INBAR Working Paper

Technical Paper

Remote Sensing–Based Bamboo Resource Inventory in The Republic of Malawi

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June 2024

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How to Cite

[Kamba, M., Patrick, J.S., Kebede, B., and Durai. J. (2024) *Remote Sensing–Based Bamboo Resource Inventory in The Republic of Malawi*. Beijing, China: INBAR.]

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The International Bamboo and Rattan Organization (INBAR) is an intergovernmental organization dedicated to the promotion of bamboo and rattan for sustainable development. For more information, please visit www.inbar.int.

About this Working Paper

- This work is an INBAR publication produced as part of the technical support that INBAR provides to its Member States.

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Acknowledgements

The study was made possible through the financial support from the International Bamboo and Rattan Organization (INBAR). Antlia Geo-engineering Consultants undertook extensive field visits to collect ground truth samples for training datasets, classified images, and assessed the accuracy of the classifications.

We would like to express our sincere appreciation and gratitude to Mr. Robert Chenda Hopson Mzumara, Senior Forestry Research Officer/ National Bamboo Focal Point for coordinating the bamboo resource inventory assignment. Special thanks also go to the District Forestry Officers, Forest Assistants, and Forest Guards involved in the project for their incredible support and cooperation during field visits for ground truth sample collection.

We would like to acknowledge Mr. Jairus Haindi (National Herbarium and Botanical Gardens) and Mr. Moffat Thera (Mzuzu Botanical Garden) for their support, guidance, and sharing of relevant data for the study. We thank the Department of Forestry and the Forestry Research Institute of Malawi for their support, guidance, and contributions to this study.

Last but not least, our heartfelt thanks go out to Ms. Qinghui Liu, INBAR for coordinating the publication of this study.

The nationwide remote sensing–based bamboo resource inventory was a great attempt for Antlia Geo-engineering Consultants and the experts who worked on this study—good experience was gained in all phases of the study. This inventory is the first of its kind in this field of research in Malawi and will accelerate actions to integrate resources into sustainable policies. Furthermore, the study is a useful reference for both academic and developmental studies.

Authors

List of Abbreviations

AEDO	:	Agriculture Extension Development Officer
FA	:	Forest Assistant
FAO	:	Food and Agricultural Organization
GIS	:	Geographic Information System
GPS	:	Geographical Positioning System
INBAR	:	International Bamboo and Rattan Organization
KM	:	Kilometer
L1T	:	Level 1 Terrain-corrected
MASDP	:	Malawi Spatial Data Platform
NDVI	:	Normalized Difference Vegetation Index
ODK	:	Open Data Kit
RS	:	Remote Sensing
USGS	:	United States Geological Survey

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Executive summary

This report introduces the Remote Sensing–Based Bamboo Resource Inventory in The Republic of Malawi. The study establishes the spatial distribution and area statistics of bamboo coverage in Malawi. Malawi is estimated to have a bamboo coverage of 466.26 km^2 comprised of both indigenous and exotic species. Indigenous bamboo species include *Oreobambos buchwaldii*, a sub montane bamboo, *Oxytenanthera abyssinica* and *Oldeania alpina*, while the exotic bamboo species in the area include *Bambusa vulgaris* (Yellow bamboo), *Bambusa multiplex* and many others including the recently introduced *Dendrocalamus asper* (Giant Bamboo).

Bamboos are widely distributed in the central region of Malawi, with an estimated coverage of 375.94 km^2, accounting for 81.63% of the country's total bamboo resources. The southern region hosts the second-most bamboo coverage, with an estimated area of 90.12 km^2, accounting for 19.33% of the country's total bamboo coverage. The northern region has the least bamboo coverage area estimated at 0.2 km^2, which represents 0.04% of country's bamboo covering area.

In the central region of Malawi, Nkhotokota District has the largest bamboo coverage (estimated at 113.13 km^2). Salima District has the second-largest bamboo coverage at 107.36 km^2, followed by Dedza (93.13 km^2), Mangochi (88.72 km^2) and Lilongwe District (58.04 km^2). Indigenous bamboos are highly distributed in forest reserves, including Nkhotakota, Thuma, Mua Livulezi, Thambani, and Tsamba. The Nkhotakota Wildlife Reserve is endowed with local bamboos (*Oxytenanthera abyssinica*) which grow on escarpments, covering an estimated area of 113.13 km^2. The bamboo coverage area in Thuma forest reserve is approximately 107.36 km^2. Mua-Livulezi Forest Reserve and Namizimu Forest Reserve have bamboo coverage areas of 93.13 km^2 and 88.72 km^2, respectively. In Malawi, most indigenous bamboo is located in forest reserves and along the streams and rivers, whereas planted bamboo (*Bambusa vulgaris* and *Dendrocalamus asper*) are found in the farm lands.

1. Introduction

1.1 Bamboo resources

Bamboo are perennial woody grasses. Globally, there are 1,642 bamboos species under 121 genera, with native species distributed across 122 countries and distinct islands/regions (Canavan et al, 2017). Bamboo covers a total area of about 35 million hectares worldwide or around 1% of all global forest resources (FAO, 2020). Annual bamboo production is measured at more than 20 million tons and has a trade value worth approximately USD 60 billion annually (Yiping, 2007; Junqi and King, 2019). The global distribution of bamboo resources is found in three major geographic regions (Zehui, 2010; Jiang and Liu, 2007). The Asia Pacific region contains 900 species of bamboo, representing approximately 80% of bamboo species (Chen, Dong and Dai, 2010; Fu, Xie, Zhou, Li and Xiao, 2007). The Americas contains over 500 bamboo species (Meredith, 2001). The African region has 83 bamboo species belonging to 30 genera, of which 20 species are indigenous (native) and 63 species were introduced (i.e., exotic) from other regions (Asia-Pacific and Americas) (Bahru and Ding, 2021). Bamboo plays an important role in rural societies and economies by providing livelihood and income opportunities, and by providing numerous ecosystem services namely controlling erosion, conserving biodiversity, protecting riverbanks, sequestering carbon, and maintaining forest health (Shinohara et al, 2019; ISFR, 2017). Bamboo has enormous potential to increasing terrestrial carbon sinks than woody forests in the same environment; thus, the former plays a unique role in absorbing atmospheric CO_2 (Feng, et al, 2023). Although 12.3% of global bamboo resources are currently located in the African region (Bahru and Ding, 2021), the region still has untapped bamboo resource potential with immense socioeconomic, cultural, and ecological implications.

Predominantly six bamboo species are found in Malawi. Three of them are indigenous to Malawi: *Oldeania alpina* (Syn. *Arundinaria alpina*; *Yushania alpina*), a montane bamboo; *Oreobambos buchwaldii*, a sub montane bamboo; and *Oxytenanthera abyssinica* (Banda and Johnsen, 2005) and the remaining three species: *Bambusa vulgaris* (Yellow bamboo), *Bambusa multiplex* and *Dendrocalamus asper* are introduced or exotic species.

1.2 Application of remote sensing to bamboo resource assessment

The use of remotely sensed data in resource mapping and as a source of input data for environmental modeling has gained popularity in recent years. The availability of remotely sensed

data from different sensors of various platforms with a wide range of spatiotemporal, radiometric, and spectral resolutions has made remote sensing the best source of data for large-scale applications (Melesse, Weng, Thenkabail and Senay, 2007). Mapping the distribution of bamboo is critical for its sustainable management, assessing its valuable ecological services, and determining its socioeconomic value. Despite this, it remains quite difficult to classify bamboo with other vegetation land covers based on remotely sensed data due to spectral similarity (Zhou, Ni, Zhao and Luan, 2022). The homogeneity of bamboo's spectral signature relative to other vegetative cover affects the extraction of bamboo from other types of vegetation. Furthermore, most bamboo stands grows as patches and as mixed vegetation; thus, images with high spatial resolution are necessary to carry out high-quality classification (Tsinghua University, 2018).

