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**ESTIMATION OF WOOD VOLUME OF TREES OUTSIDE FORESTS (TROF)  
IN NUWARA ELIYA DISTRICT OF SRI LANKA  
AS A MEASURE OF CARBON STOCK**

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*Summary*

*The potential of Trees Outside Forest (TROF) systems to act as a sink for carbon (C) is of high interest. However, estimations of C stocks of TROF systems are lacking in Sri Lanka. Therefore, the objective of this study was to identify distribution of TROF systems among agro-ecological regions in Nuwara Eliya District and to estimate tree density variation and wood volume of each TROF system as a measure of C stock of the district. Five classes of TROF systems were identified using medium resolution Landsat ETM satellite images. Since agro-ecological conditions play a vital role in growth of trees, TROF systems were further sub-divided according to agro-ecological regions. A total of 251 sample points of 400 m<sup>2</sup> were established to collect tree measurements. Volume of each tree within each TROF system was calculated using volume functions. Different form factors were used for volume estimation based on calculations, and also based on shape and the tapering of the stem of trees. Highest tree density (565 trees/ha) was recorded in homegarden TROF systems located in IU<sub>2</sub> agro-ecological region whereas lowest tree density was recorded in the annual crop based TROF system. Among the TROF systems highest and lowest wood volume per ha were recorded in the homegardens (86.1 m<sup>3</sup>/ha) and in annual crop based TROF systems (0.89 m<sup>3</sup>/ha). Estimated wood density was mapped and total wood volume of the district was estimated at 5.553 million m<sup>3</sup>. Total estimated biomass and carbon stock of TROF systems of Nuwara Eliya District were estimated at 5,194.8 Gg and 2,604.6 Gg, respectively.*

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## INTRODUCTION

Forest cover of Sri Lanka has been decreasing continuously at an alarming rate over the years resulting social, economic and environmental problems (FSMP, 1995). Decreasing forest cover leads to decrease in availability of forest products and environmental and other services which in turn will create a need for the protection of existing natural forests and searching for alternative strategies to obtain forest products and environmental services (FSMP, 1995; Gamage, 1995; Gunawardane, 2003; World Agroforestry Centre, 2007). Plantation forestry has been identified as an important option for obtaining timber and fuelwood and also an option for climate change mitigation through sequestration of carbon (Costa and Suranga, 2012), though the annual rate of expansion of plantation forestry is marginal in Sri Lanka (FSMP, 1995). Alternatively, Trees Outside Forests (TROFs) is also identified as one of the alternative sources which provide goods and services similar to forests though the magnitude may differ (Kleinn, 2000; World Agroforestry Centre, 2007). Recent studies at national and international levels revealed that the number of trees outside forests is in increasing trend whilst the number of trees in natural forests is in decreasing trend (World Agroforestry Centre, 2007). Currently, it is recognized that TROF embrace not only many ecological functions, such as conservation of biodiversity, erosion control, and carbon sequestration, but also economic functions, such as provision of firewood, fodder, fence posts,

and living fence posts. The presence of forests and TROFs increases ecosystem resilience and the capacity of people to meet their nutritional needs (FAO, 2013). Although TROF is an important resource base in Sri Lanka due to many reasons, information about their distribution in terms of quality and quantity is scattered and not accurate. Only if information on TROFs is available their impact on economy and ecological processes can be quantified and strategies for sustainable management can be developed.

Forest inventory is an accounting of trees and their related characteristics of interest over a well defined land area which provides quantitative information on volume of timber and structural composition of the forest (Scott and Gove, 2002). Similarly, inventory of TROFs is an accounting of trees and their related characteristics in an area concerned. However, methodology to assess TROF resources is at its early stage. Even though forests and TROFs have some similarities, there are many differences that have to be considered in TROF inventories. These differences may be the biophysical and socio-economic characteristics of the resource base (Kleinn, 2000). TROF is a highly heterogeneous resource base for which it is difficult to devise a unified classification system. Thus, assessment of TROF has marked differences from traditional plantation and natural forest surveys (Giri, 2004). In Nuwara Eliya District, five major TROF systems of Sri Lanka have been recorded representing more than 50% of its land area (Premakantha *et al.*, 2008) and 14 of 46 agro-ecological regions of the country are also identified from the district (Punyawardena, 2007; Figure 1).

