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Economic Valuation of Ecosystem Services of Bamboo in Tanzania

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Abstract

Deforestation increases in many countries but globally bamboo forests increased and replaces demand of forest resources which offset supply. The study employ adapted benefit transfer resulted from common environmental value assessment methods, the economic value of bamboo forest ecosystem services in Tanzania was evaluated for water conservation, carbon fixation and oxygen release, soil conservation, nutrients accumulation, and biodiversity conservation. The results reveals that the total ecosystem services of bamboo in Tanzania is 39.64 trillion TZS year-1 and value per unit area was 38.7 million TZS ha-1 year-1. Among them water conservation services and carbon fixation and oxygen release services contributed the highest values which was 21.42 trillion TZS year-1 and 10.51 trillion TZS year-1 totally accounting for 54%, 26.5% of the total value of the ecosystem services. It could be seen that water conservation and carbon fixation and oxygen release were the main services provided by the bamboo forest ecosystem in Tanzania. The evaluation results could provide references for the subsequent evaluation of bamboo forests and ecological benefits.

Keywords: Bamboo Forest; Ecosystem Services; Economic Valuation; Tanzania

Abbreviations: VC: Value Coefficient; ESV: Ecosystem Service Values; EF: Ecosystem Functions

Introduction

Bamboo is a non-timber forest product widely distributed outside the forests and an integral part of forests in tropical and subtropical regions of Africa, Asia, and America Paudyal [1]; Buckingham [2]; Troy Mera & Xu [3]. Bamboo belongs to the grass species of the family Poaceae in subfamily Bambusoideae and grows fast in farmlands, riverbanks, roadsides and urban areas Paudyal [1]. While deforestation increases in many countries, bamboo forests increased globally Paudyal [1] and Buckingham [2]. Bamboo forests cover 31.5 million ha worldwide FAO [4]. These bamboo forests support poverty reduction, economic development and contribute to environmental conservation Effah [5]; Phimmachanh [6]. Thus, the bamboo forests can replace timber and other raw materials from forests as demand of forest resources offset supply Paudyal [1]. Ecosystem services from bamboo are goods and services provided by bamboo forests to promote human well-being includes landscape restoration, prevention of soil and sediment loss, food supply, domestic and industrial raw materials, and carbon sequestration Sohel [7]; Paudyal [1]. Many studies show that bamboo is also important for restoring degraded lands and plays a key role in achieving recently adopted global restoration targets. Targets include the Bonn Challenge (to restore 150 million ha of degraded and deforested land by 2020), the New York Declaration on Forests (to restore 350 million ha by 2030) Jacobs [8]; Paudyal [9]; Reij & Winterbottom [10], the Great Green Wall Initiative1, Land Degradation Neutrality and Sustainable Development Goals Wood [11]. Moreover, bamboos are the world's most traded NTFPs, and have become central to emerging economies around the globe, especially in tropical regions INBAR [12-15]; and Paudyal [1].

Global bamboo industries contribute more than USD 60 billion annually INBAR [14], thus have potential contribution of green economic developments at regional and global levels INBAR [14]. Bamboos are fast growing and a sustainable wood alternative, have a high potential for carbon sequestration and are viable resources for poverty alleviation and climate change adaptation INBAR [14,15]; and Paudyal [1]. Furthermore, bamboo is important for the rehabilitation of degraded land, as a timber substitute, for erosion control and watershed protection INBAR

[12]. With its fast growth rate and high annual regrowth after harvesting, bamboo forests have a high carbon stock potential especially when the harvested culms are used as durable products Paudyal [1]. Recent study conducted by Lyimo et al. (2019) in Tanzania identified 11 bamboo species distributed in 5 genera within two woody bamboo tribes of Arundinarieae and Bambuseae, distributed within three indigenous species and eight exotic species. These species cover about 1,025,033 ha in Tanzania. However, there is dearth of information regarding total economic value of ecosystem services of bamboo in Tanzania (Figure 1). To fill this gap, the study employed benefit transfer method for current shilling value to measure the ecosystem service of bamboo available in Tanzania. Specifically, the study intended to determine economic value of; (i) ecosystem services of bamboo in Tanzania, and (ii) ecosystem functions of bamboo in Tanzania. The results of this study concurred with sustainable development goals (SDGs) 1, 7, 11, 12, 13 and 15.

