NAFORMA Process and Biophysical Results

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Abstract

Tanzania has undertaken a National Forest Inventory popularly known as National Forestry Resources Monitoring and Assessment (NAFORMA). The selected statistical framework was double sampling for stratification. All together there were 3,349 clusters and 32,000 plots. One quarter (ie. more than 800) of the clusters are permanent. In implementation NAFORMA measured a total of 30,773 plots out of which 25% are permanent for long-term monitoring. The remaining plots could not be accessed due to various reasons including remoteness, floods and bad terrain. Data were analyzed using locally available allometric functions and the literature. The total land area is 88,334,300 ha while the total growing stock is 3,322 million m^3. NAFORMA biophysical results show that total forest area is estimated to be 48.1 million ha which is 54.4% of the total land area. The results are highly precise and as an example, the error estimate for forests and woodlands is below ten percent at 95% probability level indicating highly reliable volume estimates. The total Carbon in the living trees is 1,060.8 million tons. The major carbon sink is the woodland with 73.5% of the Tanzania mainland Carbon. TFS is committed to monitor her forests through re-measurements of the permanent sample plots established by NAFORMA. NAFORMA answers to the increasing need for forest resources data for national policy and international reporting addressing REDD and climate change as a whole.

Key words: *total forest area, growing stock, volume and carbon*

Introduction

Tanzania has undertaken a National Forest Inventory popularly known as National Forestry Resources Monitoring and Assessment (NAFORMA). Before NAFORMA, the state and trends of the forestry resources in the country were largely unknown as the information that existed was fragmented and outdated. Under the National Forest Programme (NFP) of Tanzania, NAFORMA was identified as a priority activity for the Forestry and Beekeeping Division (FBD). NAFORMA answers to the increasing need for forest resources data for national policy and international reporting addressing REDD and climate change as a whole. This paper addresses some aspect of the NAFORMA process and some of the important results from the biophysical data.

Survey design and procedures

The selected statistical framework was double sampling for stratification, Cochran (1977). The first phase sample consists of a dense grid of clusters which were overlaid over Tanzania at distances of 5 km x 5 km between the clusters. The variables used for stratification were volume predictions of a field plot cluster based on satellite images, estimated measurement time of a cluster considering accessibility and slope. This resulted into 18 strata.

The second phase is a sub-sample of the first phase sample and was actually measured in the field. The sampling densities vary by strata. Cluster level mean volumes were calculated per land area,

using re-classified Hunting Technical Services classes such that classes 1-6 was wooded land and classes 1-3 treated as forest land. Cluster level costs were calculated. The sampling intensities in different strata were selected using optimal allocation, (Cochran 1977) such that the sampling intensities are proportional to the quantity;

$$s^t/\sqrt{c}$$

where: s = within stratum standard deviation of the mean volume of the growing on land on a cluster
c = the average costs (measurement) time of a cluster
t = an exponent to be determined to control the effect of the standard deviations on the strata weights (intensities).

Higher density of clusters was allocated to areas with high variation and high forest percentage and less clusters where variation and or wood volume were low. The densities were adjusted to three different total cost levels, 1 million, 2.5 million and 4 million US dollars. Eventually the 2.5million US dollars model was selected. The distance between clusters varies from 5 to 45 kilometres (Tomppo *et al* 2010).

The distance between clusters varies by stratum, from 5 to 45 kilometres. The plots are grouped into clusters in order to reduce travelling time between plots and hence reducing inventory costs. As a rule of thumb one cluster is the measurement unit and should to be measured within one working day for a field crew. However, for difficult clusters a crew used more than one day to accomplish the measurements. The maximum number of days to accomplish a cluster was 3 days. A cluster taking more than 3 days to measure was declared inaccessible.

All together there were 3 349 clusters (Fig 1) and 32,000 plots. One quarter (ie. more than 800) of the clusters are permanent. In implementation NAFORMA measured a total of 30,773 plots out of which 25% are permanent for long-term monitoring. The remaining plots could not be accessed due to various reasons including remoteness, floods and bad terrain.

The sampling unit is a concentric circular sample plot (**Error! Reference source not found.**2). The use of concentric plots in forest inventory aims at increasing the accuracy of the measurement and sampling intensity of large trees, and simultaneously at saving time. The concentric plot design ensures that small trees are measured in small plots and large trees (which constitute most of the biomass per unit area) are measured in large plots. This arrangement results in measuring approximately the same number of trees for the different size classes.

The number of plots in a cluster varies from 6 to 10, depending on the estimated difficulty to access the plots. However, the number of plots is always the same within one stratum. The distance between plots within a cluster is 250 m (Figure 2).

