9	46.4	7.7	12.5	161.2	5.1	13.1
14	0.0	0.0	0.0	0.0	0.0	37.3	37.3	6.2	15.2	244.9	6.2	16.0
15	0.0	19.7	0.0	0.0	0.0	22.9	42.6	7.1	11.0	155.5	4.5	11.6
16	0.0	3.7	53.4	2.8	0.0	2.9	62.8	10.5	21.1	201.7	8.6	22.2
17	0.0	0.0	0.0	0.0	0.0	97.7	97.7	16.3	39.9	244.9	16.3	41.9
18	1.5	40.6	0.0	1.4	0.0	16.8	60.4	10.1	16.3	162.1	6.7	17.1
20	0.0	0.0	0.0	0.0	0.0	26.3	26.3	4.4	10.7	244.9	4.4	11.3
21	5.9	0.0	0.0	0.0	0.2	47.6	53.7	8.9	19.1	213.4	7.8	20.0
Mean	1.8	7.8	7.0	2.6	2.0	32.8						
SD	3.0	13.4	14.3	3.7	3.5	23.5						
CV%	166.6	172.2	203.6	146.5	176.2	71.6						

$VBEF = V * p * BEF$

Where SD is standard deviation, CV% is coefficient of variance in percent, SE is standard error and CI confident interval at 95%.

Table VBEF 4 Tara Gedam main tree species in each plot above ground biomass (ton/ha).

Plot	*Acacia abysynica*	*Albizia schimperiana*	*Buddleia polystachya*	*Croton macrostachyus*	*Juniperus procera*	*Olea europaea*	*Teclea nobilis*	*Others*	*Plot sum*	*Plot mean*	*Plot SD*	*Plot CV%*	*Plot SE*	*Plot CI*
1	0.0	0.0	0.0	58.9	0.0	0.0	0.0	0.0	58.9	7.4	20.8	282.8	7.4	17.4
3	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	2.1	0.3	0.7	282.8	0.3	0.6
5	0.0	0.0	0.0	11.0	0.0	0.0	0.0	0.0	11.0	1.4	3.9	282.8	1.4	3.2
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	3.4	0.0	2.4	0.0	58.7	0.0	0.0	0.0	64.5	8.1	20.5	254.4	7.2	17.1
9	39.9	0.0	8.6	0.0	0.0	0.0	0.0	0.0	48.5	6.1	14.0	230.7	4.9	11.7
10	65.9	0.0	0.0	0.0	0.0	0.0	0.0	34.2	100.1	12.5	24.7	197.1	8.7	20.6
11	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	2.1	0.3	0.7	282.8	0.3	0.6
12	0.0	0.0	0.0	0.0	136.8	0.0	0.0	0.0	136.8	17.1	48.4	282.8	17.1	40.4
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	16.7	0.0	0.0	0.0	0.0	0.0	16.7	2.1	5.9	282.8	2.1	4.9
16	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.0	2.1	6.0	282.8	2.1	5.0
17	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	19.3	40.9	0.0	0.0	0.0	0.0	0.0	60.2	7.5	15.1	200.4	5.3	12.6
20	0.0	0.0	0.0	0.0	202.4	0.0	0.0	3.2	205.6	25.7	71.4	277.9	25.2	59.7
21	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	11.5	16.0	0.0	12.5	0.0	0.0	0.0	11.2	51.3	6.4	7.0	109.2	2.5	5.9
23	7.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	1.0	2.7	282.8	1.0	2.3
26	0.0	0.0	0.0	0.0	0.0	30.1	0.0	0.0	30.1	3.8	10.6	282.8	3.8	8.9
27	0.0	0.0	12.4	13.7	0.0	0.0	4.0	40.6	70.8	8.8	14.0	158.7	5.0	11.7
28	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	190.3	29.5	368.	587.9	73.5	136.0	185.0	48.1	113.7
30	0.0	0.0	0.0	0.0	0.0	0.0	32.5	2.5	34.9	4.4	11.4	260.6	4.0	9.5

31	0.0	6.9	0.0	8.6	141.7	0.0	0.0	0.0	157.2	19.6	49.5	251.7	17.5	41.3
32	0.0	0.0	0.0	0.0	0.0	226.4	0.0	0.0	226.4	28.3	80.0	282.8	28.3	66.9
33	80.1	0.0	4.7	0.0	0.0	0.0	0.0	107.0	191.8	24.0	43.6	181.7	15.4	36.4
36	7.3	7.6	14.1	4.9	0.0	0.0	0.0	21.9	55.7	7.0	7.8	111.9	2.8	6.5
37	0.0	21.4	0.0	4.2	0.0	0.0	0.0	0.0	25.5	3.2	7.5	234.7	2.6	6.3
38	18.2	0.0	0.0	0.0	60.6	0.0	0.0	0.0	78.8	9.8	21.5	217.9	7.6	17.9
40	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
41	0.0	10.3	0.0	0.0	0.0	0.0	0.0	0.0	10.3	1.3	3.6	282.8	1.3	3.0
42	0.0	0.0	2.0	0.0	0.0	0.0	0.0	42.1	44.1	5.5	14.8	268.7	5.2	12.4
43	0.0	4.0	7.2	0.0	0.0	0.0	0.0	0.0	11.2	1.4	2.7	195.4	1.0	2.3
46	0.0	19.6	7.7	0.0	0.0	0.0	0.0	0.0	27.3	3.4	7.1	207.5	2.5	5.9
47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
51	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	6.8	2.8	3.2	3.2	16.2	12.1	1.8	17.0						
SD	17.9	6.2	7.7	10.1	46.3	48.0	7.1	62.7						
CV%	263.8	219.7	245.3	317.6	285.4	397.6	398.9	367.6						

$$VBEF = V * p * BEF$$

Where SD is standard deviation, CV% is coefficient of variance in percent, SE is standard error and CI confident interval at 95%.