Therefore, the objective of the present work was to estimate the total carbon stocks of TROF systems in Nuwara Eliya District. The specific objectives of the research were to: (i) identify distribution of TROF systems among agro-ecological regions of Nuwara Eliya District; (ii) estimate tree density variation of each TROF systems; and (iii) estimate wood volume of each system as a measure of estimation of carbon stock of TROF systems.

## MATERIALS AND METHODS

### Study area and sampling design

Nuwara Eliya District was selected for the study due to the presence of natural forest ecosystems, major TROF systems and a reasonable number of agro-ecological regions.

Since tree planting outside forests may vary according to agro-ecology, land size, land tenure and socio-economic factors, the assessment method has to consider all such. Thus, stratified

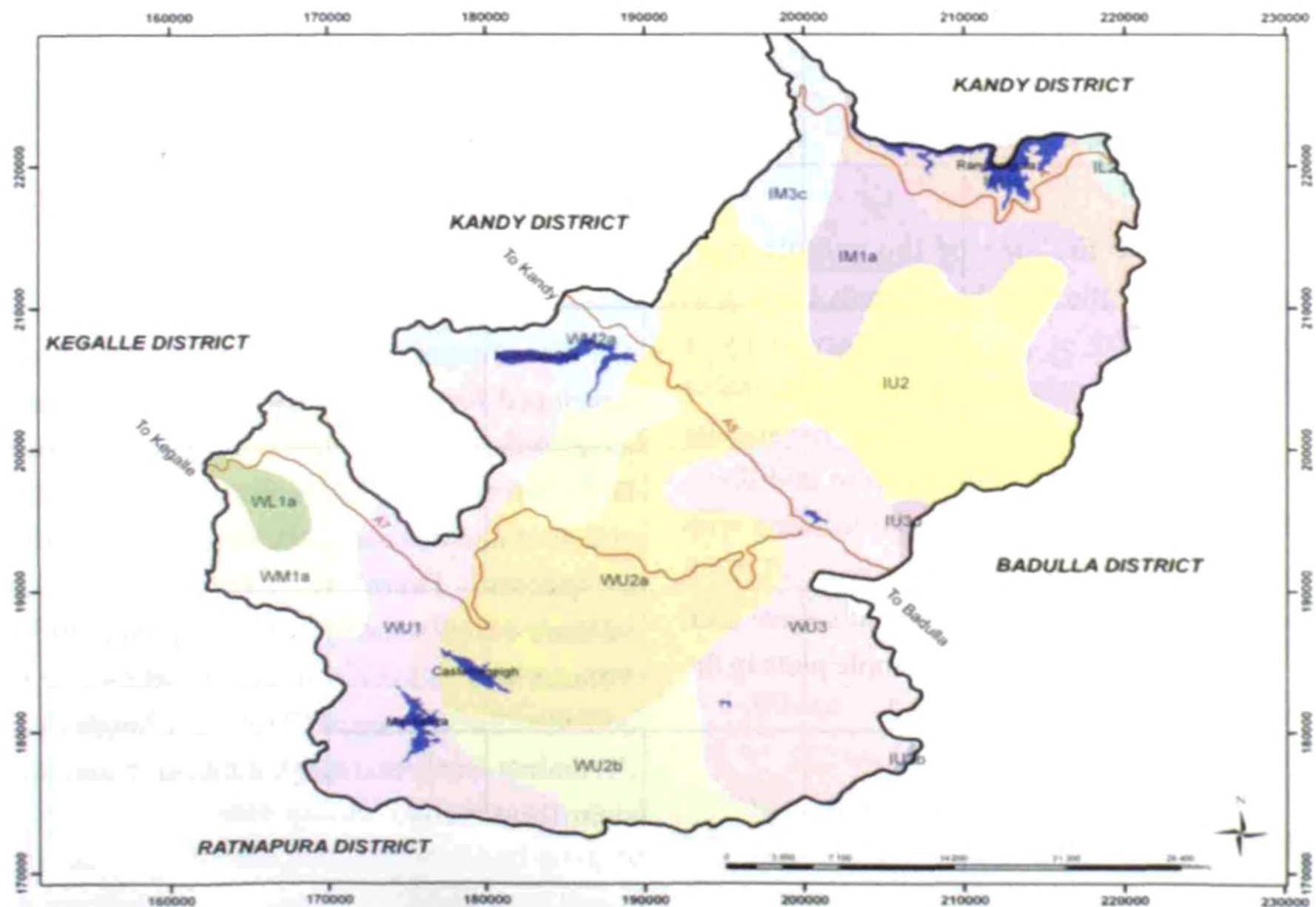


Figure 1: The variation of agro-ecological regions, in the study area

random sampling was selected to divide heterogeneous tree populations into sub-populations, known as strata. In stratification of the study area, map of TROF systems was overlaid with the agro-ecological regions developed by Punyawardena (2007). Spatial distribution map of TROF systems of Nuwara Eliya District was obtained from Premakantha *et al* (2008). Once TROF systems overlaid, the area of sub systems were identified and samples were allocated according to the proportion of area. In this study, area under roadside planting and stream reservations were not considered as separate TROF systems since they are included in other TROF systems.