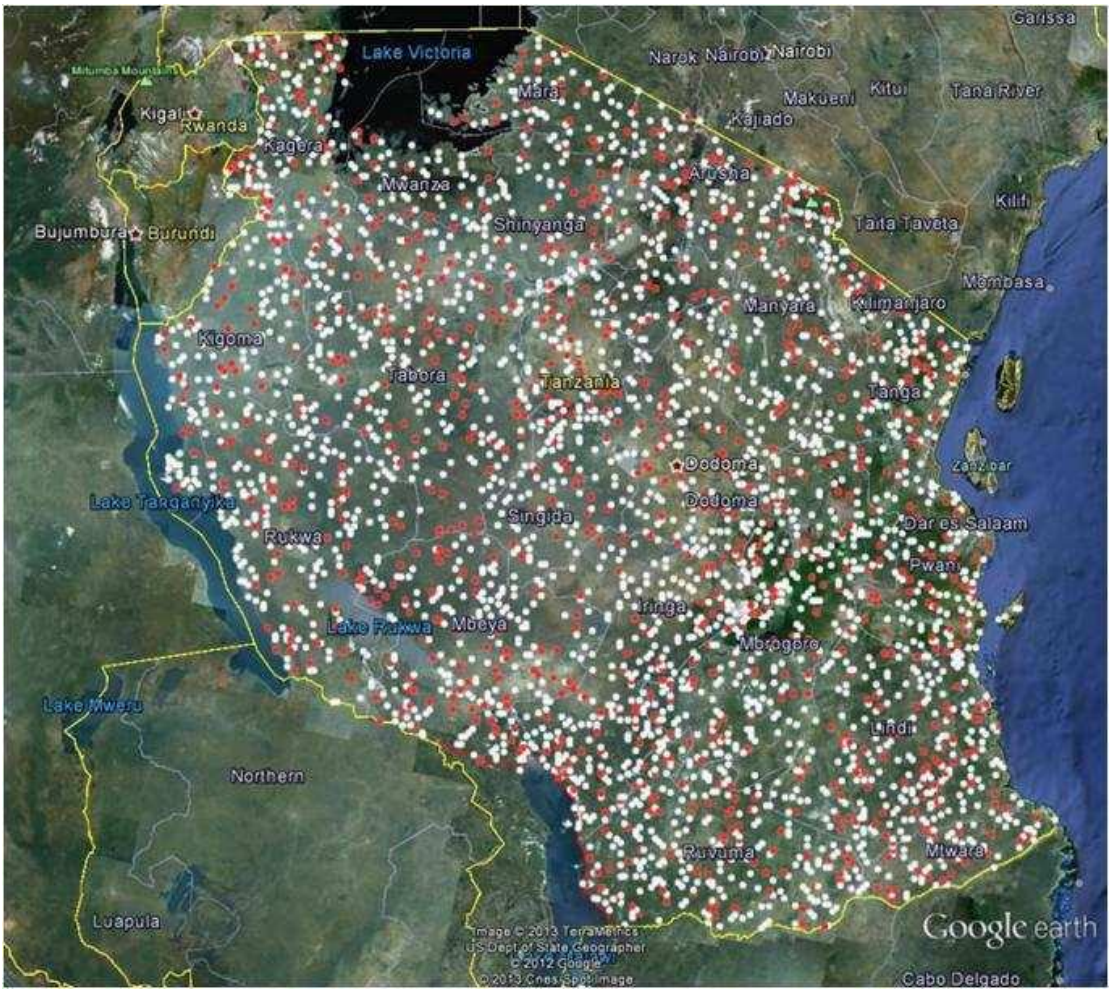

Figure 1. Distribution of NAFORMA sample plots in Tanzania

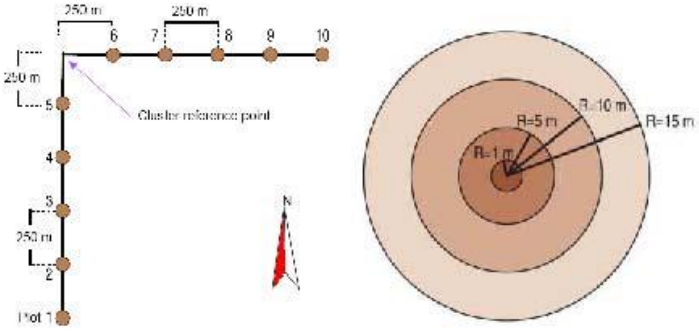

Figure 2. Cluster and plot design

Forest and Land use classification system

Land use

Land use refers to dominant land use purpose for humans at the time of observation. Land use was observed within the plot's outer boundary (radius of 15 m). If a plot was located between two land use types, it was treated as shared and two Plot Forms were filled in and **all trees** on both shared plots were recorded on separate field forms. Field forms are not filled out for more than for 2 land use classes. Table 1 shows the major land use classes adopted in NAFORMA.

Vegetation types

Vegetation type (Table 2) was recorded on all land types. The NAFORMA vegetation classification system was based on the land cover classes applied in the 1995 map by HTSL structured to fit the FAO GFRA definitions (FAO 2013) of the four Global Land Cover Classes: forest, other wooded land (OWL), other land and inland water (Table 3.2).More detailed information about vegetation classification is in the Biophysical Field manual (MNRT 2011a).

Data variables

Sample plot information was collected in the plot area and observations were carried out on the area surrounding the plot. Plot information includes vegetation type, land use, and ownership was recorded. Also information about shrubs, regeneration, dead wood, stumps and bamboos was collected. For each tree inside the plot species and breast height diameter were recorded. Every 5th tree in the cluster was selected as sample tree and more parameters were recorded in appropriate field forms.

Selection of tally and sample trees

Trees were measured in each plot as shown in Table 3. A tree is in the plot, if the estimated centre point of its base is inside the plot boundary. All trees within the subplot's borders were recorded, both live and dead trees. Cactuses and palms were recorded as trees. Information about bamboos was filled into the Bamboo Field Form. The data collection starts at the plot starting point and continues from the north in clockwise direction.

Table 1. Major land use classes adopted in NAFORMA

Code	Description	Explanation
1	Production forest	Land designated for production and extraction of products (wood, fibre, bio-energy and/or non-wood forest products). Includes concessions, exploitation licenses, community forests etc.
2	Protection forest	Protected forest lands. Including also nature reserves, soil conservation, water and watershed protection, protection against erosion and landslides.
3	Wildlife reserve	National parks, game reserves, game controlled areas etc
4	Shifting cultivation	
5	Agriculture	Incl. agro-forestry
6	Grazing land	
7	Built-up areas	Urban or rural, or mixed. Including roads, buildings, power lines etc.
8	Water body or swamp	Seasonal, Permanent or Swamp
99	Other land	To be specified in Remarks

Table 2.Vegetation classes used under NAFORMA

Vegetation type			
Code	**Text Code**	**Description**	**Explanation**
101	Fhm	**Forest**: Humid Montane	Catchment forest, ≥ 800 m asl
102	Fl	Forest: Lowland	Groundwater forests, some coastal forests, < 800 m asl.
103	Fm	Forest: Mangrove	Area of forest and other wooded land with mangrove vegetation.
104	Fp	Forest: Plantation	Note: Detect *Planting year* in Plot data
201	Wc	**Woodland**: Closed (>40%)	Beekeeping, Hunting, Recreation, Grazing, Conservation, Timber production
202	Wo	Woodland: Open (10–40%)	
203	Wsc	Woodland: Scattered cropland (Unspecified density)	Shifting cultivation
301	Bt	**Bushland**: Thicket	*below 5 m*
302	Bd	Bushland: Dense	Grazing
303	BSc	Bushland: Scattered cultivation	Shifting cultivation
306	Bo	Bushland: Open	Hunting, Recreation, Grazing
401	Gw	**Grassland**: Wooded	Hunting, Recreation, Grazing
402	Gb	Grassland: Bushed	
403	Gsc	Grassland: Scattered cropland	Cultivation
404	Go	Grassland: Open	Hunting, Recreation, Grazing
501	Caf	**Cultivated land**: Agro-forestry system	Home gardens with multi-storey tree covers shading other crops e.g. Banana, Coffee, beans and yams.
502	Cwc	Cultivated land: Wooded crops	Monocultures and mixed crops of Tea, Cashew nuts, Cloves, mangoes, oranges etc.
503	Cbc	Cultivated land: Herbaceous crops	Various herbaceous crops e.g. Cotton, vegetables, sisal, tobacco, flower plantations etc.
504	Cgc	Cultivated land: Grain crops	Various types of grass crops e.g., maize, wheat, millet, rice, sorghum.
601	Bsl	**Open land:** Bare soil	E.g. Around larger lakes and disturbed areas
602	Sc	Open land: Coastal bare land	E.g. beach
603	Ro	Open land: Rock outcrops	Places dominated by rocks
604	Ice	Open land: Ice-cap / snow	
701	Wo	**Water:** Ocean	
702	Wi	Water: Inland water	Lake, river
703	Wsc	Water: Wetlands	Water-logged, seasonally inundated
800	Other	**Other areas**	Urban and rural built-up areas, air fields, infrastructure (power lines, railways, mining sites etc).

