Final Technical Report

Project Title: Enhancing Monitoring of Forest Structure and Threats to Biodiversity Using Remote Sensing Techniques”

Prepared

By

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Executive summary

Monitoring of forest structure attributes and associated threats is important for sustainable management of forest resources. In the recent decade, combination of remotely sensed data and field based data through mathematical models have emerged as the best options for quantifying forest structure attributes. Thus, this project was conducted in Amani and Nilo Nature Reserve to assess the capability of different remotely sensed data in enhancing the accuracy and precisions of quantification of forest structure attributes. Furthermore, we also evaluated the potential of remotely sensed data and techniques in identifying threats to biodiversity. Four key objectives were addressed including, 1) reviewing and mapping forest boundaries; 2) quantifying tree biomass using remote sensing techniques; 3) quantifying and mapping the occurrences and distribution of threats to biodiversity i.e. invasive plant species and fire; 4) quantifying forest cover changes over time . Standard field and remotely sensed data use methodology were adopted to answer the key objectives.

The results showed that remotely sensed data can be used for estimation of above ground biomass with reasonable accuracy and precisions as the key forest structure attribute. The results were in line with other studies conducted in similar vegetation types elsewhere. The methodology can be adopted for mapping and monitoring the forest biomass and other structure attributes in other biomes. Our project had also shown that remotely sensed data could be used for threat detection. In both of two-Nature forest reserve there was very little evidence of threat. Fire incidence was not observed during the survey only the historical fires was indicated. This was the sign of good conservation efforts, which we witnessed during our survey even though it was out of the scope of this study.

Generally, the project had generated a fundamental knowledge for use of remotely sensed data for biomass estimation and threat detection. However, there was a challenges of meeting the goals related with development of publications. Four publications were anticipated but due to budgetary and time constrains one manuscript is in progress. Nevertheless, all the data have been analyzed with credible outputs and efforts are current made to secure resources to facilitate upscaling of these results through scientific publications.

1.0 Introduction.

Monitoring of forest structure attributes and associated threats is important for sustainable management of forest resources. However, conventional methods for assessment have regularly been done using field based methods, which are often expensive, laborious, and sometimes imprecise because of small sample sizes relative to population variability. Combination of remotely sensed data and field based data through mathematical models have recently emerged as the best options for quantifying forest structure attributes. This is further supported by the ongoing climate change mitigation policies such Reducing Emission from Deforestation and Forest Degradation (REDD+). Thus, this project was conducted in the two Nature Forest Reserves namely Amani Nature Fores Reserve and Nilo Forest Reserve to demonstrate the use of Mult Source remote sensing data for estimation of forest structure attributes. While there are number of structure attributes which can be estimated using remote sensing, but among all aboveground biomass is considered to be the most important and benchmark for testing the technical capability of remote sensing.

2.0 Project purposes

The purpose of this project was to assess and monitor forest structure (i.e. tree species diversity and biomass), the occurrence and distribution of threats to biodiversity using remote sensing techniques in the East Usamabara mountain Forests.

3.0 Objectives

The project was aimed to address the following specific objectives: 1) reviewing and mapping forest boundaries; 2) quantifying tree biomass using remote sensing techniques; 3) quantifying and mapping the occurrences and distribution of threats to biodiversity i.e. invasive plant species and fire; 4) quantifying forest cover changes over time

4.0 Planned activities and outputs

The planned activities of the project are outlined in Table 1 below.

Table 1. Planned activities and output

Activity	Output
Geo-referencing of forest boundaries	Maps of Amani and Nilo Nature Reserves
Field based measurements (i.e. ecological survey)	Field data, report/ publication on assessment of forest structure using ground field inventory
Acquisition of remote sensing data	Remote sensing data and use of it for estimation and mapping of forest structure
Estimation and mapping of biomass and carbon stock	Report/publication on estimation and mapping of tree species diversity biomass and carbon stock
Mapping the occurrence of invasive plant species and fire incidences	Report/publication on the occurrence of invasive plant species and fire incidences
Estimation and mapping of forest cover	Forest cover change map
Training of conservators and foresters/stakeholder workshop	Conservators and 13 Foresters having skills and well trained in remote sensing and GIS and ecological survey.
Publishing and disseminating the results	At least four publications submitted to journals

5.0 Implementation methodologies

The project is implemented in two Forest Nature Reserves namely Nilo in Korogwe district and Amani in Muheza district. As by to date the activities of the project have focused on one site in Amani Nature Reserve. The methodology used to implement the activities is detailed below.

5.1 Sampling design

Field work was planned by utilizing the existing systematic design (450 m× 900 m) established in 1999–2000 in Amani and Nilo Nature Forest Reserves by a non-governmental conservation and development organization, Frontier Tanzania (Figure 1). A small sub-sample of 30 large circular plots was established this project within the existing grids for each of the forest. The plots were established across the entire Amani and Nilo Nature Reserve to account for the altitudinal effects on biomass distribution. The radius of the plots for Amani Nature Reserve were ranging from 5 to 25 while for Nilo the plot radii was 18m. Crown cover, diameter at breast height for all trees with Dbh>=5, stump count, stump diameter and identification of tree species under two categories named indigenous and invasive. Other threats such as fire, and human disturbance such as illegal logging are also documented.