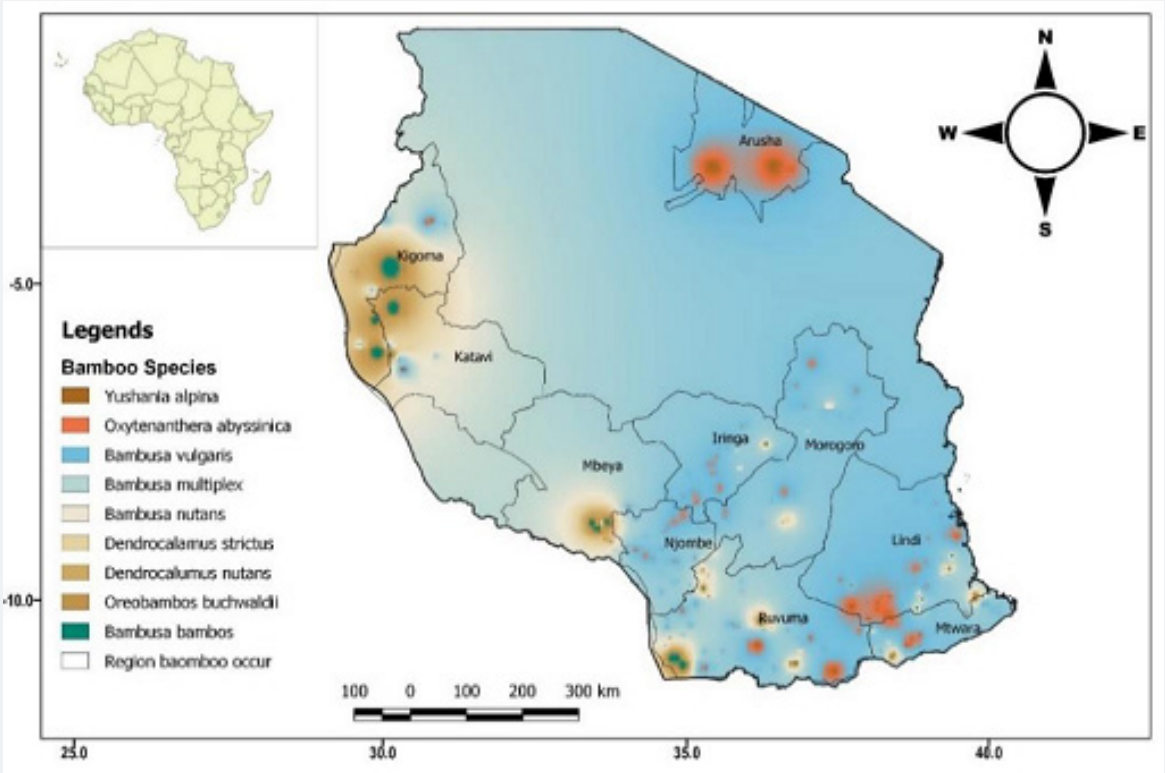

Figure 1: A map of bamboo species distribution in Tanzania.

Materials and Methods

Materials

Description of the Study Area: Tanzania is located between 1° 00' S and 12° 00' S and between 30° 00' E and 41°00' E at an altitude between 358 m a.s.l. and 5,950 m a.s.l. Mainland Tanzania is characterized by tropical climate, which can be divided into four distinct climatic zones, namely, the hot humid coastal plain, the semi-arid zone of the central plateau, the high-moist lake regions, and the temperate highland areas. The country has mean maximum day-time temperatures ranging from 10°C to 31°C and a mean annual rainfall ranging from 500 to 2,500 mm across the four zones (URT, 2017). The study was conducted on forestland in Tanzania Mainland which covers an estimated area of 48.1 million ha (MNRT, 2015).

Bamboo Species Distribution and Coverage in Tanzania: Bamboo covers about 1,025,033 ha in Tanzania. About 62% (636,545 ha) of bamboo are found in the Southern zone (Lindi, Mtwara and Ruvuma) of Tanzania [16]. Bamboo are distributed in eleven administrative regions of Arusha, Tanga, Morogoro, Lindi, Mtwara, Ruvuma, Njombe, Iringa, Mbeya, Katavi and Kigoma regions. Bamboo are most abundant in Lindi, Ruvuma, Mtwara, Iringa and Njombe with 75.2% of total population. Less abundance of bamboos are in Arusha, Mbeya, Katavi and Tanga that constitute to 7.9% of the total population. Most bamboo species are distributed in low altitudes compared to high altitude, and about 85.2% of bamboo is distributed below 1500 m.a.s.l. Bamboo has been distributed in all land use types. They are widely distributed in production forest, protection forest and Wildlife protected areas, which all together forms the public forests and