Bamboo mapping cannot be achieved using satellite data alone—field observations are an important requisite for training and validation purposes (Tamang, Nandy, Srinet, Das and Padalia, 2022). The difference between bamboo forests and evergreen woody forests resulted in the identification of a close temporal trend and magnitude for vegetation indices, indicating that merely employing spectral band-derived indices may have failed to differentiate these two categories (Feng, et al, 2023). However, the literature has proven the effectiveness of using remote sensing approaches in mapping bamboo with high classification accuracy. The time-series patterns of reflectance and index provide sufficient information for classification that assist in the differentiation of vegetation categories (i.e., bamboo forests, woody forests, and croplands) with validation and uncertainty assessment thus critical for classifying homogenous land cover (Feng, et al, 2023; Loew, et al, 2017).

Xiang et al (2023) assessed the efficacy of various types of remote sensing data in their study on mapping bamboo forests' bright and shadowy areas using optical and SAR satellite data from Google Earth Engine. The normalized shaded vegetation index (NSVI) was employed to differentiate bright and shadowy woodlands. The results showed that (1) the red-edge and short-wave infrared bands of Sentinel-2 optical images and their corresponding vegetation indices are significant for bamboo forest information extraction. (2) The dissimilarity and homogeneity of Sentinel-2 texture features in bright areas and dissimilarity in the shadow area (i.e., the Sentinel-1 backscatter features in the bright area and the VV and VH in the bright area and VV-VH in the shadowy area) exhibit some variability between bamboo and non-bamboo forests, which can be

used effectively for bamboo forest extraction. (3) A combination of spectral, texture, and backscatter features yields the highest overall classification accuracy and Kappa coefficient at 87.96% and 0.7435, respectively.

Tsinghua University (2018), used a Level-1 terrain-corrected (L1T) Landsat 8 satellite image in their study of remote sensing–based regional bamboo resource assessment in Ethiopia, Kenya, and Uganda. The estimated bamboo coverage areas were 14,744.63 km^2, 1,332.73 km^2, and 545.33 km^2 for Ethiopia, Kenya, and Uganda respectively. Qi et al (2022) applied remote sensing in bamboo forest mapping in China using the Dense Landsat 8 Image Archive and Google Earth Engine. The random forest algorithm using Landsat 8 images based on the GEE platform indicated an estimated bamboo coverage area of 709.92 × 10^4 hectares, with the largest areas being in Fujian (135.13 × 104 hectares), Jiangxi (118.11 × 10^4 hectares), and Zhejiang (108.33 × 10^4 hectares).

The development of space technology including satellite remote sensing with various spatial and temporal scales, offer a means of identifying bamboo-growing areas with standard supervised classification technique based on bamboo index (Goswami, Tajo and Sarma, 2010). Remote sensing based on the bamboo index has shown potential in mapping the distribution of bamboos in Cameroon (Nfornkah et al, 2020). Further, remote sensing has been useful in China in bamboo resources inventory indicating 6.5 million hectares of forests comprising 40 genera and 800 species (INBAR, 2019a). In addition, land use land cover (LULC) analysis provides resource distribution information for land cover including exact area under bamboo (IUCN, 2010). Therefore, remote sensing and the mapping of bamboo resource inventory in the Republic of Malawi was carried out.

1.3 Objective

The objective of the study was to conduct remote sensing–based bamboo resource inventory in the Republic of Malawi to help accelerate actions to integrate resources into sustainable policies.

2. Methodology

2.1 Data

Remote sensing technology was used in mapping of the bamboo resource inventory in the Republic of Malawi. L1T Landsat 8 images acquired between 2018 and 2022 from United States Geological Survey (USGS) Earth Explorer was used in the study. The study used ten (10) images, each acquired in both dry season and wet season (rain season) between 2018 and 2022 to address bamboo seasonal spectral variations. Additional spatial data, including the MODIS Normalized Difference Vegetation Index (NDVI) time series, climate data, and topography data were used in the study. A 30 m resolution of Shuttle Radar Topography Mission (SRTM) elevation data was applied together with topographic variables (e.g., slope). Other ancillary data were acquired from the Malawi Spatial Data Platform (MASDP).

2.2 Field sample

Extensive field visits were conducted to collect ground truth samples for training dataset and for accuracy assessment of bamboo growing areas. With the help of local experts, ground truth samples were collected in 20 districts spread across three regions (North, Central, and South Malawi) covering 3,050 kilometers. In each district, data collection was carried out in the localities identified in the literature, bamboo dealers, local forest officers, and bamboo craftsmen as bamboo growing areas, harvesting and selling (INBAR, 2020). A total number of 109 samples were collected during field visits by the study experts. Ground truth samples of croplands, forests, grasslands, wetlands, water bodies, impervious surfaces, and bamboos were collected using Handheld GPS and supported by a digital mapping form embedded in the Open Data Kit (ODK).

Due to the scattered distribution of bamboo in Malawi, the study involved local experts including Forest Assistants (FA), Agriculture Extension Development Officers (AEDO) and Forest Guards who supported in data collection. Local experts submitted 41 ground control samples captured using ODK with allowable precision of <6 meters.

In addition, multiple ground truth samples were collected at a single site to address landscape spatial variability (Salas et al, 2021). Figure 1 shows the distribution of the collected ground truth samples.