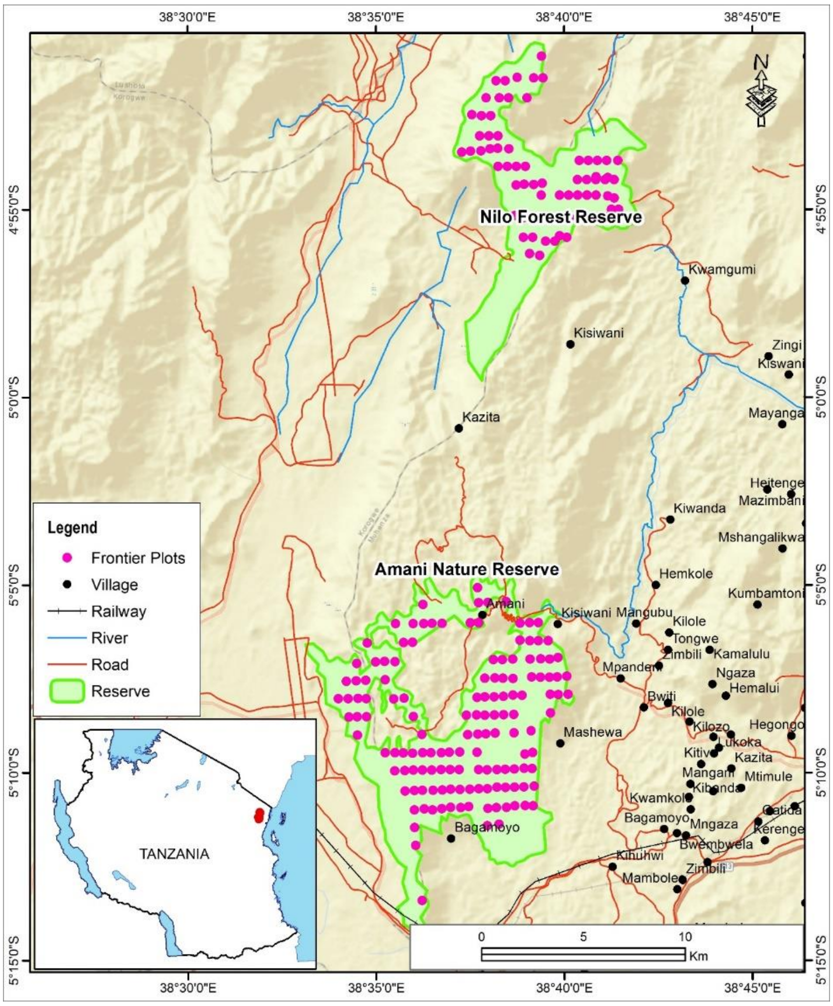

Figure 1. Frontier field plots in Amani and Nilo Nature Forest Reserves

5.2 Data Collection

Global Positioning Systems (GPS) was used to locate and geo-referenced the coordinates of the corner points of each of the plot. In each plot all trees with Diameter at Breast Height (DBH) greater than or equal to 10cm were measured. Likewise, threats to biodiversity such as invasive plants species and fire occurrence were identified and Geo-referenced in each plot and in areas adjacent to the plot or forest boundary. Stand structure parameters including basal area, volume, and biomass and carbon stock were be computed accordingly. Tree species richness and Shannon Winner Index were also computed for each of the plot.

Aboveground biomass for individual trees ($\widehat{\mathrm{AGB}}_t$) was computed using a locally developed allometric model:

$$\widehat{\mathrm{AGB}}_t = 0.402 * \mathrm{DBH}^{1.4365} * \mathrm{H}^{0.8613}$$

The model is developed from 60 trees from 34 different species in the Amani Nature Reserve and has a pR2 of 0.84. The single tree AGB values were scaled to per hectare values using a plot size of 1000 m2 for both ANR and Nilo

Four types open source remotely sensed data were acquired , processed and both spectral/band values and texture variables were computed . These included:Landsat 8, Sentinel 2, Sentinel1 and ALOS PASAL2. Statistical models relating field reference AGB and remotely sensed predictor variables were developed and evaluated. Random Forest regression technique was used and implemented in R statistical software. To evaluate the performance of remotely sensed data in estimating AGB, we used out of the bag samples and computed reliability measures. Assessment of forest cover changes for each forest was also done for period from 2002 t0 2013 using Landsat time series data.

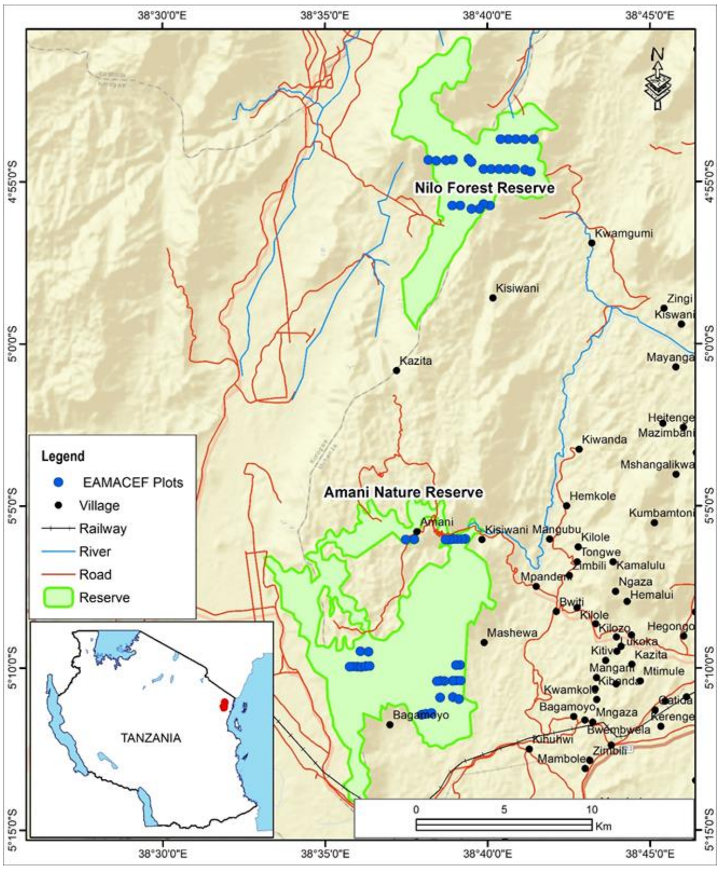

Figure 2. Field plots in Amani and Nilo Nature Forest Reserves

6.0 Outcomes, results and impacts

Reviewing and mapping forest boundaries

An updated maps for both Amani and Nilo Nature forest reserves have been produced as presented in Figures 3&4.