### **Size and shape of plot**

To decide the size of the sample plot, minimum curvature method (Smith 1938) was tested. Results of the preliminary analysis revealed that 400 m<sup>2</sup> sample plots are reasonable in size to capture the variance. Thus, rectangular plots of 400 m<sup>2</sup> (100 x 40 m) were laid down after navigation into the sample location with the help of Trimble Geo Explorer XT GPS receiver. A total of 251 sample plots were used in this study. Distribution of sample plots in the study area is shown in Figure 2.

### **Field measurements**

Field measurements were taken only from trees having the diameter at breast height (dbh) greater than 10 cm and all others were

considered as seedlings/saplings. In each sample plot, in all trees above 10 cm dbh, diameter measurements were taken using a dbh tape to the nearest 0.1 cm accuracy according to the guideline of the Inventory Manual of Forest Department (1996) whereas total tree heights were measured using a clinometer to the nearest meter. The slope of each sample plot was also recorded to correct the area of sample plots. Some sample locations of grasslands had to be changed because of inaccessibility due to steepness of the land and unavailability of access roads. Reaching these areas takes longer time which is not worth since the representative sample could be taken from adjacent areas.

### **Volume calculation and estimation of carbon stock**

There are only a few volume functions developed for species grown in Sri Lanka and most of them are for plantation species (Forest Department, 1996). Even from other countries volume functions cannot be found for majority of species. Therefore, a basic formula of volume calculation was used in this study. Volume was estimated in cubic meters and is considered a function of (i) total tree height (m); (ii) diameter at breast height (dbh; cm); and (iii) stem form factor.

Twenty five trees each were felled from coconut and arecanut and measurement of diameters and lengths of each log were taken