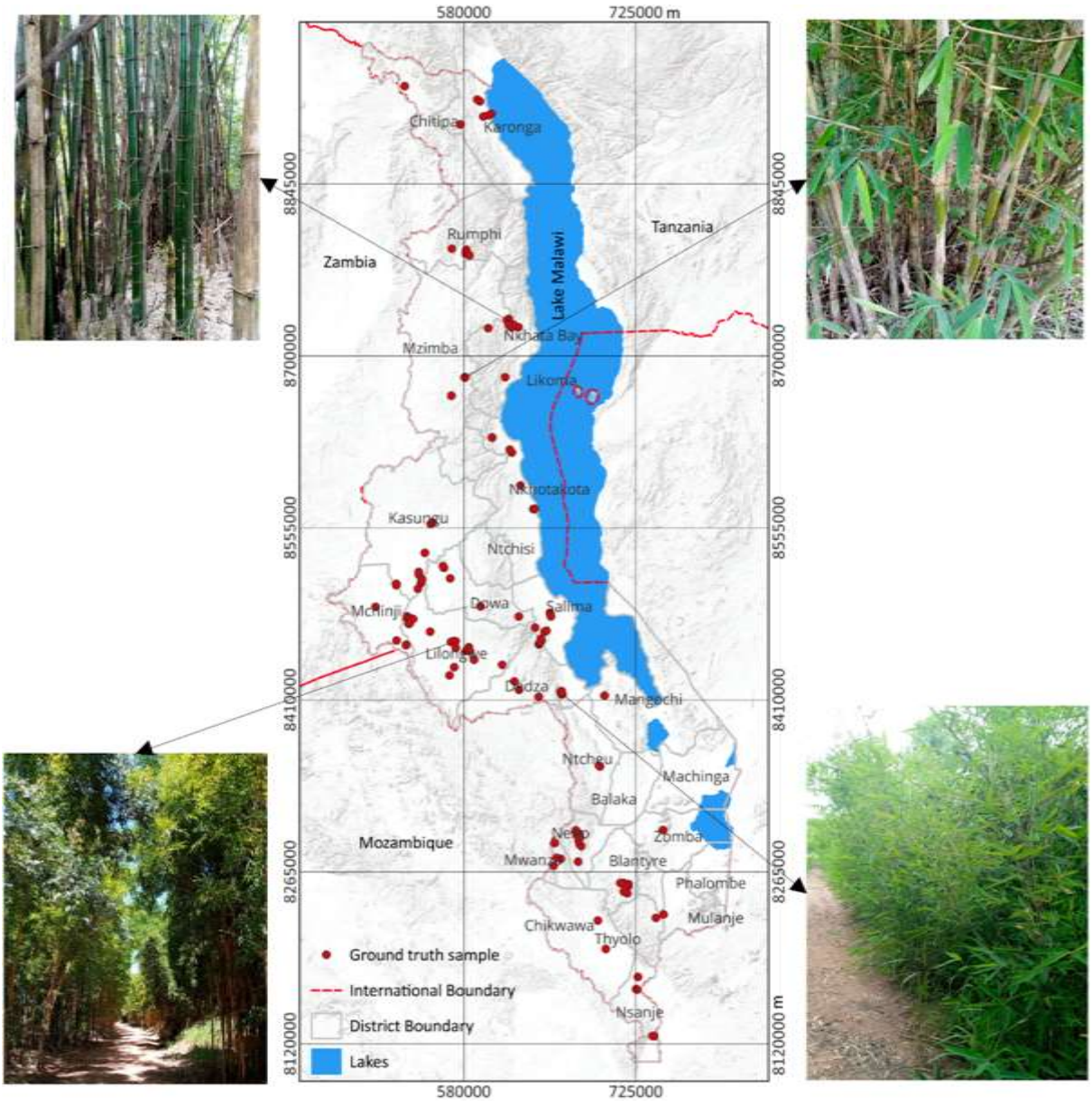

Figure 1: Ground truth sample collection locations.

2.3 Mapping design and limitation

The bamboo inventory study was designed to provide critical basis to spatially measure the status of bamboo resources in Malawi. The methodology focused on generating relevant data critical for generating sufficient results to inform sustainable policies (figure 2). Land cover maps composed in this study included several classes but not limited to bamboos, croplands, wetlands, water bodies and other classes. The study used a multi-temporal set of Landsat images.

Several observations put forth during the field visit:

a) Small bamboo patches are highly spread across the country following bamboo interventions focused on distributing bamboo seedlings to smallholder farmers. Most of these bamboo patches are less than 163.5 m^2, hence the need for a household survey targeting smallholder farmers to quantify bamboo coverage area of tiny patches,

b) it was observed that bamboos in Malawi are used for demarcating farm boundaries,

c) a considerable number of people in Malawi are involved in bamboo weaving as one way for generating income. The methodology supported the study in generating results in bamboo spatial distribution and coverage area in Malawi.

FAO., 2000 defined forest as land of more than 0.5 hectares containing a tree canopy cover of more than 10% that is not primarily used for agricultural or urban purposes. The study used a 30 m * 30m (900 m^2) pixel size, which proved challenging for depicting small patches due to conflicting pixel values. Table 1 shows the tools and materials used during data collection.

Table 1: Tools and materials used.

No	Tools and Materials	Quantity	Details
1	Handheld GPS, battery charger, and spare battery	2	For spatial data collection
3	Laptop	1	For importing field data
4	Smart phone	2	For digital data collection
5	Machete	1	For clearing bushes
6	QGIS	1	For data management, analysis and visualization
Digital Documents and Forms			
7	Survey form	1	For collecting data in the field
8	Look up name of species and plants	2	For checking bamboo and rattan species/genera
Logistic			
9	First aid box	1	

2.4 Mapping approach

The resource inventory study employed purposive sampling technique guided by information obtained from literature, bamboo dealers, local forest officers, and bamboo craftsmen (Nfornkah et al, 2022). The selection of bamboo samples plots for GPS coordinate collection was based on the bamboo coverage area with over a 30 m^2 pixel size.

Figure 2 shows the methodological framework for mapping the distribution of bamboos in Malawi. The study involved data preparation, ground truth sample collection, image classification (i.e., preprocessing, processing, and post-processing).

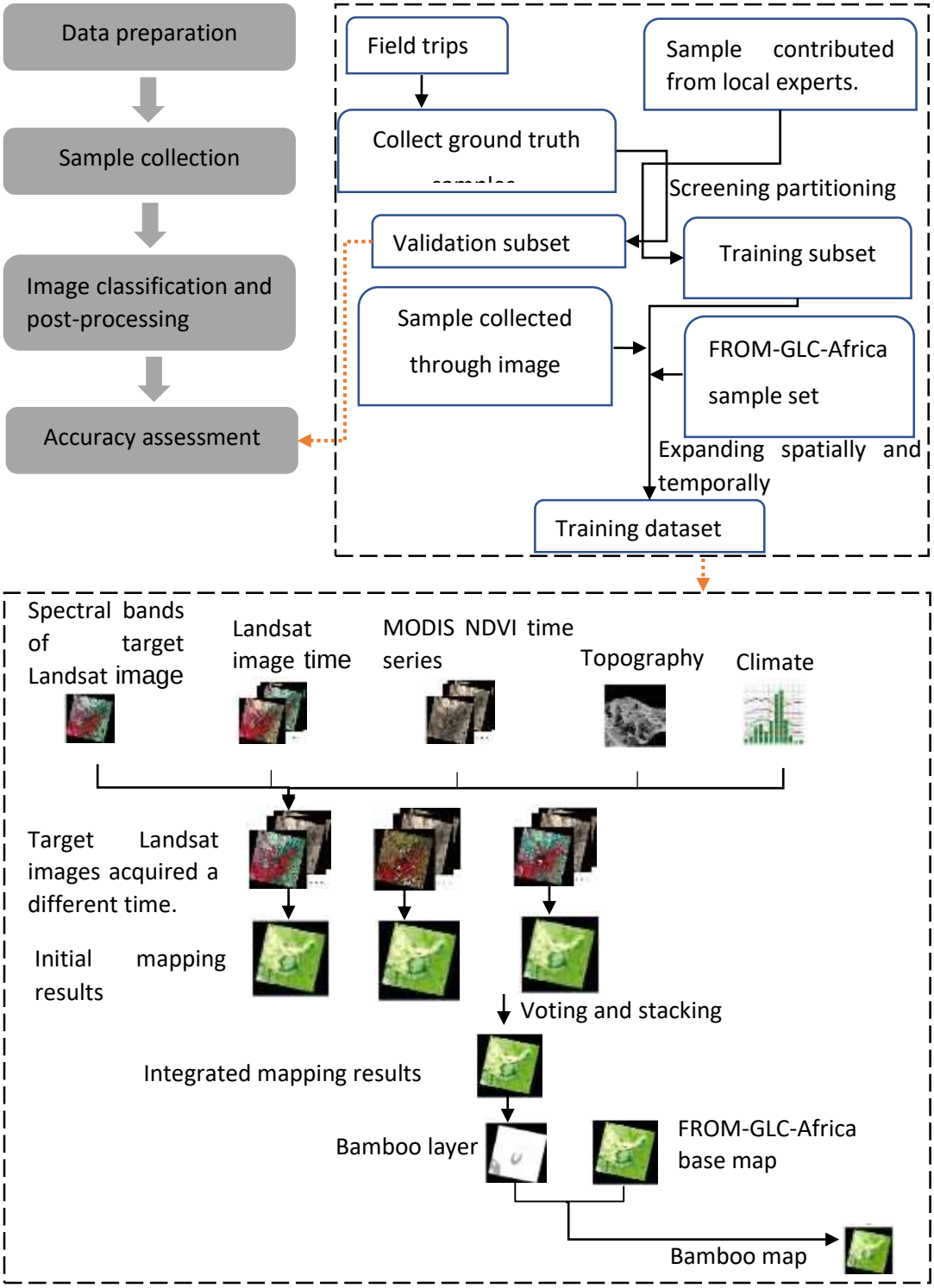

Figure 2: Workflow of bamboo mapping in Malawi (Zhao et al., 2017).