Table 3.Trees to be measured in the concentric plots.

Plot radius (m)	Tree dbh measured (cm)	Actual trees to measure (cm)
1	D<5	>1
5	5<D<10	>5
10	10<D<20	>10
15	20<D	>20

Every 5th tree in the plot was selected as a sample tree. If the 5th tree is dead or deformed, then the next live tree was selected as a sample tree. The following parameters were measured from the sample trees; stump diameter, stump height (default=15 cm above ground), total tree height

Bole height was measured for each sample tree DBH>20 cm, but estimated for every tally tree where DBH≥20 cm. So this data is recorded for every living tree where DBH≥20 cm. Bole height refers to merchantable height that is defined as the distance from the base of the tree to the first occurrence of the lowest point on the main stem, above the stump where utilization of the stem is limited by branching or other defect

Marking of trees

In all plots located in Forest or Woodland vegetation types, the 3 closest trees to the plot centre with DBH ≥ 5 cm were marked with a painted dot. The marked (painted) trees were ticked off as *Painted* in the Tree Form if they have been recorded as tally or sample trees.

Tree diameter measurement

Tree diameter was measured over bark, at 1.3 m breast height above the ground with the exception of particular cases such as buttressed, forked, and other deformations which were measured using standard mensuration procedures as described in the Biophysical Field Manual. DBH was measured using callipers and diameter tapes to the nearest millimeter. To ensure consistence during re-measurements, all tree diameters on the permanent sample plots were recorded using the diameter tape.

Tree height measurements

Tree height was measured using standard mensuration procedures as described in the Biophysical Field Manual. The Suunto hypsometer was used and measurements were taken to the nearest 0.5 m.

Canopy coverage measurements

Canopy cover was measured using the densiometer. The instrument has a reflective spherical surface divided into a grid of 24 squares. When the instrument is taken under the forest canopy, the images of overhead crowns can be seen in mirror and the amount of canopy coverage is estimated based on proportion of the mirror surface reflecting the overstory crown. The measurement procedure is explained in the Biophysical Field manual. However during data analysis these measurements did not prove to be useful. Further research on the use of the instrument is recommended.

Dead wood measurements

Dead wood are tree parts that are lying on the ground. Dead wood constitutes one of the carbon pools under REDD. The field crew determines dead wood parts which are inside the plot area (within the radius of 10 m). The length and diameter at both ends of all pieces of fallen wood with diameter larger or equal than 10 cm within the plot area were measured. Measurements of length were made to the plot border. Hence when a stem crosses the plot border, the length is measured to/from that limit where the stem's centre line crosses the border.

Two diameter measurements were for calculation of volume and biomass using Smalian's formula. The diameters were measured over bark if bark still existed; otherwise without bark. For measurements at the bases of fallen, buttressed trunks, diameters were measured above the buttress. The total length of the stem was also recorded. Other details on dead wood measurement are described in the Biophysical Field manual.

Soil sampling

Soil information is required as part of the forest ecosystem and carbon reporting. Only soil depth, was recorded in the field. Other physical properties such as soil colour, soil structure, and stoniness were recorded in the laboratory. Similarly the carbon content was analysed in the laboratory at Sokoine University of Agriculture, Morogoro. All team

members were able to conduct soil sampling to allow for rotations and qualified discussions.

Details of soil sampling were are explained in the Biophysical Field manual

Photo of the plot

Each inventory team had digital camera to record the view on the plot. Photos were used to document the plot characteristics such as vegetation type, and to ease the relocation of the plot in the future .

reassessments. Collected photos will also be utilized as training materials in the future. The crew added a label hanging on a tree with the following information: Cluster ID and Plot ID (Fig 3). The photos in combination with Google Earth images were later used to verify doubtful vegetation types.

Figure 3. Photo of plot center and sign

Description of field forms and variables

Six different field forms were used for collecting biophysical data, as indicated **Error! Reference source not found.**.

Form No.	Information
1	Cluster description form
2	Plot: General plot description data, location, and measuring time
3a	Shrubs: Coverage and mean height of shrubs/bushes.
3b	Regeneration: Number of seedlings and saplings
4	Trees: Tree measurements (DBH ≥1 cm) from differing sub-plots
5a	Dead wood measurements
5b	Stump measurements
6	Bamboo
7	Field crew contact details

Details of information to be collected in the above forms are found in the Biophysical Field Manual [1] Name and phone number of field crew members including local staff

Data analysis

Analyses of biophysical and socioeconomic data were done using the OpenForis Calc (OF-Calc). The OpenForis tools are described at the FAO website (www.fao.org/forestry/fma/openforis/en/) and on the OpenForis wiki-page (www.openforis.org/OFwiki/index.php/Main_Page). Biophysical data analysis aimed at computing forest stand parameters namely number of stems per ha (N), basal area per ha (G), volume per ha (V) and biomass per ha. It was also important to estimate total number of stems, basal area, volume, biomass and Carbon for each land use category and therefore total values for the entire country. For this purpose, area estimate for each land use category was required.