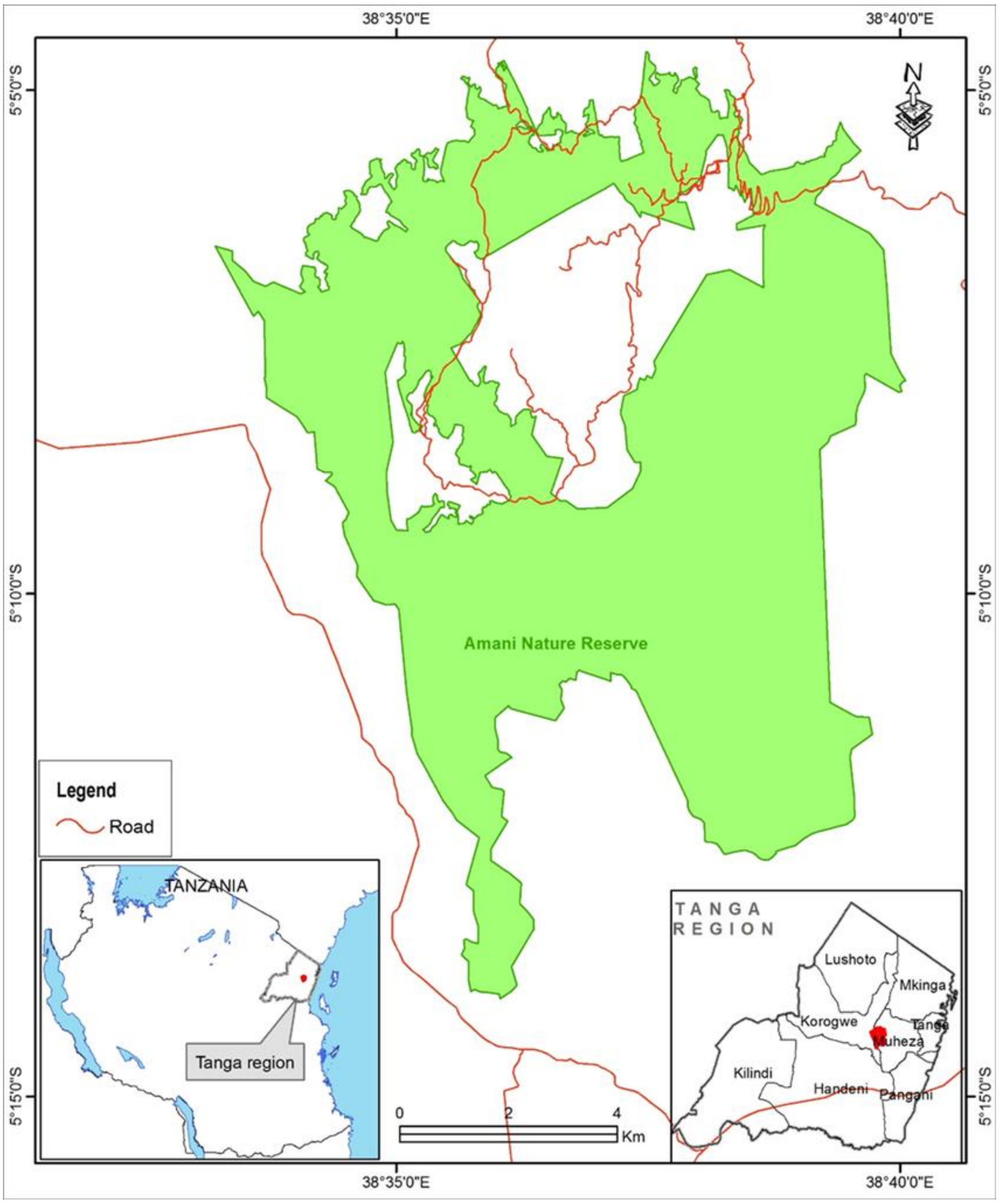

Figure 3. Boundary Map for Amani Nature Forest Reserve

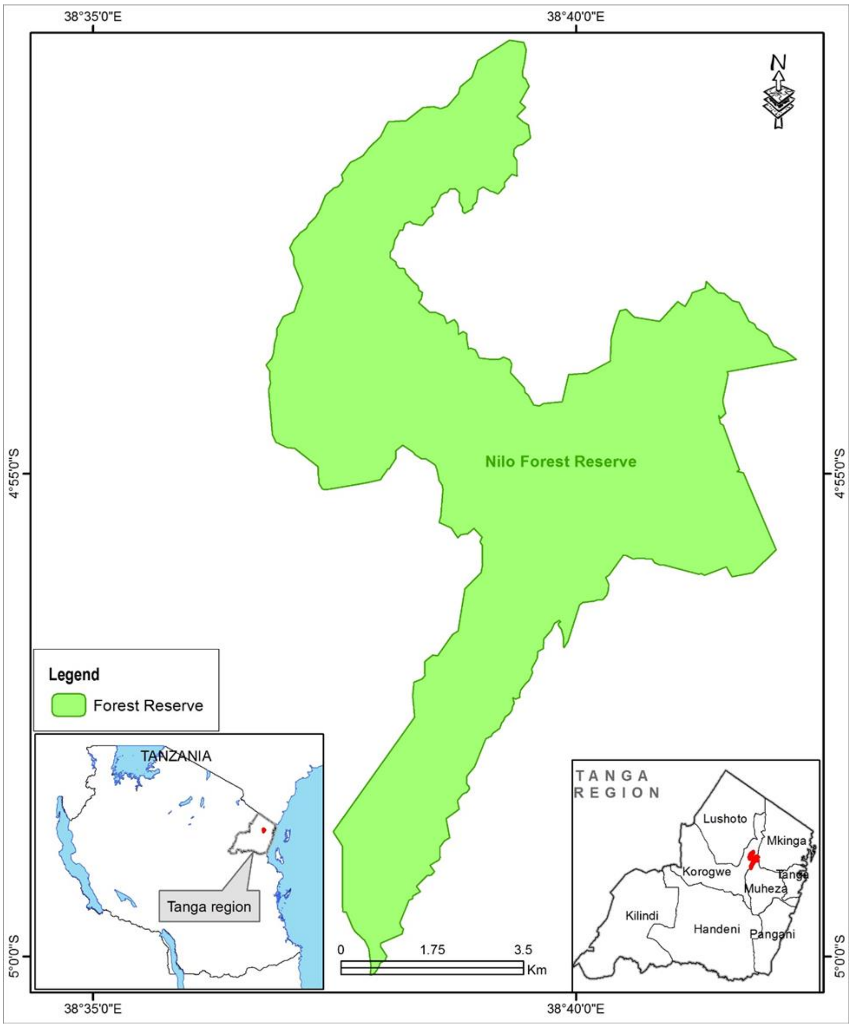

Figure 4. Boundary Map for Nilo Forest Nature Reserve

Quantifying tree biomass using remote sensing techniques

The distribution of Above ground biomass (AGB) for the two forests are shown in Figures 5& 6. Quantification using remote sensed data had also been done for the two both sites Amani and Nature Forest reserve. Our study had revealed unique potential of integrating Sentinel 2 data and machine learning techniques in particular Random Forest for predicting AGB. The R2 OF 