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contributes about 65% of the total distribution of bamboo across different land use. Furthermore, bamboo species distributed across all vegetation types in Tanzania. The highest proportion of occurrence is in woodland, cultivated land, and forest, with 66%, 12% and 10% respectively. Most of the bamboo species area distributed on woodland, especially in open woodland with 10-40% of the canopy cover. Despite of bamboo species being distributed across all types of land use, there is variation in species richness in each land use. More bamboo stems are in lower Dbh class (<4cm) and bamboo forest is composed of many small diameter culms and very few large diameter culms which made an inverse J structure [17].

Data Used and Methods

Figure 2 below shows the flow chart of the methodological approach used in this study for the estimation of the ecosystem service values (ESVs) of bamboo in Tanzania following URT (2015) and Lyimo et al. (2019).

The bamboo datasets in Tables 1-4 were adapted from Lymo et al. (2019) who extracted bamboo data from the NAFORMA database server located at Sokoine University of Agriculture, Tanzania. The whole NAFORMA data set was imported to R software for the extraction of bamboo data and their related cluster and plot information. The extraction of the data was then done by performing Structured Query Language (SQL) queries within R software using sqldf package. After extraction, the data were subjected to validation, cleaning (removal of noisy data and data cleansing) and outliers' analysis. Besides, bamboo biome equivalent with its corresponding ecosystem service value coefficient (VC) in 2021 TZS ha^{-1} $year^{-1}$ (38.7 Million TZS ha^{-1} $year^{-1}$) were adapted from Hao (2019). This study employed the benefit transfer approach to estimate economic values of ecosystem services based on the adapted VC of the ecosystem services for the bamboo forest. Detailed ecosystem service functions and their value coefficients are shown in Table 5 below as adapted from Hao (2019).

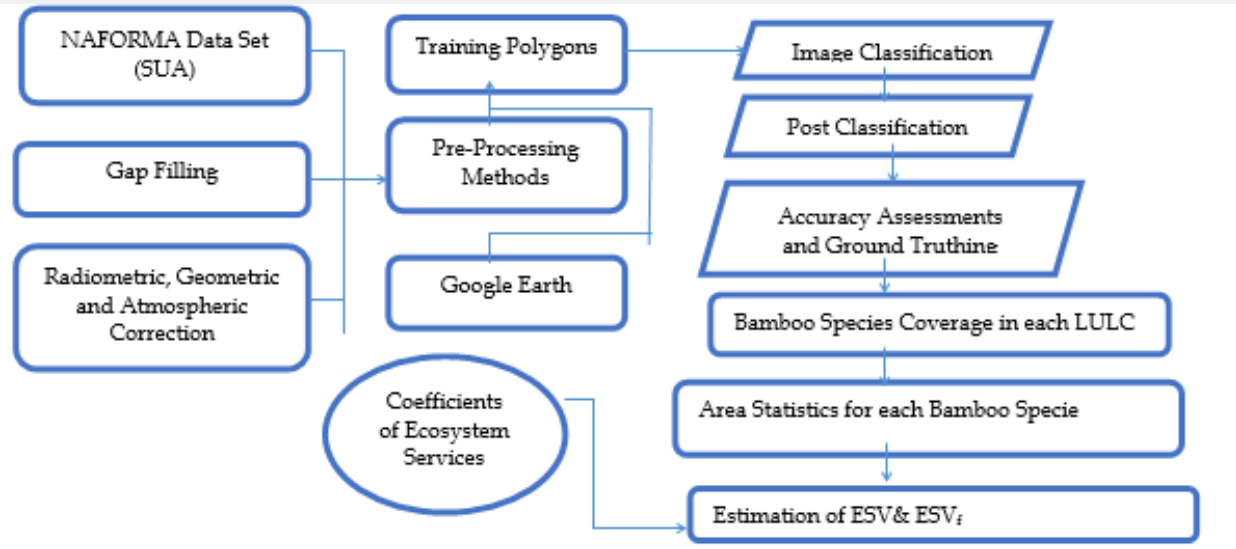

Figure 2: Flowchart of the methodological approach for this study.

Table 1: Bamboo species coverage in Tanzania.