Tree height

Missing tally tree heights were computed using 2-parameter Naslund height function with the help of R library LMFOR[2] developed by expert in statistics and forestry, Dr. Lauri Mehtätalo (University of Eastern Finland, Joensuu). The model is of the following form:

$$H_{ij} = \frac{DBH_{ij}^2}{(\alpha+\beta\ DBH_{ij})^2} + 1.3$$

where *Hij* and *DBHij* are the total height (m) and breast height diameter (cm) of the *i*th tree on the *j*th plot, respectively. And are empirical parameters which needs to be estimated with the help of height sample tree data. Height of tally trees within each cluster were computed each cluster. For sample trees, the recorded tree heights were used.

Number of stems and basal area

The number of stems and basal area per ha were computed using standard procedures.

Tree volume

Tree volumes were calculated using six different models for different species or species groups. Except for woodlands, the models do not include branches and twigs. The models used are

(i) *Eucalyptus grandis*
V = 0.000065 x DBH1.633 x H1.137
(Malimbwi and Mbwambo 1990);

(ii) *Pinus patula (pine)*
V = 0.00002117 x DBH1.8644 x H1.3246
(Malimbwi 1987);

(iii) *Tectona grandis*
V = 0.*0001* x DBH1.91 x H0.75
(Malimbwi *et a*l 1998);

(iv) *Dalbergia melanoxylon*
V = 0.*00023* x DBH2.231 (Malimbwi *et*
al 2000);

(v) *Woodlands*
V = 0.0001 x DBH2.032 x H0.66
(*Malimbwi et al* 1994); and

(vi) Other vegetation types
V = 0.5 x pi x (0.01 x DBH / 2)2 x H
(Haule and Munyuku 1994).

Where:

V = volume (m3 solid measure of the tree stem only);
DBH = diameter at breast height (1.3 m)
H = total tree length (m)

Tree length of living sample trees was measured from ground level to the top of the tree. Sample trees data is applied using a naive Bayesian3 model for tree length predictions of trees without length measurement.

Biomass

Forest Carbon was estimated in three pools namely AGB, BGB and DW. BGB was estimated as a fraction of AGB. AGB and BGB were estimated as follows:

3 A **naive Bayes classifier** is a simple probabilistic classifier based on applying Bayes' theorem with strong (naive) independence assumptions; in R a function **random effect** is applied so that it measures the difference between the average score of tree species' length and the average score in the entire tree population and it is "random" because the

trees have been randomly selected from a larger population of trees

(i) AGB (tonnes/ha) = Tree stem volume (m^3/ha) * wood density/1000; and
(ii) BGB (tonnes/ha) = AGB * 0.25 (as default), or root to shoot ratios.

The following conversion factors were programmed into the NAFORMA analysis system by tree species or species groups:

Wood density
- Pines 390 kg/m^3
- *Dalbergia melanoxylon* (Mpingo) 1060 kg/m^3
- Humid montane forest 580 kg/m^3
- Other woody vegetation 500 kg/m^3

Biomass Expansion Factor (BEF)
Not used, only bole volume calculated!

Default carbon conversion factor: 0.47

Root/shoot conversion ratios: *Default 0.25*
- Lowland forests 0.37
- Humid montane 0.27
- Bushland 0.40,
- Open woodland, scattered cropland 0.37
- Grassland 0.37
- CL:herbaceous crops, CL:grain crops 0.37
- Wooded grassland , 0.37
- OL:Coastal bare land, bare rock 0.37
- Wa:Ocean, Inland water built-up areas 0.37
- Mangroves, closed WL, WL:AF systems, wooded crops 0.28
- Plantations 0.20

Deadwood biomass
DW biomass was estimated from the volume computed using Smalian formula multiplied by wood density of 619 kg/m^3 (Chidumayo 2012).

Carbon
Carbon was computed as follows:
Carbon (tonnes/ha) = Biomass * 0.47

Determination of land area
Based on the sampling design, the land area of each stratum was estimated using the first phase sample and the known land area of Tanzania, which was assumed to be error-free. The area estimate of a land category (eg vegetation type, land use, ownership) in each stratum was estimated using the ratio of the number of the second-phase plots on the land category and the number of the second-phase plots on land in the stratum, and the estimated land area of the stratum from the first phase sample. Consequently the, mean volume and other stand parameters on a land category for each stratum were calculated using the second phase.plots. Elaborate description of the procedure is presented in Tomppo *et al.* (2014).

Wood balance
Wood balance analysis was carried out using the NAFORMA inventory data and best available information on wood loss. MAI adopted were from related research (Malimbwi 1987; Malimbwi & Philip 1989; Mgumia 2013; Zahabu 2001; Klitgaard & Mikkelsen 1976; Schaafsma *et al*. 2014; Treue *et al*. 2014) and when it was not available in the literature, expert opinion on yield or percentage growth of the stock was used. AAC was obtained as a product of MAI and the area of the land cover category excluding protected areas.

Data Management
Data management involves all stages of handling, processing and securing data from the field to analysis. The stages are indicated in Fig. 4

Figure 4: Flow of the field data

Data were recorded in cluster book containing cluster variables, plot variables, tree variables and information on dead wood and stumps. A rough estimate of the cost of one cluster was USD 1000. At any one stage, loss of one cluster means loss of USD 1000. As such, it was necessary to maintain quality assurance and safety of the data through all the stages.

Results

Land area and growing stock

The total land area is 88,334,300 ha while the total growing stock is 3,322 million m^3 NAFORMA biophysical results show that total forest area is estimated to be 48.1 million ha which is 54.4% of the total land area. The results are highly precise and as an example, the precision of volume by vegetation types is shown in Table 3. The error for forests and woodlands is below ten percent at 95% probability level indicating highly reliable volume estimates. The high number of sample plots by vegetation type has contributed to the high precision and accuracy of the baseline information on above ground biomass and its Carbon content.

The total volume reported includes the volume of *Adansonia digitata* tree which is believed to have low carbon content. There are estimated 23.6 million *A. digitata* trees with an average volume of 6.5 m^3 per tree. This is equivalent to 147.5 million m^3, which is about 4% of the total volume.

By vegetation types

About 55% of the land area is forest and woodland. Woodlands alone cover 51 % of the total land area. Previous estimate of the forest area in Tanzania was 38% of the total land area (FAO 2010). NAFORMA ground observations captured 40% more forest areas than earlier estimates which were based on satellite images alone. Satellite imageries are incapable of distinguishing from degraded and sometimes open woodland. During NAFORMA field work the vegetation types were recorded in the field based on the crews' judgment. The crews were trained on vegetation classification before field work started. It is clear that measurements in the field are necessary for accurate assessment of forest resources

Table 5 shows the total growing stock of various parameters while Figure 5 shows the distribution of volume in mainland Tanzania by vegetation types. Woodland areas (44.7 million ha) represent 73.9% of the growing stock in the country. Forest areas (3.4 million ha) account for 11.3 % of the growing stock. The remaining 14.8% of the growing stock are made up of TOF[4], which are found on various non-forest vegetation types (40.1 million ha).