3. National Assessment for Malawi

3.1 Distribution pattern

The Republic of Malawi has both indigenous and exotic bamboo species distributed across the country. The indigenous bamboo species include *Oreobambos buchwaldii*, a sub montane bamboo, *Oldeania alpina*, and *Oxytenanthera abyssinica*, while the exotic bamboo species are *Bambusa vulgaris, Bambusa multiplex,* and the recently introduced *Dendrocalamus species* including *Dendrocalamus asper*. Some parts of the Northern and Central Malawi have sparsely distributed Yellow and Green Giant Bamboos. Indigenous bamboo is highly distributed in forest reserves, including Nkhotakota, Thuma, Mua Livulezi, Thambani, and Tsamba. Figure 1A shows the distribution of indigenous bamboo in the Thuma Forest Reserve located in Salima, Lilongwe and Dedza districts. These bamboo species are mostly found along streams as a pure stand and a mixed stand with natural trees spreads within forest reserves.

Nkhotakota Wildlife Reserve, to the east of Central Malawi and near Lake Malawi, is one of the two large wildlife areas in Malawi. It covers 1800 km^2 of rugged terrain crossed by several rivers which tumble down the edge of the Rift Valley escarpment as they make their ways to the Lake. Nkhotakota Wildlife Reserve has altitudinal range between 500–1,638 meters above sea level (GoM., 2020). The reserve is endowed with local bamboos (*Oxytenanthera abyssinica*), which grow on escarpments and cover an estimated area of 113.13 km^2 (Figure 1A).

Thuma Forest Reserve covers an area of roughly 197 km^2 in the Great Rift Valley Escarpment near Lake Malawi. The altitude of Thuma Forest Reserve varies from 575–1564 meters above sea level. Generally, the topography is rugged. Bamboo coverage area in the Thuma Forest Reserve is estimated to be 107.36 km^2 (Figure B—the zoomed-in map). Both the upper and lower levels of the reserve are characterized by mixed low-altitude woodlands with widely spread bamboo patches.

Mua-Livulezi Forest Reserve (Figure 1C) is located within the Kirk Range escarpment, which runs from Ntcheu to Salima and covers an area of 121.47 km^2 (DoF 2007). The Mountain lies at an altitude of 747 meters above sea level, with dense bamboos occupying the plateau, the slopes, and the valley bottom. The bamboo resource inventory revealed that approximately 93.13 km^2 of the reserve is covered in bamboo.

Namizimu is a major forest reserve containing bamboo resources in Mangochi District located in Southern Malawi. The Namizimu escarpment (northeast of the town Mangochi) marks the start of a large upland area east of the Rift Valley that extends into Mozambique and southern Tanzania. Namizimu escarpment encompasses a wide altitudinal range, rising steeply from the Lake shore plain (500 m) to the Msondole Peak (1,800 m). Namizimu forest reserve hosts a total forest cover of 889.66 km^2, out of which a densely distributed ground cover of *Oxytenanthera abyssinica* is found in an estimated 88.72 km^2 area (Figure 1D).

In Malawi, most planted bamboos (*Bambusa vulgaris* and *Dendrocalamus asper*) are found in the boundaries of mega farms, whereas indigenous bamboos are located in forest reserves and along streams and rivers.

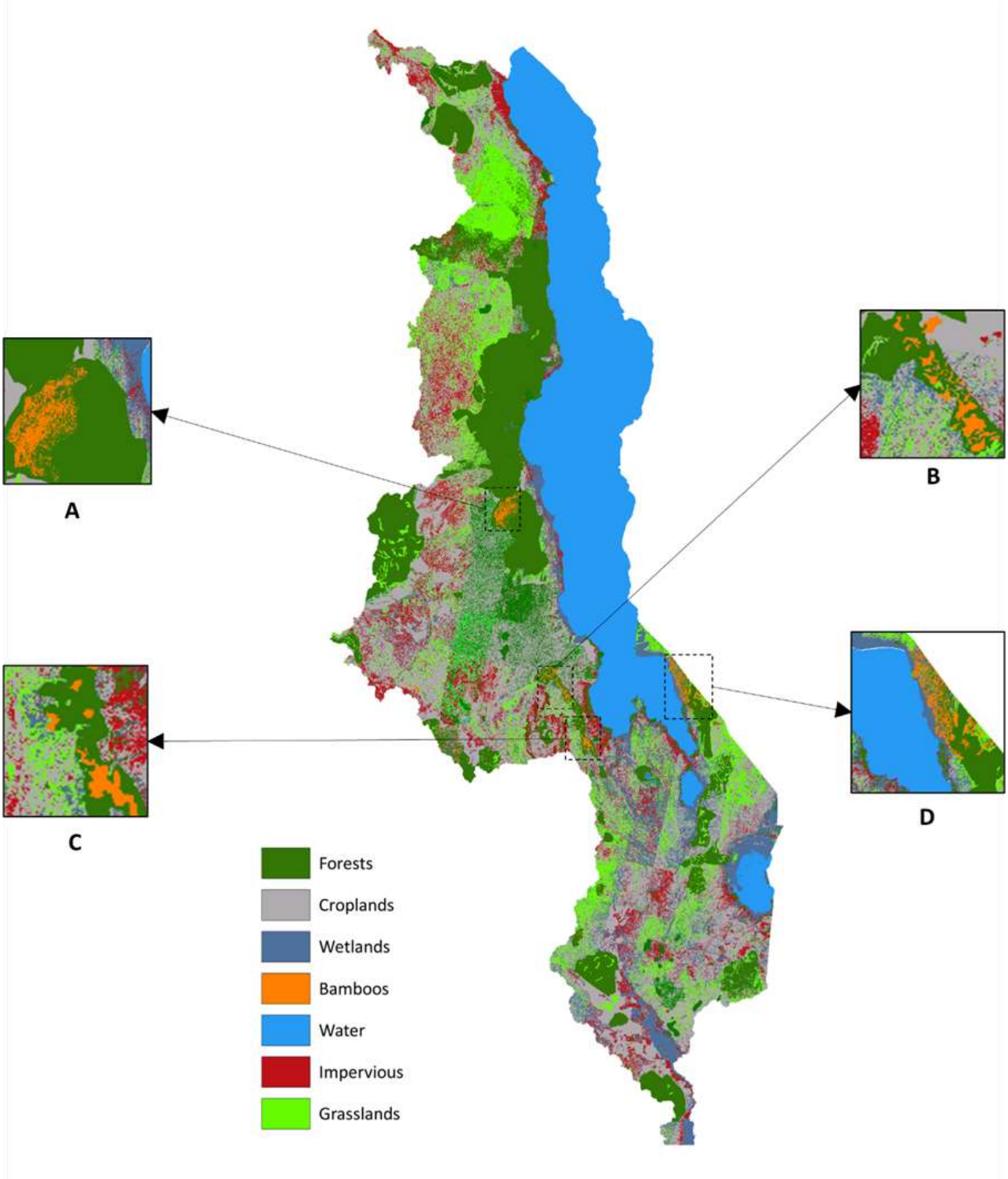

Figure 3: Bamboo land cover map of Malawi depicting four sites with numerous bamboo clusters.