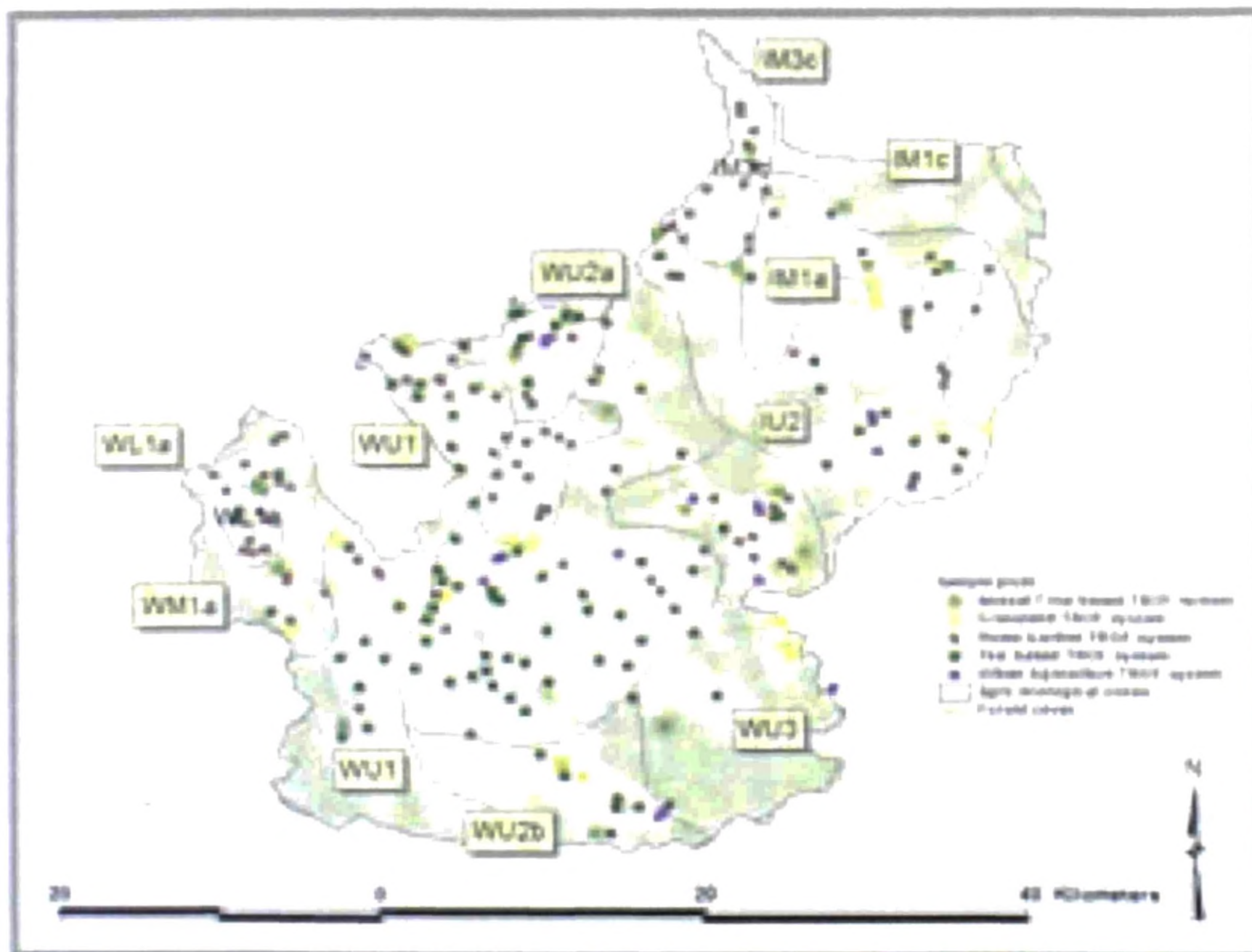


Figure 2: Distribution of 251 sample points in the study area.

for volume calculation. Data for Pinus and Eucalyptus were obtained from the records from the Forest Department. Log data for halmilla were obtained from a felling site of Kurunegala Plantation Ltd. Accordingly, the form factor for each species was calculated. These form factors were also used as a guild to assign form factors to other species. In order to identify form factor of other species, they were observed in sample plots and photographed and grouped according to the shape of the stem. Then, a form factor was assigned to each group as given in Table 1, and was used in the volume calculation.

Individual tree volume was calculated using the Equation 1.

$$V = n \times (dbh / 200)^2 \times h \times f \text{ ----- Equation 1}$$

Where,

- V=individual tree volume (m<sup>3</sup>)
- dbh=the diameter at breast height (cm)
- h=total tree height (m)
- f=form factor,
- n=3.141592

Biomass density was calculated from wood volume per hectare by first estimating the biomass of the inventoried volume and then “expanding” this value to take into account the biomass of the other aboveground components as given in Equation 2. (Brown and Lugo, 1992).

$$\text{AGB Density (m}^3\text{/ha)} = \text{WVOB} \times \text{WD} \times \text{BEF}$$

----- Equation 2

Where,

WVOB = Wood volume over bark (m<sup>3</sup>),

WD = Wood density (kg/m<sup>3</sup>),

BEF = Biomass expansion factor

Accordingly, aboveground biomass (AGB) content was estimated using the Equation 3 as suggested by Cost *et al.* (1990).

$$\text{AGB} = 1.6 p \times n \times (\text{dbh} / 200)^2 h \times f$$

----- Equation 3

Where,

1.6 is the biomass expansion factor.

*p* = wood density (kg/m<sup>3</sup>)

Belowground biomass is also an important component in TROF systems because it comprises a relatively high proportion of the ecosystem and the contribution in terms of carbon sequestration is substantial.