The average growing stock in Tanzania is 37.7 m^3/ha which compares well with earlier estimation of 38 m^3/ha (FAO 2010).

The woodland is the most extensive vegetation type in the country, and most activities are carried out in the woodlands (Table 6)

[4] The term TOF (trees outside forest) is used by the FAO/FRA to report those trees that are not included in forest and woodland classes

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Table 3: Sampling errors and precision estimates by primary vegetation type

Primary vegetation type	Number of sample plots	Mean volume (m3/ha)	Error Est (m3/ha)	Precision (%)
Forest5	1,594	111.84	8.09	6.87
Woodland	15,640	55.11	1.13	2.02
Bushland	2,671	21.85	1.76	8.91
Grassland	2,742	5.70	0.62	10.10
Cultivated land	6,067	11.76	1.14	10.13
Open land	85	5.72	2.73	45.14
Water	405	9.19	4.22	42.95
Other areas	656	16.79	4.17	22.96

Table 5. Tree growing stock by primary vegetation types in Tanzania

Primary Veg Type	Area ha	Volume1000 m3	Vol m^3/ha	No of trees per hectare	Basal Area m^2/ha
Forest	3,364,457	374,962	111.8	2031	14.8
Woodland	44,726,246	2,456,252	55.1	1053	8.3
Bushland	6,445,471	140,324	21.8	2009	5.0
Grassland	8,242,245	46,838	5.7	227	1.2
Cultivated land	22,248,092	260,661	11.8	354	2.0
Open land	252,516	1,439	5.7	608	1.4
Water	1,162,552	10,647	9.2	117	1.5
Other areas	1,892,720	31,669	16.8	298	2.8
Total/mean	88,334,300	3,322,791	37.7	877	5.8

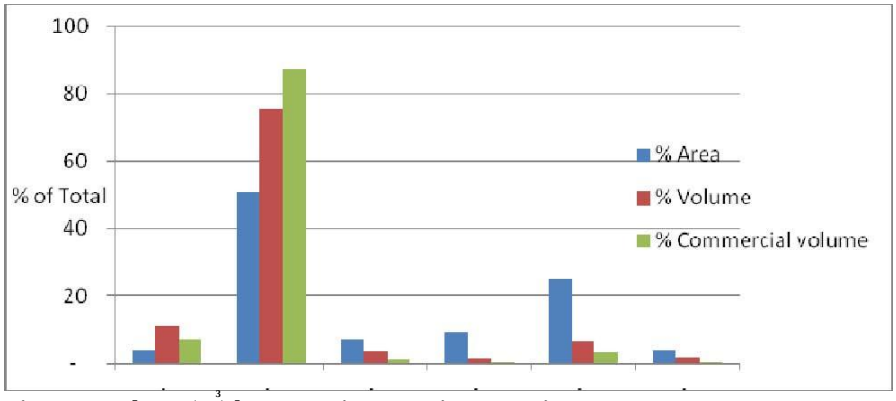

Figure 5. Volume (m^3) by vegetation types in Tanzania

Table 6. Major land uses are carried out in the woodland

Land use	Percent in the woodlands (%)
Wild life	70
Production forest	79
Grazing	53
Protection forest	69
Shifting cultivation	33

[5] FAO/FRA definition of forests is being used (a minimum area of 0.5 ha, the trees must be at least 5 m in height or capable of reaching that height on the site and canopy cover must be 10% or more). There are four forest classes in the detailed vegetation classification: The humid montane forest, lowland forest, mangrove forest and plantations. Please note, that for FRA reporting both the forest and woodland primary vegetation classes are classified as forest.

A closer observation of the 'forest' (Table 7) shows that the plantation area has increased from 250,000 ha (FAO 2010) to more than 500,000 ha as revealed by NAFORMA.

Table 7. Area distribution of the 'forest'

Forest	Area (ha)
Humid Montane	991,737
Lowland	1,650,656
Mangrove	157,570
Plantation	552,576
Total	**3,352,538**

This is a result of response from communities to establish woodlots and most of these efforts are in the Southern Highlands (Fig 6).

By landuse

The most dominant land uses in Tanzania are; Agriculture (23%), Production forest (22%) and Wildlife areas (21%). The three land uses account for more than 60% of total land area. One third of the country land area is protected wild life reserves and protection forest and 48% of total volume is in these areas (Fig 7).

By Ownership

All land in Tanzania is considered public land, which the President holds as trustee for the people. The Land Policy of 1995, the Land Act and Village Land Act of 1999 set out the fundamental principles guiding land rights and management. The Land Act classifies land in three categories: (1) reserved land; (2) village land; and (3) general land. The reserved land is land under the central and local governments. Village land constitutes about 36% of the total land area. Other dominant land owners are central government and private land. The local governments and general land have minor shares (Fig 8).

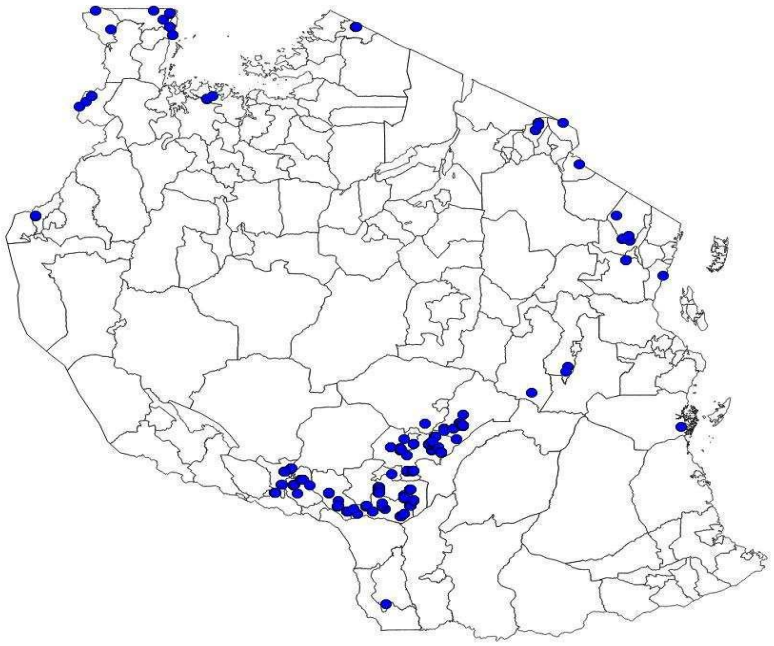

Figure 6: Distribution of NAFOMA sample plots containing plantation tree species in Tanzania