3.2 Area Statistics

The Republic of Malawi is a landlocked developing country with a total geographical area of 118,480 km^2, of which 24,400 km^2 (21%) is composed of surface water (predominantly Lake Malawi). Malawi's state lands include forest reserves (36.2%), national parks (11.3%), built-up areas, and public areas.

Figure 4 contains a map overlaid with administrative boundaries showing the spatial distribution of bamboos in Malawi. The bamboo land coverage area in Malawi is estimated to be 466.26 km^2, which represents 0.5% of the country's total land area. Malawi's three regions (Northern, Central, and Southern Malawi) have varying amounts of bamboo-covered areas. The central region has the highest bamboo coverage area at 375.94 km^2, which accounts for 80.63% of the country's total bamboo cover area. The Southern Region's total bamboo-covered area amounts to 90.12 km^2, or 19.33% of the country's total bamboo area. The Northern Region has the least amount of bamboo coverage at 0.2 km^2, representing 0.04% of country's bamboo-covered area.

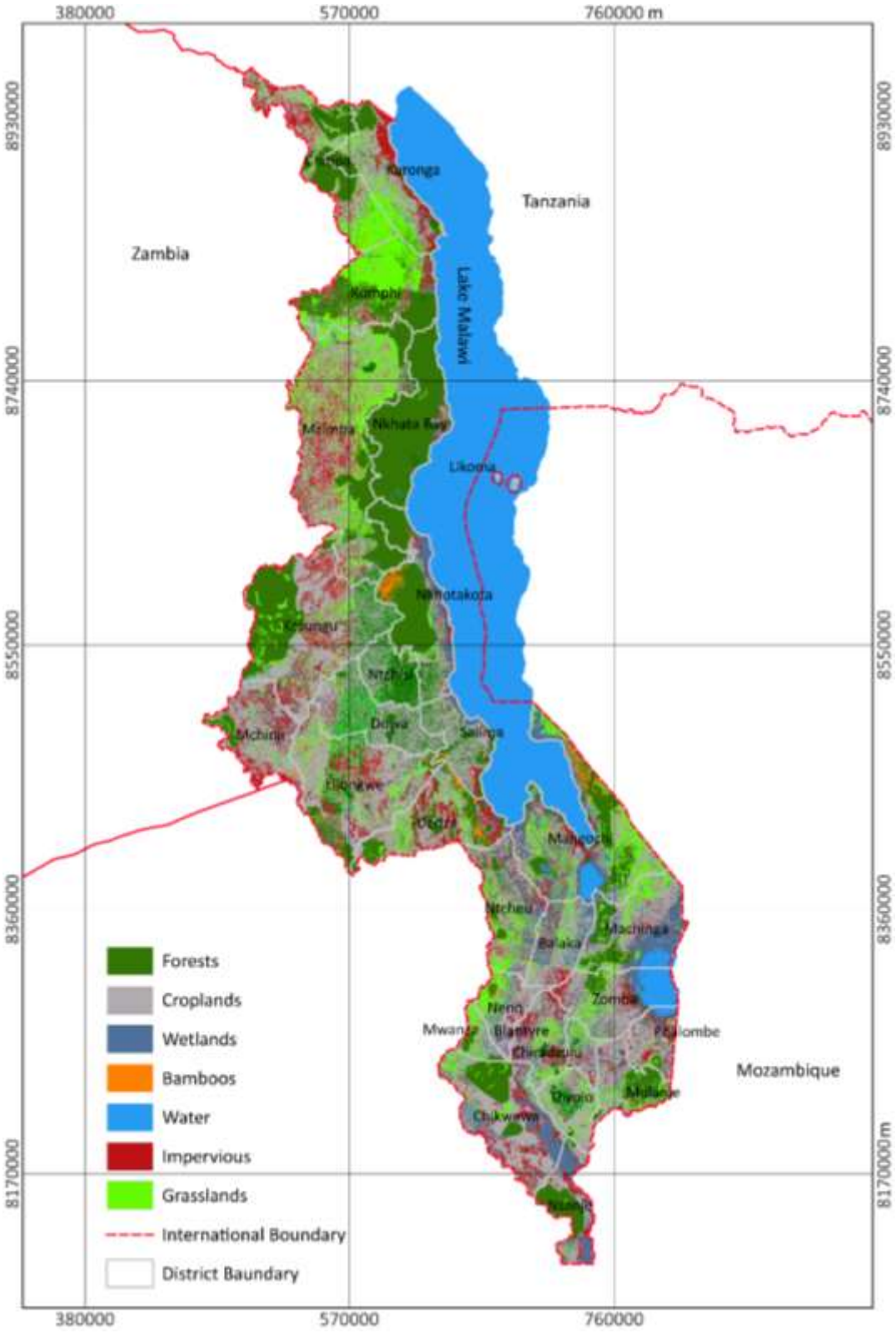

Figure 4: Bamboo land coverage map of Malawi overlaid on administrative boundaries.

Figure 5 shows bamboo coverage area in Malawi by region. Central Malawi had the largest bamboo coverage area of 375.94 km^2. This was followed by the southern region (90.25 km^2). The northern region had the smallest bamboo coverage area.

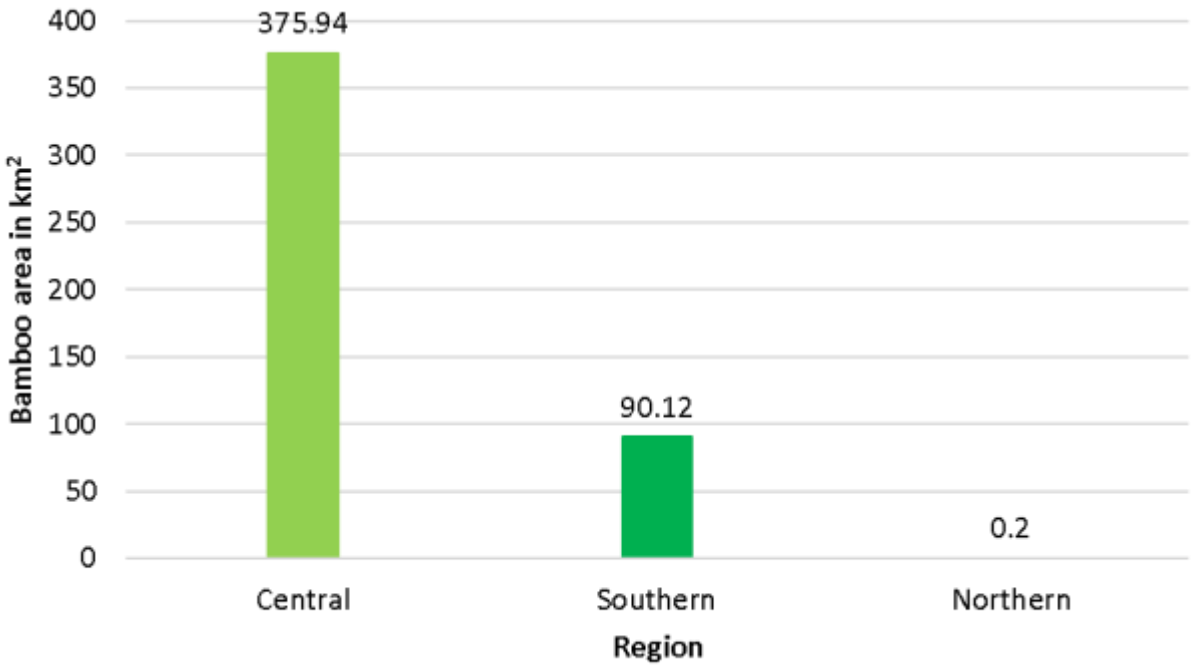

Figure 5: Bamboo-growing areas by region in Malawi.