83% indicate good fit between ground field measured AGB and remotely sensed data. This is further supported by the Root Mean Square Error value 18.5% which a reasonable precision for estimating AGB. Furthermore, the relative efficiency of 5.8 indicates that by integrating remotely sensed data in AGB estimation we improve the accuracy for almost 6 times more. This would mean also that we will need 6 times more field plots to reach the same precision. The good performance is also demonstrated Figure 7.

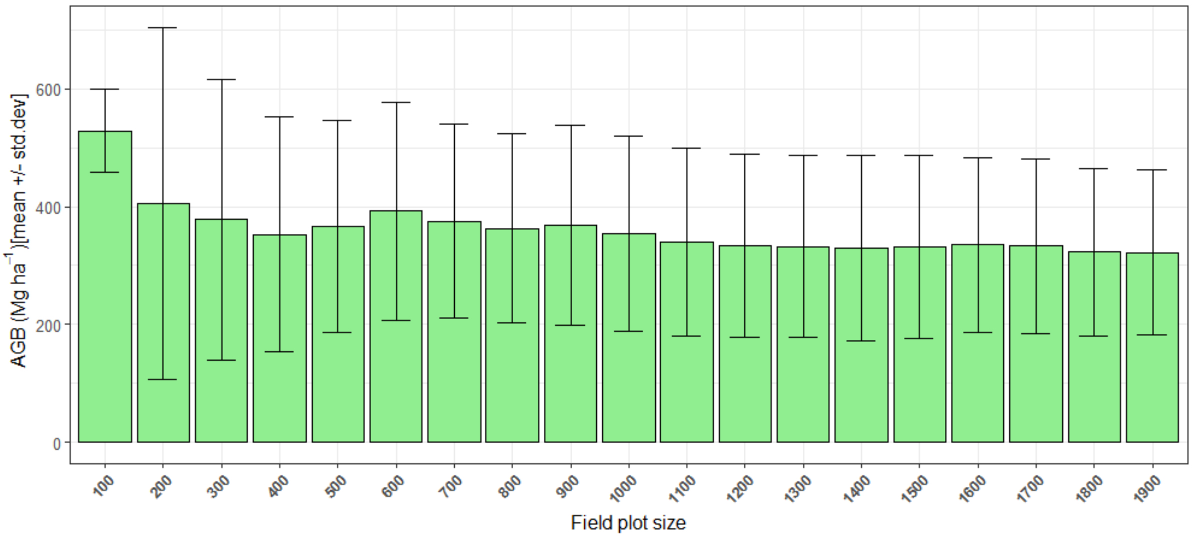

Figure 5. AGB distribution in different plot sizes for Amani Nature Forest Reserve