**Table 1: The form factors used in the study based on the shape of the trees**

Tree species	Form factor
Jakfruit ( <i>Artocarpus heterophyllus</i> Lam.)	
Mango ( <i>Mangifera indica</i> L.)	
Mahogany ( <i>Swietenia macrophylla</i> King)	
Burutha ( <i>Chloroxylon swietenia</i> DC)	0.45
Arecanut ( <i>Areca catechu</i> L.)	0.44
Pinus ( <i>Pinus caribaea</i> L.)	
Coconut ( <i>Cocos nucifera</i> L.)	
Kitul ( <i>Caryota urens</i> L.)	0.37
Lunumidella ( <i>Melia azedarach</i> L.)	
Mee ( <i>Madhuca longifolia</i> (L.) Macbride)	
Toona ( <i>Toona sinensis</i> M. Roemer.)	
Halmilla ( <i>Berrya cordifolia</i> (Willd) Burret.)	0.35
<i>Eucalyptus</i> Species	0.33
All Others	0.30

As Cairns *et al.* (1997) suggested the following equation (Equation 4) was used in calculating belowground biomass.

$$BBD = \exp (-1.0587+0.8836 \times \ln (ABD))$$

----- Equation 4

Where,

BBD = Belowground biomass density (t/ha),

ADB = Aboveground biomass density (t/ha)

Total biomass of the tree components of TROF systems was estimated by adding the aboveground and the belowground biomasses. Finally, carbon content of tree component of TROF systems was estimated by multiplying total biomass by 0.50 as the average carbon content of biomass to be 50% (Birdsey, 1992; Sampson, 1992).

## RESULTS AND DISCUSSION

Average tree density of five TROF systems varied from 8 to 383 trees/ha (Table 2). Highest tree density was recorded from homegarden TROF systems while least tree density was recorded from annual crop based TROF systems. Average tree density of TROF systems in different agro-ecological regions varied from 64 to 412 trees/ha (Table 3).

Total wood volume in all TROF systems of Nuwara Eliya District was estimated at 5.553 million m<sup>3</sup>. The variation of total wood volume according to TROF systems and agro-ecological regions are given in Tables 4 and 5, respectively.

About 96% of wood volume of Nuwara Eliya District is contributed by tea based TROF systems (53%) and homegardens (43%). IU2, WU2a and IM1a agro-ecological regions contributed over 56% wood volume of the district. Average and total wood volumes vary in the different agro-ecological regions mainly due to differences in the land extent and tree density. Least tree density and the lowest wood volumes were recorded in WU2b and WU3 agro-ecological regions where intensive agriculture, which avoids extensive tree planting to prevent effects of excessive shade on annual crops, is practised.

The contribution of top 10 tree species to the wood volume of three major TROF systems are given in Table 6. *Artocarpus heterophyllus* Lam. is the dominant contributor to the wood volume in both homegarden and urban TROF systems though magnitude of contribution is remarkably different (Table 6). In the tea based TROF systems, major contributor to wood volume was sabukku (*Grevillea robusta* A.Cunn. ex R.Br.). Distribution of wood density in Nuwara Eliya district is shown in Figure 3 and it ranges from 20-80 m<sup>3</sup>/ha.

The variation of aboveground biomass and carbon content according to TROF system and agro-ecological regions are given in Tables 7 and 8, respectively. The highest biomass and carbon content was reported from the tea based TROF systems. It is largely due to the total area of tea based TROF systems. However, homegarden TROF systems produced highest

**Table 2: Average tree density of TROF systems in Nuwara Eliya District.**

TROF system	Average tree density (trees/ha)	Range (trees /ha)
Homegarden TROF system	383	78-565
Tea based TROF system	86	25-150
Urban agricultural based TROF system	65	0-175
Grassland TROF system	27	0-50
Annual crop based TROF system	8	0-50

**Table 3: Tree density of Nuwara Eliya District according to agro-ecological regions**

Agro-ecological region	Average tree density (trees/ha)
IL <sub>2</sub>	249
IM <sub>1a</sub>	185
IM <sub>1c</sub>	291
IM <sub>3c</sub>	156
IU <sub>2</sub>	166
IU <sub>3b</sub>	166
IU <sub>3d</sub>	166
WL <sub>1a</sub>	412
WM <sub>1a</sub>	185
WM <sub>2a</sub>	194
WU <sub>1</sub>	135
WU <sub>2a</sub>	75
WU <sub>2b</sub>	64
WU <sub>3</sub>	90