Table 2 depicts bamboo-growing areas disaggregated by district. The remote sensing–based bamboo resource inventory showed that large bamboo patches are mostly found in Central Malawi. 30.11 % of the total bamboo resources in Central Malawi is located in Nkhotakota District, followed by Salima (28.56%), Dedza (24.77%), Lilongwe (15.76%), Mchinji (0.53%), Dowa (0.25%), and Kasungu (0.02%). In the Southern Region of Malawi, Mangochi District has the highest bamboo coverage at 98.51% followed by Neno (1.20%), Chiradzulu (0.13%), Mwanza (0.12%), and Thyolo (0.03%). In the Northern Region, Nkhatabay District, at 40%, had the highest bamboo coverage area, followed by Rumphi (35%), Mzimba (15%), and Chitipa (10%) (Figure 5).

Table 2: Bamboo coverage area by district in Malawi.

Region	District	Area (km^2)
Northern	Chitipa	0.02
	Rumphi	0.07
	Mzimba	0.03
	Nkhatabay	0.08
Central	Nkhotakota	113.21
	Kasungu	0.06
	Dowa	0.94
	Lilongwe	59.24
	Mchinji	2
	Salima	107.36
	Dedza	93.13
Southern	Mangochi	88.78
	Thyolo	0.03
	Mwanza	0.11
	Neno	1.08
	Chiradzulu	0.12

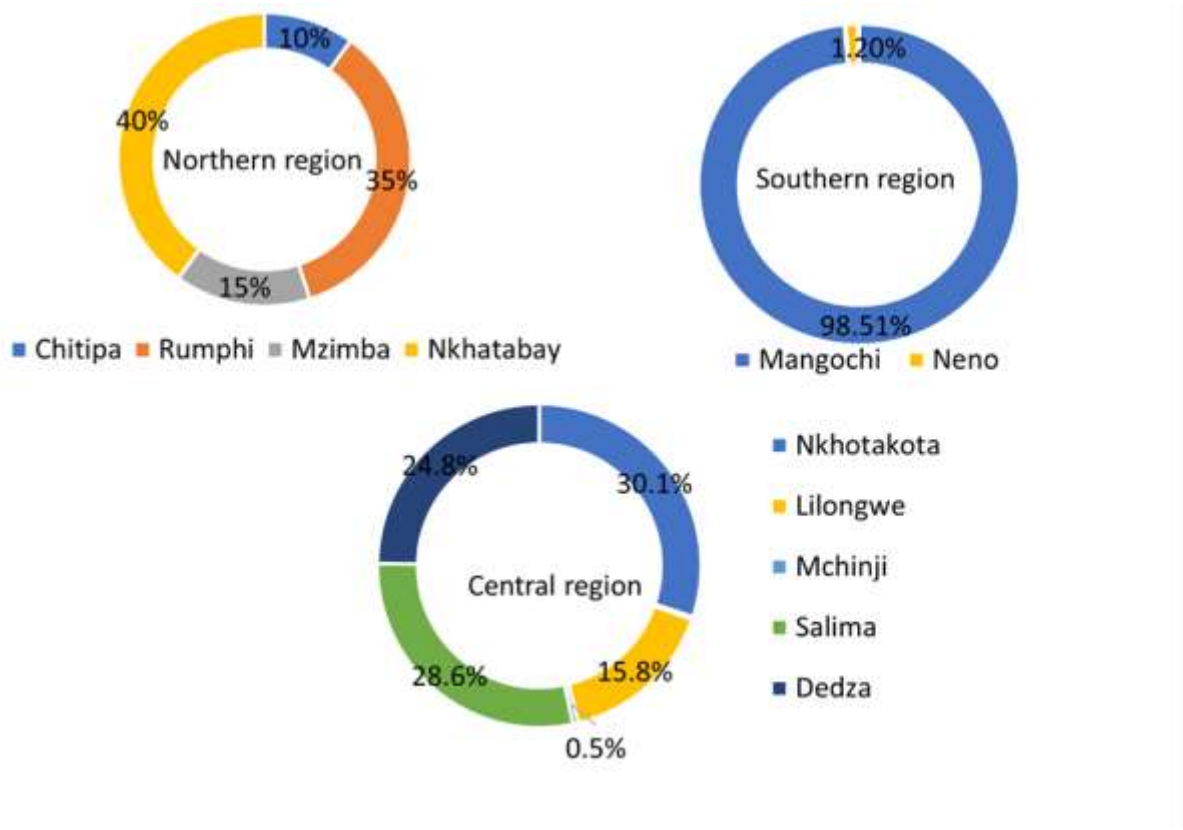

Figure 6: Distribution of Bamboo-growing Areas (%) in various Districts.

Table 3 shows the top 13 bamboo-growing districts in Malawi. Nkhotokota District in the Central Region has a large bamboo coverage (113.13 km^2) in Malawi. Salima is the second largest bamboo-growing district (107.36 km^2) followed by Dedza (93.13 km^2), Mangochi (88.72 km^2), and Lilongwe (58.04 km^2). Mwanza had the lowest bamboo coverage among the top 13 districts at 0.11 km^2.

Table 3: Top 13 bamboo-growing districts in Malawi.

No	Region	District	Bamboo area in km^2	Bamboo inside forest area (km^2)	Bamboo outside forest area (km^2)
1	Central	Nkhotakota	113.21	113.21	-
2	Central	Salima	107.36	107.36	-
3	Central	Dedza	93.13	93.13	-

4	Southern	Mangochi	88.78	88.78	-
5	Central	Lilongwe	59.24	58.04	1.2
6	Central	Mchinji	2	-	2
7	Southern	Neno	1.08	1.08	-
8	Central	Dowa	0.94	-	0.94
9	Southern	Chiradzulu	0.12	0.12	-
10	Southern	Mwanza	0.11	0.11	-
11	Northern	Nkhatabay	0.08	0.08	-
12	Northern	Rumphi	0.07	-	0.07
13	Central	Kasungu	0.06	-	0.06

4. Conclusion

Malawi has both indigenous and introduced bamboo species spatially distributed across the country. The indigenous bamboo species include *Oreobambos buchwaldii, Oldeania alpina* and *Oxytenanthera abyssinica*, while the country's exotic bamboo species are *Bambusa vulgaris, Bambusa multiplex* and the recently introduced *Dendrocalamus species* including *Dendrocalamus asper*. Understanding spatial distribution and bamboo coverage area are critical for policy formulation relevant to socio-economic development, biodiversity conservation and ecosystem services. This study used remote sensing methods by using 30-m spatial resolution Landsat imagery to map bamboo resource inventory for the first time in Malawi. This study utilized extensive field visits across the country to collect ground truth samples with the high levels of precision necessary for training datasets and validating image classification results. Accuracy assessments revealed that the overall classification accuracy among seven classes (i.e. forests, croplands, wetlands, bamboos, water, impervious, and grasslands) was 82% with a kappa value of 0.75.