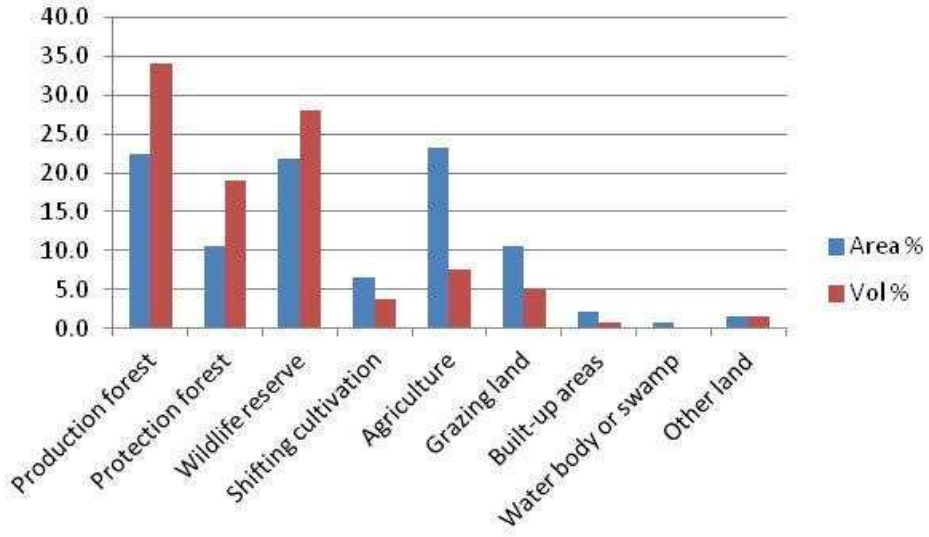

Figure 7: Area and volume distribution by land use

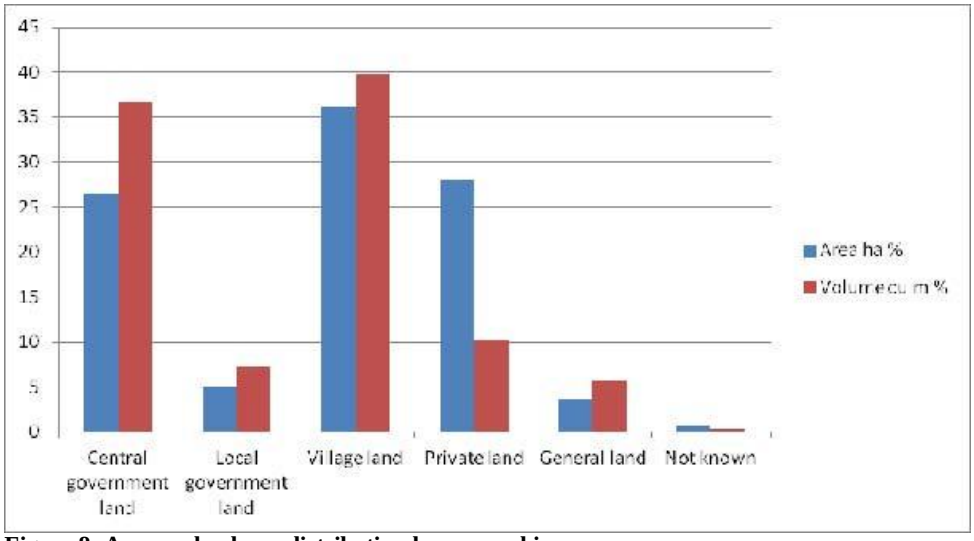

Figure 8: Area and volume distribution by ownership

In the Forest Policy of 1998 (MNRT 1998), the area of non-reserved land (general land) was 19,038,000 ha. Since then the major part of General land has shifted into village land and the remaining area now stands at 2,732,575 ha according to the NAFORMA findings. This is the result of implementing Property and Business Formalization Program (PBFP) popularly known as *MKURABITA* established in 2004. The goal of the program was to facilitate formalization of property and business assets in the extralegal sector, into legally held and formally operated entities in the formal sector of the economy.

About 22% of the land use area in Tanzania is production forests (Figure 7) and village land constitutes 36% of the total land area and in the country (Figure 8). Calculations show that 66% of the volume in production forest is in village

land. In order achieve SFM, TFS needs to guide forest management in the village land which in the past was known as general land, with no clear ownership.

By regions

Table 8 summarizes distribution of forest and woody vegetation resources by regions. Morogoro, Lindi, Ruvuma, Mbeya, Tabora and Katavi regions have the largest wood volumes. The average number of trees per ha is 876 varying from less than 200 in Simiyu to about 1,700 stems in Mtwara region. The large number of trees is due to the methodology used by NAFORMA of measuring all trees with Dbh of one cm and above. When the number of trees in one ha exceeds 1,000, it may demonstrate that most of the trees are small. In forest plantations, this may be young stands while in natural forests, it indicates good regeneration.

Katavi, Lindi, Ruvuma and Mbeya regions are the most forested. More than 70% of the land of these regions is covered by forests and woodlands.