**Table 4: Total wood volumes estimated in different TROF systems in Nuwara Eliya District**

TROF system	Extent (ha)	Total wood volume (m <sup>3</sup> )	Percentage
Homegarden TROF system	27,440	2,362,399	42.5
Tea based TROF system	79,182	2,935,791	52.9
Urban Agricultural TROF systems	3,885	171,165	3.1
Grassland TROF system	4,289	71,986	1.3
Annual crop based TROF systems	13,154	11,774	0.20
<b>Total</b>	<b>127,950</b>	<b>5,553,115</b>	<b>100.0</b>

**Table 5: Total wood volumes according to agro-ecological regions in Nuwara Eliya District**

Agro-ecological region	Extent (ha)	Total wood volume (m <sup>3</sup> )	Percentage
IL2	249	19,318	0.3
IM1a	13,487	745,142	13.4
IM1c	4,775	254,230	4.6
IM3c	5,731	212,977	3.8
IU2	20,059	1,512,963	27.2
IU3b	23	1,411	0.0
IU3d	228	15,508	0.3
WL1a	2,001	146,260	2.6
WM1a	6,616	425,009	7.7
WM2a	6,910	451,530	8.1
WU1	15,770	421,331	7.6
WU2a	29,177	822,958	14.8
WU2b	12,860	254,233	4.6
WU3	10,064	270,246	4.9
<b>Total</b>	<b>127,950</b>	<b>5,553,115</b>	<b>100.0</b>

**Table 7: Wood volume contribution from dominant tree species in three major TROF systems.**

Home garden TROF systems		Tea based TROF systems		Urban agricultural TROF systems	
Species	Wood volume (m <sup>3</sup> /ha)	Species	Wood volume (m <sup>3</sup> /ha)	Species	Wood volume (m <sup>3</sup> /ha)
<i>Artocarpus heterophyllus</i>	24.02	<i>Grevillea robusta</i>	20.39	<i>Artocarpus heterophyllus</i>	8.84
<i>Mangifera indica</i>	11.38	<i>Albizia falcataria</i>	3.39	<i>Eucalyptus grandis</i>	5.37
<i>Cocos nucifera</i>	8.60	<i>Toona sinensis</i>	2.28	<i>Cocos nucifera</i>	1.23
<i>Michelia champaca</i>	7.07	<i>Eucalyptus grandis</i>	1.03	<i>Michelia champaca</i>	0.92
<i>Ceiba pentandra</i>	7.05	<i>Erythrina variegata</i>	1.32	<i>Cypress macrocarpa</i>	0.52
<i>Eucalyptus grandis</i>	5.01	<i>Michelia champaca</i>	0.23	<i>Toona sinensis</i>	0.45
<i>Toona sinensis</i>	4.39	<i>Cypress - macrocarpa</i>	0.22	<i>Persea americana</i>	0.37
<i>Swietenia - macrophylla</i>	2.43	<i>Acacia decurrens</i>	0.06	<i>Acacia decurrens</i>	0.28
<i>Grevillea robusta</i>	2.39	<i>Gliricidia sepium</i>	0.11	<i>Mangifera indica</i>	0.23
<i>Albizzia lebbek</i>	1.91	<i>Calliandra calothyrsus</i>	0.02	<i>Syzygium aromaticum</i>	0.16