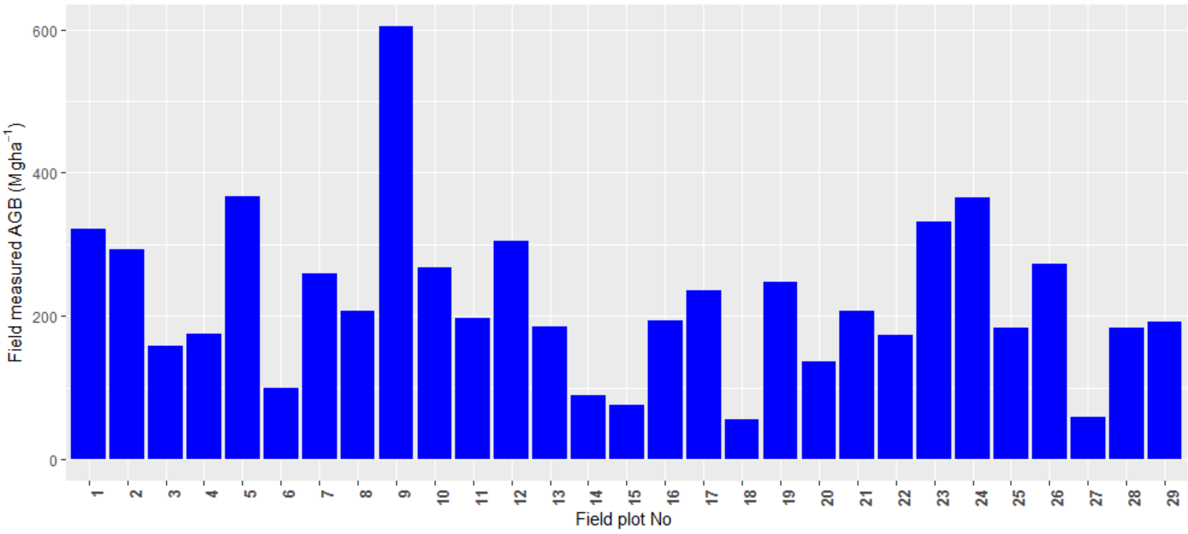

Figure 6. Distribution of Above ground biomass in Nilo Nature Forest Reserve

Table 2. Accuracy of predicting AGB using Sentinel 2 data

Remote sensing data	Predictor variables	R2%	RMSE%	Relative efficiency
Sentinel 2	Spectral values	81	19.1	5.4
	Textures	83	18.9	5.8
	Spectral and Texture	83	18.5	5.8

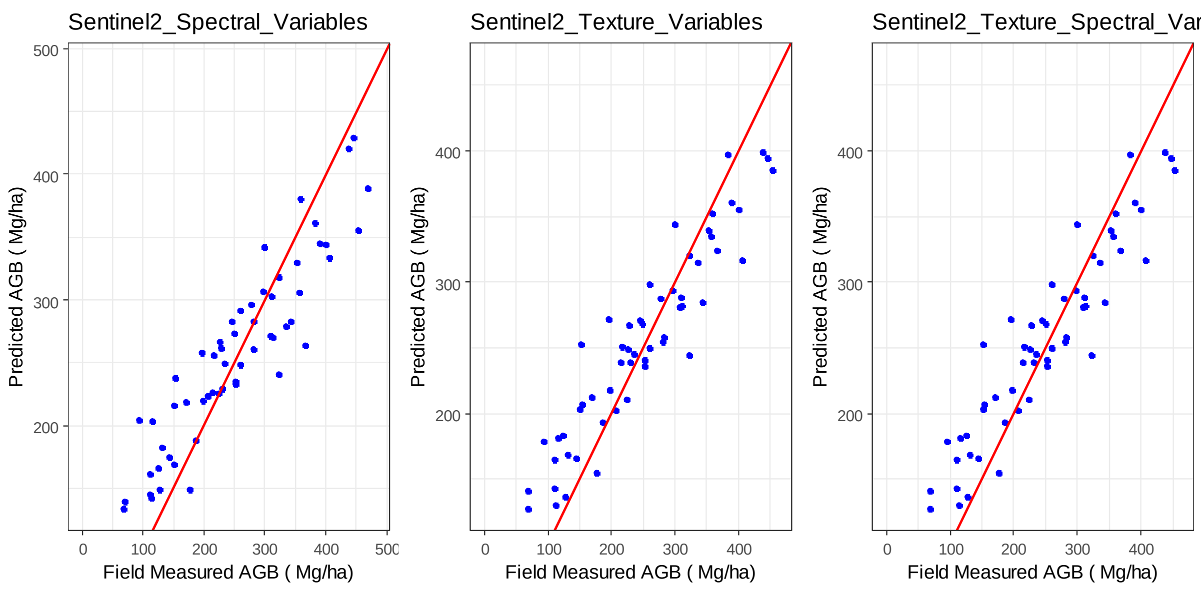

Figure 7. Observed vs predicted AGB

Quantifying and mapping the occurrences and distribution of threats to biodiversity i.e. invasive plant species and fire.

Amani Nature Forest Reserve (ANFR)

In ANFR There was no recent fire incidence recorded during the time of survey in 2018 but MODIS data shows that there were historical fire incidences of fire in Amani is a sign that the risk of fire does exist and management should always have strategy to prevent it. Moreover, although mining has been recorded in previous reports as one of the major threats in Amani, there were signs of new artisanal mining during the time of survey this should by any means be prevented. There was number of invasive species encountered during the survey especially around the botanical garden. Most of the invasive species have either naturalize and some studies have suggested that they are not spreading. However, some species like Lantana camara and Maesopsis eminnii poses threats as they can occupy new gaps and abandoned farms quite rapidly.

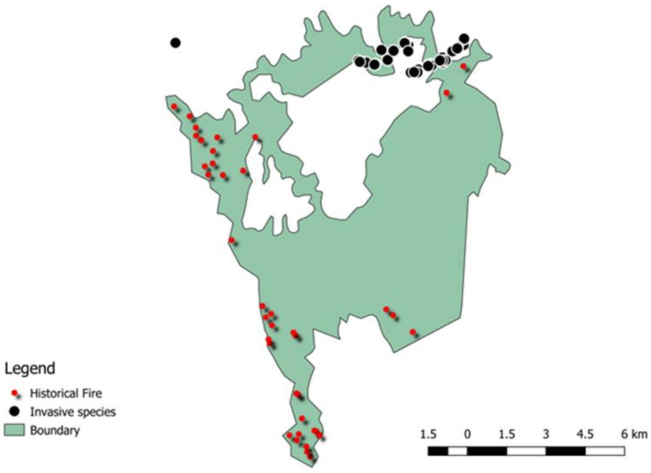

Figure 4: Threats in Amani Nature Reserve

Nilo Nature Forest Reserve (NNFR)

In NNFR, during the survey, there were no evidence of fire observed, although in previous years there has been few case of fires as shown in Figure 2. This suggest that fire remains a potential threat which require constant monitoring and prevention strategies should be in place. Other threats to biodiversity are increasing agriculture and settlement expansion towards the reserve which can lead into increase illegal pole harvesting and serious fragmentation which deterred movement of animals from one patch to another. Most of villagers surrounding the nature reserve depend on agriculture for their livelihood by growing fruits (mango, avocado and pawpaw); spices (cloves, black pepper, cinnamon and cardamom); food crops (rice, coconuts, maize, cassava, bananas, beans) and cash crops which include spices, tea, coffee and coconut.