Table 8: Distribution of forests and woody vegetation resources by regions

Zone	Region				Number of trees /ha		Forest + wood land, m3/ha
Eastern	Dar es Salaam	150,809	24.9	3.7	704	32.5	53.4
	Morogoro	6,886,883	54.8	376.2	1,268	63.6	76.7
	Pwani	3,196,403	37.4	118.9	1,508	58.7	54.5
Southern	Lindi	6,785,532	55.2	372.8	1,622	77.2	64.1
	Mtwara	1,794,853	43.4	77.5	1,685	41.4	81.1
	Ruvuma	6,338,030	52.6	332.0	968	74.6	64.9
Southern Highlands	Rukwa	2,167,494	29.7	64.1	454	41.2	57.0
	Njombe	2,194,407	26.5	58.0	641	37.0	52.2
	Iringa	3,453,694	37.2	127.8	762	52.1	57.3
	Mbeya	6,106,391	52.3	318.2	786	70.6	69.7
Central	Manyara	4,469,962	19.9	88.4	588	45.5	32.8
	Dodoma	4,183,192	28.3	117.8	685	32.8	45.3
	Singida	4,856,938	25.8	124.7	930	45.7	40.1
Lake	Mara	2,189,924	9.4	20.4	289	15.7	34.5
	Simiyu	2,345,074	8.5	19.9	186	18.0	30.8
	Mwanza	1,092,257	13.3	14.5	284	14.3	61.3
	Kagera	2,527,312	25.1	63.3	763	54.3	39.1
	Geita	2,098,555	34.5	72.1	674	48.1	60.8
Western	Tabora	7,595,994	39.8	301.3	689	61.2	58.9
	Shinyanga	1,853,931	11.5	21.3	425	17.1	48.2
	Kigoma	3,819,825	42.4	161.4	534	60.4	61.0
	Katavi	4,342,814	59.4	256.9	730	82.7	69.2
Northern	Kilimanjaro	1,250,496	38.5	47.9	579	48.6	66.2
	Arusha	3,822,918	15.3	58.3	693	43.5	28.9
	Tanga	2,810,612	41.1	115.2	1576	47.9	67.6
Total /average		**88,334,300**	**37.9**	**3,332.7**	**876**	**54.6**	**59.4**

At district level (not reported in Table 8), only seven districts have more than 60 m^3/ha average stocking. These are Chunya, Mpanda, Nanyumbu, Kibondo, Ulanga, Namtumbo and Kilombero. The highest stocking of 67.7 m^3/ha was recorded in Ulanga district. Shinyanga, Simiyu, Mara, Mwanza and Geita regions (Figure 9) which are largely livestock keeping, have the least forest areas as well as smallest growing stock. These regions are also dominated by grassland and/or bushland. Moreover, Shinyanga, Kwimba, Kishapu, Busega, Monduli, Serengeti and Mkalama districts have forest stocking of less than 10 m^3/ha.

Living biomass carbon stocks

The total Carbon in the living trees is 1,060.8 million tons (Table 9). The major carbon sink is the woodland with 73.5% of the Tanzania mainland Carbon.

Dead wood carbon stock

The dead wood Biomass (Table 10) is relatively low since most dead wood in accessible areas is collected as fuelwood. As woodlands are generally more accessible than forests, collection of deadwood for fuelwood from these areas is easier. The relatively high volume of dead wood in water is assumed to be because dead trees lying in areas with water / wetlands are difficult to access and decay slowly and because they are wet and therefore unattractive for fuelwood

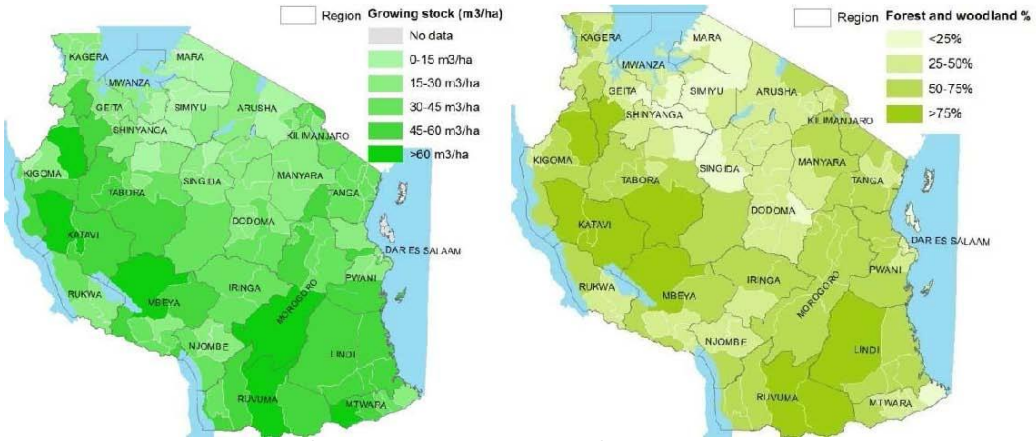

Figure 9: Average growing stock and forest and woodland share of total area

Table 9: Living tree stemwood biomass and carbon by primary vegetation type

Primary Veg Type	Volume m3/ha	Aboveground Stem Biomass, t/ha	Belowground Biomass,	Carbon t/ha	Carbon t	Share %
Forest	111.8	59.5	18.2	36.5	122,340,057	11.5%
Woodland	55.1	27.7	9.5	17.5	779,607,827	73.5%
Bushland	21.8	11.0	4.4	7.2	46,388,588	4.4%
Grassland	5.7	2.9	1.1	1.8	15,115,401	1.4%
Cultivated land	11.8	5.9	2.1	3.8	83,293,969	7.9%
Open land	5.7	2.9	1.1	1.9	466,006	0.0%
Water	9.2	4.6	1.7	3.0	3,429,530	0.3%
Other areas	16.8	8.4	3.1	5.4	10,192,480	1.0%
TOTAL CARBON, MAINLAND TANZANIA					**1,060,833,858**	100.0%

Table 10. Dead wood biomass and Carbon

Primary Veg. Type	Biomass t/ha	Carbon t/ha	Total DW Carbon, t	DW carbon %
Forest	4.87	2.39	7,997,394	12.7
Woodland	1.82	0.89	39,664,224	63.0
Bushland	0.73	0.36	2,284,911	3.6
Grassland	0.35	0.17	1,397,907	2.2
Cultivated land	0.91	0.45	9,929,475	15.8
Open land	0.22	0.11	27,480	0.0
Water	1.31	0.64	741,566	1.2
Other areas	0.99	0.48	914,657	1.5
TOTAL DEADWOOD (t)			**62,957,614**	100

Wood balance

The wood supply and loss balance is of interest for the policy makers, commercial companies and consumers of the wooden products to understand the adequacy of the supply to meet the people's needs and what actions may be needed to rectify possible shortage situation. A negative balance means that wood consumption is bigger than the wood production leading to depletion of the woody vegetation.

Table 11 shows that the total annual supply (growth) of wood at national level is estimated at 83.7 million m^3. However, only about half of this volume i.e. about 42.8 million m^3 is available for harvesting at a sustainable level which is also called the annual allowable cut (AAC).