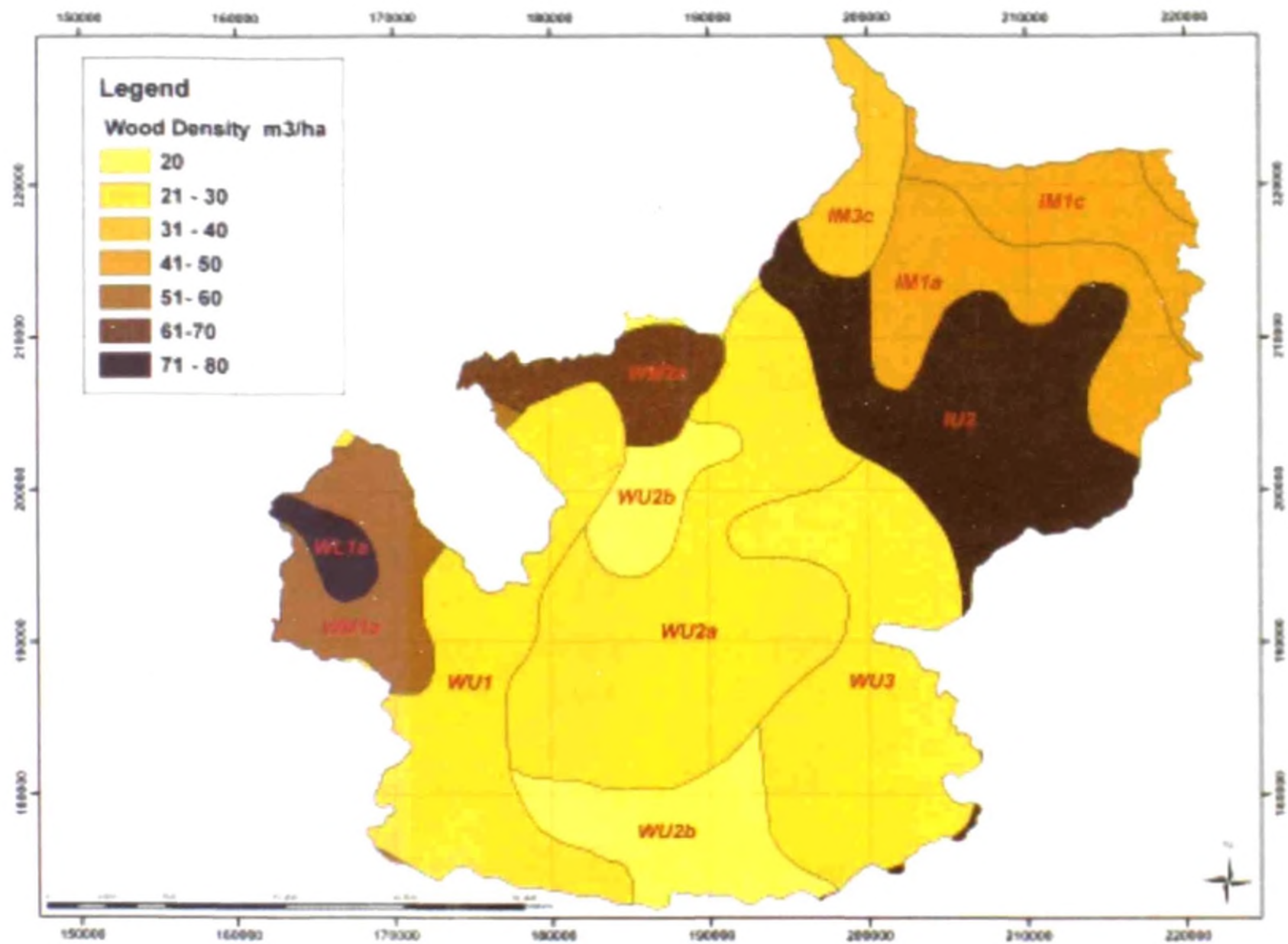


Figure 3: Estimated wood density ( $m^3/ha$ ) map of the Nuwara Eliya District.

amount of biomass amount of carbon per unit area 44.8 t/ha. In terms of agro-ecological regions, up country intermediate zone produced the highest amount of biomass and carbon content.

A summary of total aboveground and belowground biomass, total biomass and carbon contents in TROF systems of Nuwara Eliya District is given in Table 9. Accordingly, the

total estimated biomass and carbon content of TROF systems of Nuwara Eliya District amounted to 5,194.8 Gg and 2,604.6 Gg.