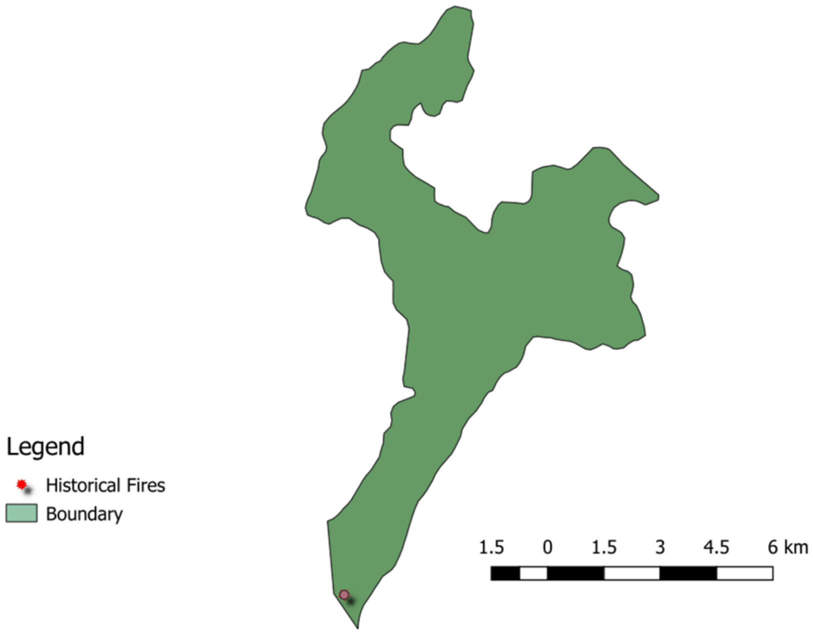

Figure 5: Threats in Nilo Nature Reserve

Quantifying forest cover changes over time

Forest cover change maps are presented in Figures 6&7. Generally there was very little loss over the reported period for both of the Nature Forest Reserves.