The bamboo resource inventory study revealed that the total coverage of bamboo in Malawi is estimated at 466.26 km^2. Bamboo, particularly indigenous species, are mostly distributed in forest reserves such as the Nkhotakota Wildlife Reserve, Dzalanyama Forest Reserve, Thuma Forest Reserve, Mua-Livulezi, and Namizimu Forest Reserve. In addition to indigenous bamboo, giant

bamboo was also planted in considerable large areas including Lisoka Farm, Kanyatula Farm, Kandaula Farm, Nyagala Estate, Mude Estate, Kasonjola Estate, Khasu Estate, and Chankhandwe Farm. The study found that with considerable bamboo resources, Malawi can position bamboo as a sustainable alternative to trees for fuelwood, raw materials for construction, materials for farming activities and weaving, as bamboo is a sustainable alternative for Malawi's lost forests and a way to address climate change issues. Classification based on two-level administrative boundary (regions and districts) was used to provide a clear understanding of bamboo distribution across the country.

The field observation revealed that smallholder farmers from several districts participate in planting bamboo at very small scales. Given this, information on tiny bamboo patches planted by smallholder farmers has not been included in this study due to their usage of images with low spatial resolution. It is therefore recommended that small-scale studies use high spatial resolution imagery to capture tiny bamboo patches. A supplementary survey based on mobile applications such as Open Data Kit (ODK) on smallholder farmers would be critical for understanding the farm level distribution of bamboos in Malawi.