The annual loss of wood was estimated at 62.3 million m^3 (Table 12). The consumption exceeds the sustainable supply, causing an annual wood deficit of 19.5 million m^3. NAFORMA estimates the average demand for wood at 1.39 m^3/year/capita while the annual allowable cut (the sustainable supply) is estimated at 0.95 m^3/year/capita.

Conclusions and Recommendations

Conclusions

The key conclusions from NAFORMA are that:

(i) NAFORMA measured a total of 30,773 plots out of which 25% are permanent for long-term monitoring;

(ii) NAFORMA has provided an objective documentation of the state of the forest resources of the country at the time of measurement. The collected field data are stored in the Open Foris-Collect database and analyzed in Open Foris-Calc. Data sharing policy is found in NAFORMA website: http://www.naforma.mnrt.go.tz;

(iii) NAFORMA has collected useful data which can be subjected to further analysis to generate more information for policy makers, revision of NFP, REDD+ and academia;

(iv) The area covered by woody resources was previously underestimated. NAFORMA has determined the area of forest and woodlands of mainland Tanzania to be 48.1 million ha. The previous projection was 33.5 million ha;

(v) Based on 2012 population census, NAFORMA data shows that there was 1.1 ha of forest and woodlands per capita and 1 m^3 per person per year available from legally accessible sources;

Table 11: Total annual wood supply and annual allowable cut (AAC)

Detailed vegetation type		Volume m^3/ha *	Estimated increment per year m^3/ha	Total annual wood supply m^3	Annual Allowable Cut (AAC) m^3
Forest	Humid montane	170.7	8	7,933,898	151,061
	Lowland	92.7	8	13,205,245	4,378,859
	Mangrove	48.8	2.5	393,924	19,617
	Plantation	64.1	15	8,288,625	8,090,527
Woodland	Closed (>40%)	78.7	2	17,396,122	5,938,340
	Open (10-40%)	47.6	0.58	20,804,454	9,758,121
Bushland	Thicket	18.4	0.22	217,061	173,649
	Dense	23.9	0.29	583,971	467,177
	Emergent trees	26.1	0.32	98,257	78,605
	Thicket with emergent trees	34.7	0.42	129,973	103,978
	Open	11.3	0.14	388,903	311,123
Grassland	Wooded	8.8	0.11	504,440	403,552
	Bushed	6.2	0.08	33,212	26,570
	Open	0.8	0.01	28,251	22,601
Woodland	Scattered cropland	21.2	0.26	652,050	652,050
Bushland	Scattered cultivation	10.8	0.13	152,756	152,756
Grassland	Scattered cropland	4.4	0.05	32,015	32,015
Cultivated land	Agro-forestry system	12.5	0.88	1,199,184	1,199,184
	Wooded crops	20.3	1.62	2,460,719	2,460,719
	Herbaceous crops	6.6	0.53	2,645,683	2,645,683
	Mixed tree cropping	64.8	4.53	698,667	698,667
	Grain crops	5.7	0.45	4,459,745	4,459,745
Open land	Bare soil	6.1	0.15	24,626	24,626
	Salt crusts	4.9	0.12	2,244	2,244
	Rock outcrops	5	0.12	9,094	9,094
Water	Inland water	14.7	0.52	79,490	79,490
	Swamp	8.3	0.29	293,149	-
	Unspecified	15.4	0.54	1,013,557	506,778
		37.6		**83,729,315**	42,846,832

*volume figures exclude baobab. **Table 12: Wood balance analysis for mainland Tanzania**

Supply and losses	Unit	2013
Supply		
Gross increment of all trees in mainland Tanzania	million m^3/yr	**83.7**
Legally available wood (AAC plus recoverable deadwood)	million m^3/ yr	42.8
Losses:		
Household wood demand (0.96 m^3/capita)	million m^3/ yr	**-43.0**
Industrial and household other wood demand (0.05 m^3/capita. FAOSTAT 2014)	million m^3/ yr	**-2.3**
LULC change analysis (1995 vs 2010 maps) on FW: (-372816 ha/a * 40 m^3/ha; 0.33 m^3/capita)	million m^3/ yr	**-14.9**
Import-export balance (charcoal, lumber and logs; 0.00 m^3/capita)	million m^3/ yr	**-0.1**
Illegal felling for charcoal/lumber mfg, trading (0.05 m^3/capita)	million m^3/ yr	**-2.0**
Total losses	**Million m^3/** yr	**-62.3**
Wood Balance	million m^3/ yr	**-19.5**

(vi) The estimated annual consumption of 62.3 million m3 exceeds the annual allowable cut of 42.8 million m3. The current supply of wood is therefore unable to meet current demands sustainably. The current wood deficit from legal sources is around 19.5 million m3 a year;

(vii) The annual deficit is currently met by overharvesting in accessible forest areas and illegal harvesting in protected areas. This leads to degradation of the remaining forests and woodlands, which lowers their productivity;

(viii) Thenational LULC map was produced and registered by the Ministry of Lands, Housing and Human Settlements Development;

(ix) NAFORMA estimated forest Carbon in three pools namely AGB, BGB and DW. AGB and BGB amounted to 1,060.8 million tonnes while DW was about 63 million tonnes. By far, the major AGB and BGB sink is the woodlands which store 73.5% of the total Carbon. Data for estimation of SOC were collected but the analysis has not yet been completed. The litter Carbon pool was not estimated.

(x) Reliability of NAFORMA data is low when used at levels lower than the regional level.

Recommendations

(i) In order to ensure long term monitoring of forest resources, TFS should re-measure the Permanent Sample Plots established under NAFORMA. Data for the Carbon pools that were not considered in the NAFORMA study should be included in the re-measurements.

(ii) Given the existing capacity of TFS and its roles on long term monitoring of forest resources, TFS should strengthen linkages with other national institutions and sectors in order to utilize the available capacity;

(iii) The apparent wood supply deficit needs to be addressed urgently;

(iv) The data from various sources used to estimate wood consumption were very variable. There is therefore need to undertake a thorough nation wide wood consumption study;

(v) Revision of National Forest Policy and National Forestry Programme (2015-2024) should use the NAFORMA findings;
(vi) The government should commit funds to support awareness and implementation of PFM outside the development partners' framework;
(vii) There is need to further develop and use Multisource National Forest Inventory (MSNFI) in order to determine forest resources at local level; and
(viii) Researchers and academia should further analyse NAFORMA data to generate more information for different stakeholders.

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