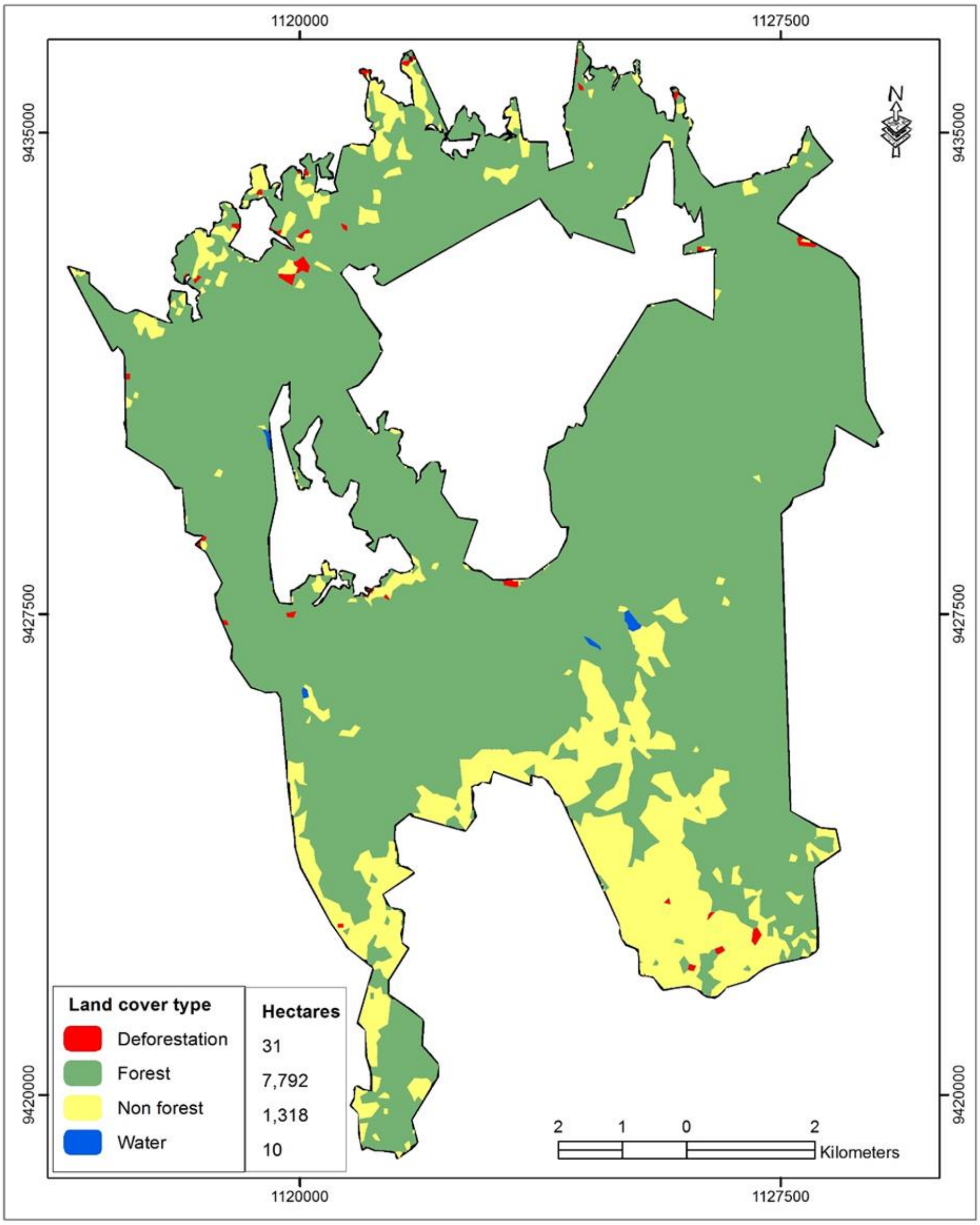

Figure3. Deforestation Map for Amani Nature Forest Reserve from 2002 to 2013

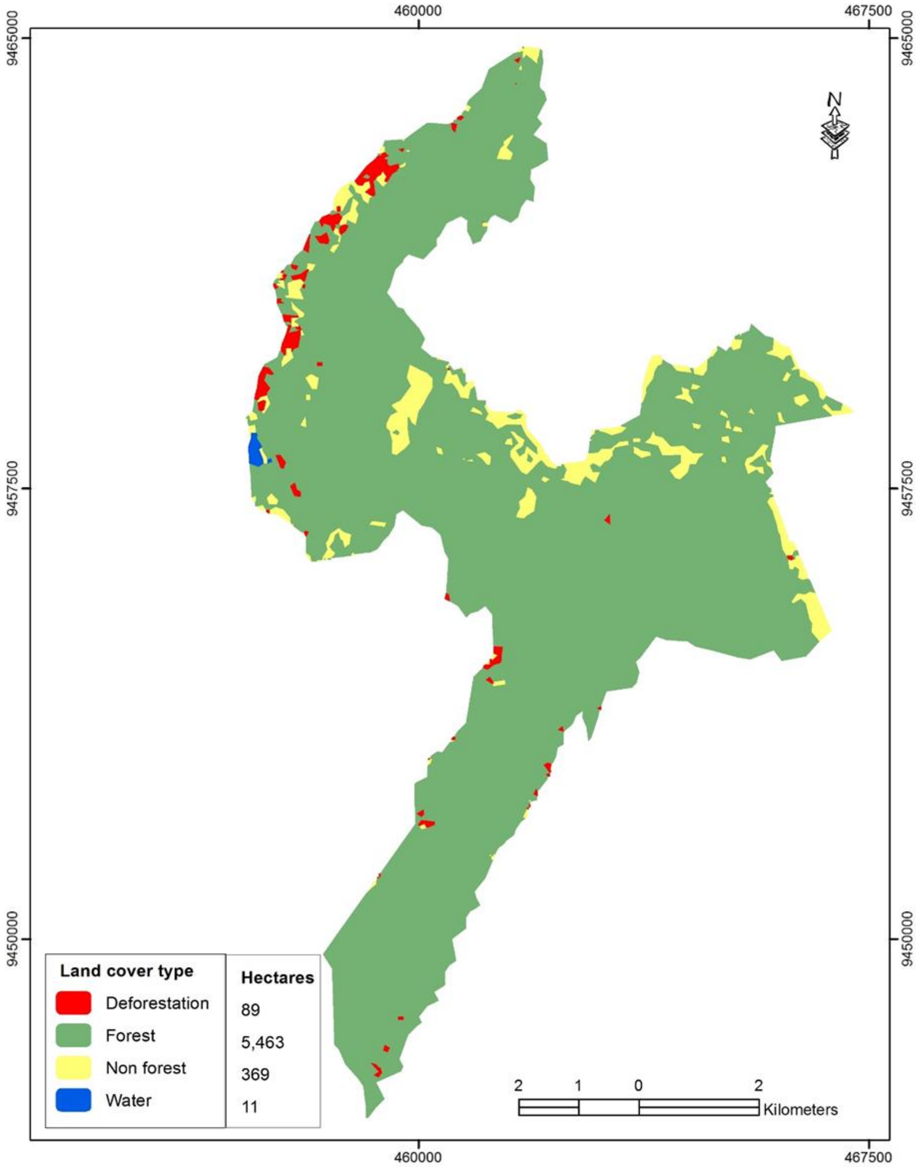

Figure 4. Deforestation Map for Nilo Forest Nature Reserve from 2002 to 2013

7.0 Lesson Learnt

Generally, the project had documented the potential of remote sensing techniques in estimation of the forest structure attributes. In particularly Sentinel 2 remote sensing data had shown a great potential, with the growing need for combination of remote sensing and field data for REDD+ reporting, these methods can be a benchmark for countrywide reporting using remote sensing data. Such approaches, had been used in Norway, Finland and Sweeden where National Forest Inventory had been using combination of field and remote sensing data. Furthermore, the project had showed that remote sensing data can be a good tool for assessing threates in the forest. The fact that there is no significant threat detected, is an indication that the two Nature Forest Reserves are well protected. This had no doubt given the current initiatives under Tanzania Forest Agency on supporting conservation and management of Nature Forest Reserves in Tanzania.

8.0 Challenges

In the planning of the project we had more optimistic plans which could not be reached within the project durations. We planned to have three papers published towards the end of the project, however this had not reached within the project duration and budget. However, applications for funding are made to ensure that this wealth of information is published.

9.0 Conclusion and recommendation

Generally, the project has generated empirical evidence over the use of remotely sensed data in estimation of forest structure attributes. Currently only one forest structure attributes and one remotely sensed data have been considered. Results shows that Sentinel 2 is the best of all. To our understanding, this is the first study to test the use of Sentinel data in biomass estimation in dense forests like Amani and Nilo. Thus, the project has generated a fundamental knowledge for use of Sentinel data for biomass estimation given that the potential of Sentinel data in estimation of Forest resources is growing globally. The methodology can be adopted for mapping and monitoring the forest biomass in other biomes. These results were also presented in the stakeholders workshop conducted Tanga with the aim assessing the potential of in cooperating these methodology in the east Usambara Restoration programme. The workshop was conducted jointly with the WWF Tanzania from 4th to 5th December 2019.