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Appendix

The top 10 bamboo-growing districts in Malawi

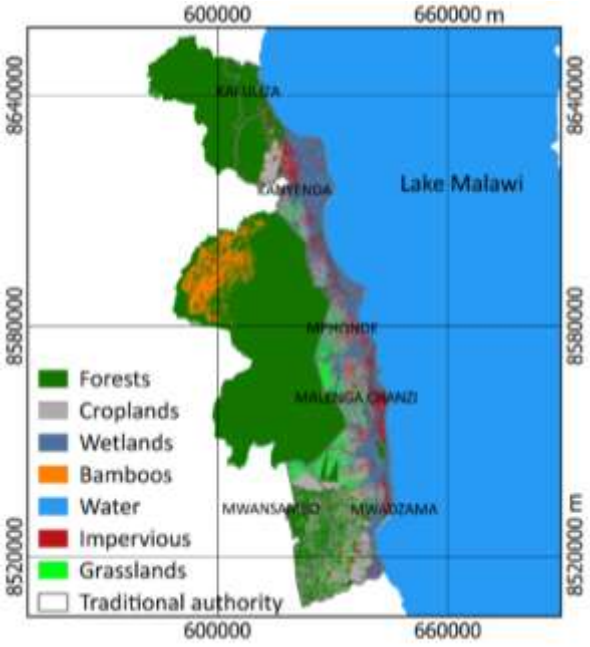

Figure 7: Bamboo distribution of Nkhotakota district, Central Malawi

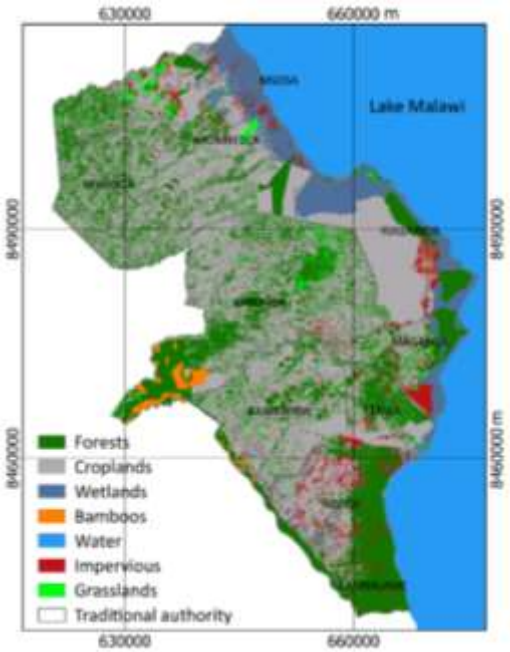

Figure 8: Bamboo distribution of Salima district, Central Malawi

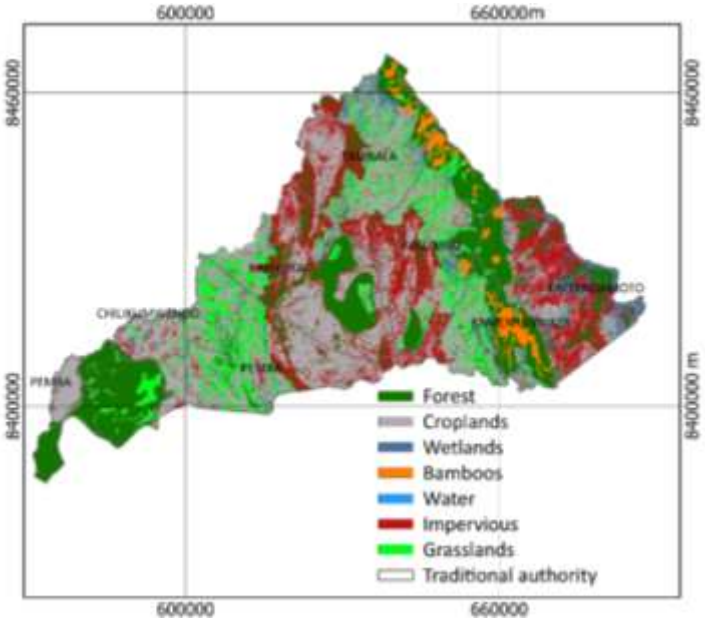

Figure 9: Bamboo distribution of Dedza district, Central Malawi

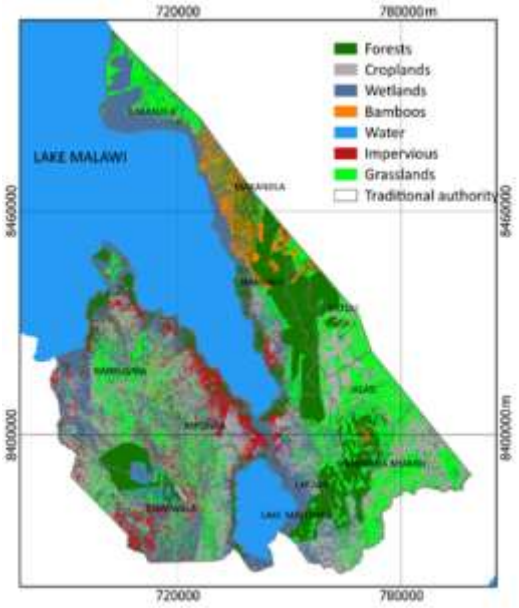

Figure 10: Bamboo distribution of Mangochi district, Southern Malawi

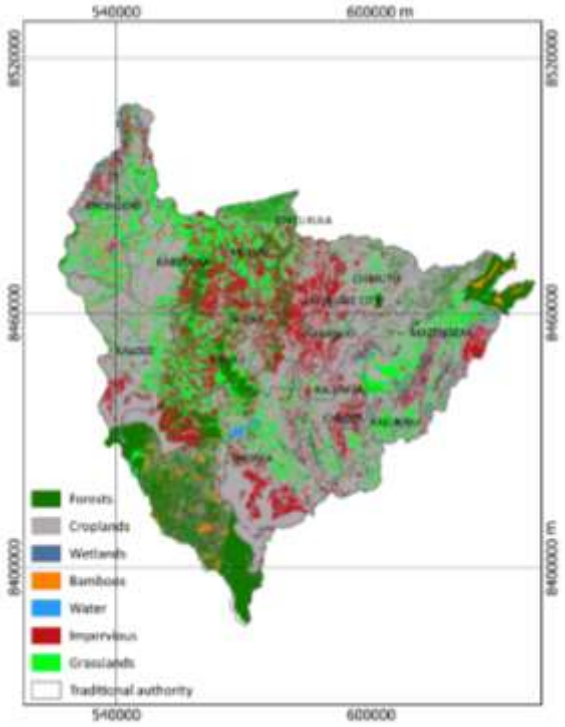

Figure 11: Bamboo distribution of Lilongwe district, Central Malawi

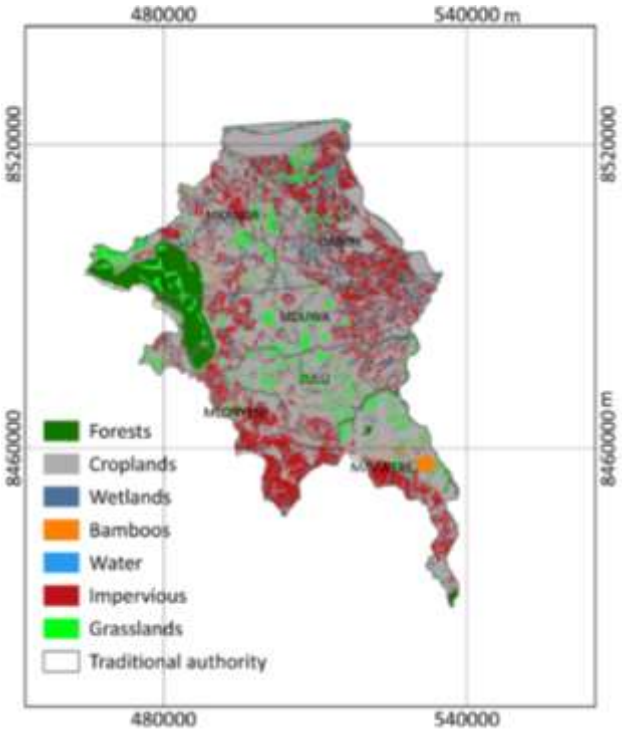

Figure 12: Bamboo distribution of Mchinji district, Central Malawi

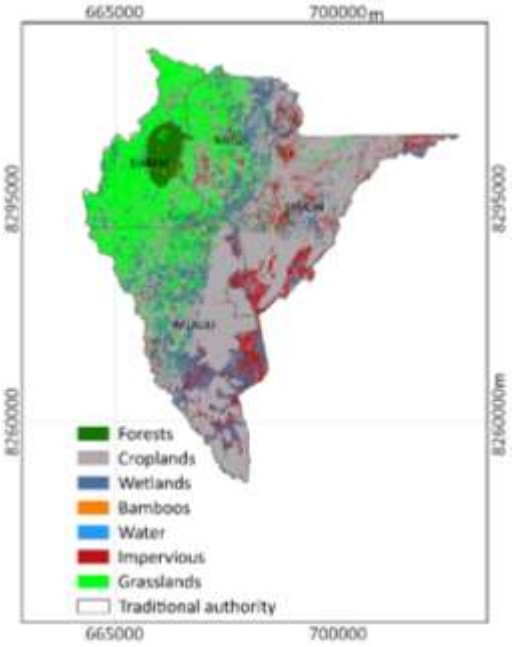

Figure 13: Bamboo distribution of Neno district, Southern Malawi

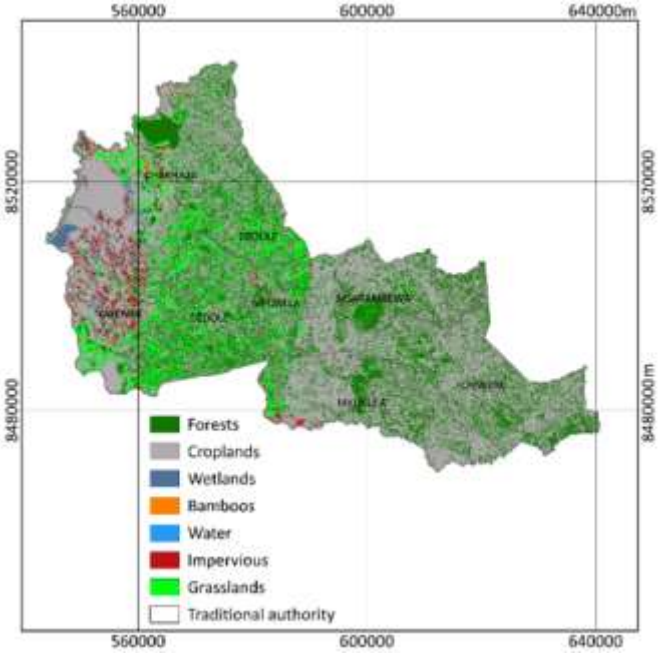

Figure 14: Bamboo distribution of Dowa district, Central Malawi

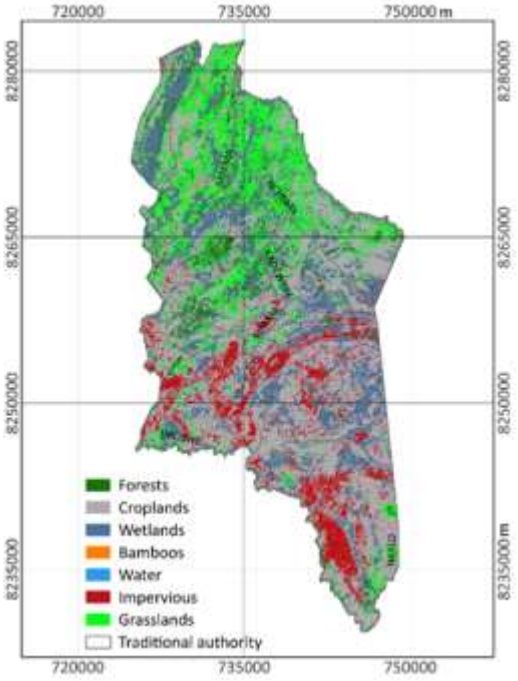

Figure 15: Bamboo distribution of Chiradzulu district, Southern Malawi

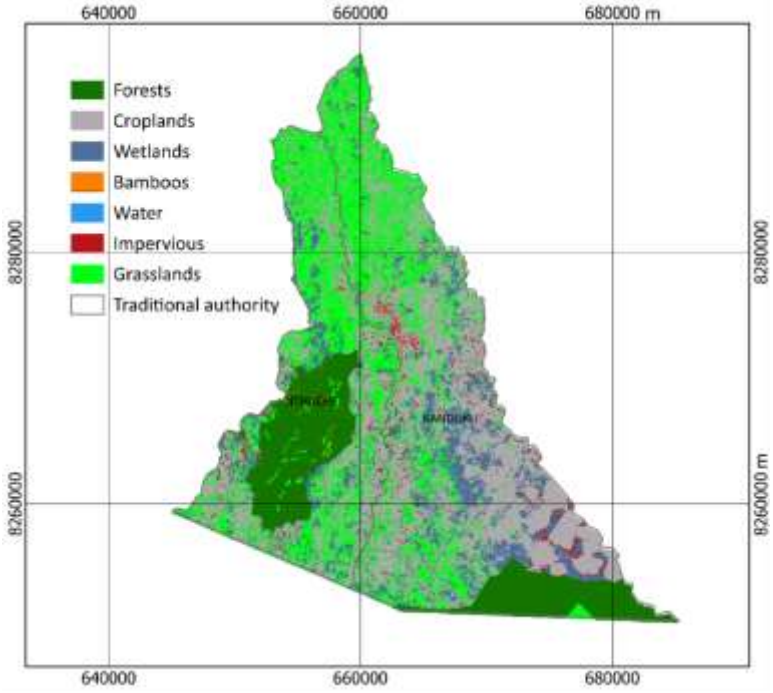

Figure 16: Bamboo distribution of Mwanza district, Southern Malawi

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