This is the first estimate of the wood volume and carbon content of TROF systems of Nuwara Eliya District and can be considered as baseline information for future assessments. For comparisons, no information is available on wood volumes or carbon content of TROF

**Table 7: Aboveground biomass and carbon stock in TROF systems in Nuwara Eliya District.**

TROF system	Extent (ha)	Aboveground		Below ground C content (Gg)	Total C content (Gg)	C content (t/ha)
		Biomass content (Gg)	C content (Gg)			
Homegarden TROF systems	27,440	2,154.5	1,077.3	152.9	1,230.2	44.8
Tea based TROF systems	79,182	2,677.4	1,338.7	185.3	1,524.0	19.2
Urban Agricultural TROF systems	3,885	65.6	32.8	7.0	39.8	10.2
Grassland TROF systems	4,289	156.1	78.1	15.0	93.1	21.7
Annual crop based TROF systems	13,154	10.7	5.3	1.4	6.7	0.5
<b>Total</b>	<b>127,950</b>	<b>5,064.4</b>	<b>2,532.2</b>	<b>361.7</b>	<b>2,893.9</b>	<b>22.6</b>

systems of Nuwara Eliya District or of any other part of the country. However, Costa and Suranga (2012) have estimated a total carbon stock of 751,549 t from 4,786 ha (157.03 t/ha) of monoculture and mixed plantation forests in Nuwara Eliya District in 2008. They also have estimated that the total carbon stock of an extent of 63,568 ha of monoculture and mixed plantations in Sri Lanka as 4.911 million tons (77.25 t/ha). Although per ha carbon stock is 7.8 times higher in plantation forests than TROF systems (Costa and Suranga, 2012), total carbon

stock of TROF systems in Nuwara Eliya District is 3.5 times higher than that of plantation forests in Nuwara Eliya District.

Carbon stock of the natural forests of Nuwara Eliya District was estimated using information from Mattsson *et al.* (2012) and calculated as 5,722.1 Gg. It is clear from the estimates of natural forests and forest plantations, TROF systems of Nuwara Eliya District also consists of a substantial stock of carbon. Thus, it is essential to develop strategies

**Table 8: Aboveground biomass and carbon contents in agro-ecological regions of Nuwara Eliya District**

Agro-ecological region	Extent(ha)	Aboveground biomass content (Gg)	Aboveground carbon content (Gg)
IL2	249	17.6	8.8
IM1a	13,487	679.6	339.8
IM1c	4,775	231.9	115.9
IM3c	5,731	194.2	97.1
IU2	20,059	1,379.8	689.9
IU3b	23	1.3	0.6
IU3d	228	14.1	7.1
WL1a	2,001	133.3	66.7
WM1a	6,616	387.6	193.8
WM2a	6,910	411.8	205.9
WU1	15,770	384.3	192.1
WU2a	29,177	750.5	375.3
WU2b	12,860	231.9	115.9
WU3	10,064	246.5	123.2
Total	127,950	5,064.4	2,532.2

and methodologies to use this carbon stock to calculate environmental services of TROF systems and also to increase carbon stock for the sustainable management of TROF resources of Nuwara Eliya District.

The methodology used here as explained above can be employed to estimate extent, wood volume and carbon content of TROF systems

in other areas of Sri Lanka which is expected to provide better estimates of TROF systems and their resources than the one generated through field survey only. Such information will elaborate the importance of TROF systems in ecological and economical considerations and carbon markets. This information eventually facilitate policy makers to understand the

**Table 9: Summary of total biomass and carbon contents in TROF systems of Nuwara Eliya District.**

Category	Amount (Gg)	Amount (t/ha)
Total aboveground biomass content	5,064.4	39.58
Total belowground biomass content	130.4	1.02
Total biomass content	5,194.8	40.60
Total carbon content	2,604.7	20.36

importance of TROF systems as a resource base and make favorable policies and strategies to manage and improve the TROF systems in sustainable manner.

### CONCLUSIONS

Carbon stock values of Trees Outside Forests (TROFs) in the present study can be considered as the first overall estimates of carbon stock in the Sri Lankan TROF systems. It is clear that the TROF systems in Nuwara Eliya District produced substantial amount of wood volumes and carbon content. Estimates of this study indicated that TROF biomass and carbon stocks are related to agro-ecological regions. Thus, relationships need to be established between biomass production and agro-ecology. Further, more attention need to pay on TROF systems and their resource base in extracting

economical and ecological benefits. The methodology used in this study can be effectively used to estimate TROF resources and their biomass and carbon content in other areas of Sri Lanka.

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