Our projects had also shown that remotely sensed data can be used for threat detection. In both of two-nature forest reserve there was very little evidence of threat. This is supported by the history from the surrounding communities but also results from the remotely sensed data Fire incidence was not observed during the survey only the historical fires was indicated. This was the sign of good conservation efforts, which we witnessed during our survey even though it was out of the scope of this study. Little deforestation was noted in the reported period of 2002 to 2013, which is the period used to generate countrywide activity data. The deforestation was mainly close to the interface of forests and villages. However, there is no any sign of deforestation observed during the survey.

To conclude, the project has generated very credible information over the use of remotely sensed data for estimation forest attributes and detecting threats to biodiversity. Much of the data had been analyzed with credible outputs, which are now used to generate scientific publication. Initially it was intended that the process of publications could be part of this project, however budgetary limitation had made this outputs not to be delivered. However, separate efforts are made to secure resources for publications including the recently proposal submitted to EAMCEF with the intention of upscaling the results. A total of three publications are anticipated from these .The plots established may be considered for monitoring in the future, given that they have good GPS locations.

10. Financial expenditure

We have received the three tranches of funds as shown in Table 2 and the expenditure per activity is presented in Table 3.

Table 2. Disbursement

Tranche	1	2	3	Total
Amount (TSHs)	11,200,000	8,400,000	8,400,000	28,000,000

Table 3. Expenditures per activity

S/N	Activity Description	Amount (TSHs)
1	Acquisition of remote sensing data	250,000
2	Geo-referencing of forest boundaries	820,000
3	Field based measurements (i.e. ecological survey)	16,190,000
4	Estimation and mapping of tree species diversity biomass and carbon stock	500,000
5	Mapping the occurrence of invasive plant species and fire incidences	6,040,000
6	Estimation and mapping of forest cover and acquisition of climatic data	900,000
7	Monitoring changes in forest cover	500,000
9	SUA institutional Overheads	2 800,000
	GRAND TOTAL	28,000,000

Extracts of the Cash Books from SUA accounts.

Sokoine University of Agriculture

SUA- EAMCEF ; 01J1076769830 - SUA EAMCEF Project (Collection)

From : 01-Jul-2017 To : 07-Aug-2020

Date	Vch. No.	Vch. Type	Payee Name	P.Method	Cheque No.	Acc. Code	Code Description	Amount
								TZS
JA-EAMCEF0		**Enhancing Monitoring of Forest Structure and Threats to Biodiversity (Dr. Mauya)**						
2T6.1R22		**Official research local trip/field travel and transport costs**						
4-Dec-2017	221	Imprest	SHIRIMA, DEO DOMINICK	EFT	376546	413001	Local Travel - DSA	3,900,000.
4-Dec-2017		Imprest	SHIRIMA, DEO DOMINICK	EFT	376546	422014	Field Research Assistant's Support Expens	3,491,308.
4-Dec-2017		Imprest	SHIRIMA, DEO DOMINICK	EFT	376546	424002	Fuel Diesel and Lubricants Expenses	340,292.
4-Dec-2017		Imprest	SHIRIMA, DEO DOMINICK	EFT	376546	444999	Staff Imprest Issue	0.
-Dec-2017	223	Payment	MAUYA, ERNEST WILLIAM	EFT	376547	413001	Local Travel - DSA	1,178,100.
7-Apr-2018	237	Imprest	SHIRIMA, DEO DOMINICK	EFT	069426	413001	Local Travel - DSA	7,400,000.
7-Apr-2018		Imprest	SHIRIMA, DEO DOMINICK	EFT	069426	424002	Fuel Diesel and Lubricants Expenses	160,000.
7-Apr-2018		Imprest	SHIRIMA, DEO DOMINICK	EFT	069426	444999	Staff Imprest Issue	0.
							Activity Total:	16,469,700.
2T6.1R26		**To meet researcher, field works,supervision and consultancy costs**						
5-Feb-2019	263	Payment	MAUYA, ERNEST WILLIAM	EFT	376564	422017	Researchers' Project Administration Expen	1,500,000.
-May-2019	265	Imprest	SHIRIMA, DEO DOMINICK	EFT	376566	422014	Field Research Assistant's Support Expens	2,000,000.
-May-2019		Imprest	SHIRIMA, DEO DOMINICK	EFT	376566	444999	Staff Imprest Issue	0.
-Nov-2019	288	Payment	MAUYA, ERNEST WILLIAM	EFT	376573	21113121	Special Allowance	4,200,000.
							Activity Total:	7,700,000.

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Date	Vch. No.	Vch. Type	Payee Name	P.Method	Cheque No.	Acc. Code	Code Description	Amount
O2T6.1R27		**Publication,dissemination and communication**						
14-Dec-2017	221	Imprest	SHIRIMA, DEO DOMINICK	EFT	376546	422014	Field Research Assistant's Support Expens	1,000,000.00
14-Dec-2017		Imprest	SHIRIMA, DEO DOMINICK	EFT	376546	444999	Staff Imprest Issue	0.00
							Activity Total:	1,000,000.00
O2T6.1R43		**SUA Institutional overhead (Agreed %)**						
05-Jan-2018	224	Payment	BURSAR-SUA	CHEQUE		444015	Institutional Overhead Fees	1,120,000.00
20-Feb-2019	261	Payment	BURSAR-SUA	CHEQUE	376563	444015	Institutional Overhead Fees	1,680,000.00
							Activity Total:	2,800,000.00
							Costcentre Total:	27,969,700.00
							TZS ***Total:***	27,969,700.00

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