Species name	Genera	Status	Area (ha)	Percentage (%)
Bamboo spp.	-	-	70,727.30	6.9
Bambusa bambos	Bambusa	Exotic and Naturalized	169,130.4	16.5
Bambusa multiplex	Bambusa	Exotic	16,400.50	1.6
Bambusa nutans	Bambusa	Exotic	17,425.60	1.7
Bambusa spp.	Bambusa	Exotic	111,728.6	10.9
Bambusa vulgaris	Bambusa	Exotic and Naturalized	212,181.8	20.7
Dendrocalamus nutans	Dendrocalamus	Exotic	27,675.90	2.7
Dendrocalamus strictus	Dendrocalamus	Exotic	19,475.60	1.9

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Oreobambos buchwaldii	Oreobambos	Indigenous	11,275.40	1.1
Oxytenanthera abyssinica	Oxytenanthera	Indigenous	150,679.9	14.7
Yushania alpina	Arundinarieae	Indigenous	218,332.0	21.3
Total			1,025,033.0	100

Table 2: Bamboo species coverage across zones and regions of Tanzania.

Zone	Regions	Coverage (Ha)	Percentage (%)
Southern zone	Lindi, Mtwara and Ruvuma	636,545	62.1
Southern highland zone	Iringa, Njombe and Mbeya	165,030	16.1
Western zone Table	Kigoma and Katavi	128,129	12.5
Eastern zone	Morogoro	77,903	7.6
Northern zone	Arusha	17,426	1.7
Total		1,025,033	100

Table 3: Bamboo species coverage across land use types in Tanzania.

Land use type	Coverage (ha)	Percentage (%)
Production forest	428,189	41.77
Protection forest	98,403	9.6
Wildlife protected areas	118,003	11.51
Shifting cultivation	116,854	11.4
Agriculture	196,881	19.21
Grazing land	3,075	0.3
Built up areas	16,401	1.6
Water body/wetland	41,000	4
Others	6,227	0.61
Total	1,025,033	100

Table 4: Bamboo species distribution across vegetation types in Tanzania.

Vegetation type	Coverage (ha)	Percentage (%)
Forest	102,503	10
Woodland	675,497	65.9
Bushland	30,751	3
Grassland	41,001	4
Cultivated land	123,004	12
Open land	1,025	0.1
Water	10,250	1
Other vegetation type	41,001	4
Total	1,025,033	100

Table 5: Details of the ecosystem service functions and their value coefficients.

Ecosystem Service Functions	Amount (2021 Million TZS ha-1year–1)
Water conservation	20.9
Carbon fixation & oxygen release	10.3
Soil conservation	2.8
Nutrients accumulation	1.1
Biodiversity conservation	3.6
Total	38.7

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Data analysis

To determine economic value of ecosystem services of bamboo in Tanzania: The datasets shown in Table 1 used and the total value of ecosystem services in the study area were calculated by multiplying the area of bamboo coverage by the corresponding ecosystem service value coefficient that was extracted from weight factors of the ecosystem services per hectare of bamboo biome, see equation (1) adapted from Zella (2021) as follows:

$$ESV = \sum_{k=0}^{k}(Ak + VCk) \quad \text{..... (1)}$$

where ESV = the total estimated ecosystem service value, Ak = the area (ha) and VCk = the value coefficient (TZS ha^{-1} $year^{-1}$) for bamboo 'k'.

To determine economic values of ecosystem functions of bamboo in Tanzania

Estimated values of the services provided by individual ecosystem functions within the study area using the following equation 2:

$$ESVf = \sum_{k=0}^{k}(Ak * VC_{fk}) \quad \text{.....(2)}$$

where ESVf is the estimated ecosystem service value of function f, Ak is the area (ha) and VCfk is the value coefficient of the function (TZS ha^{-1} $year^{-1}$) for bamboo 'k'. The contributions of the individual ecosystem functions to the overall value of the ecosystem services per year were calculated and summarized in the tables.

Results

Economic Value of Ecosystem Services of Bamboo in Tanzania

Total economic value of ecosystem services (ESV) of bamboo in Tanzania was estimated as 39.64 Trillion TZS $year^{-1}$ using November 2021 TZS value. The ESV calculated mainly from provisioning, regulating, and supporting services with specification on water conservation, carbon fixation & oxygen release, soil conservation, nutrients accumulation, and biodiversity conservation. These specifications were considered as the most ecosystem functions of bamboo that make up the supply of ecosystem services accrued from bamboo. Average bamboo per hectare is 300 plants equivalent to ESV of 129, 000 TZS $year^{-1}$ per plant. The distribution of ESV in bamboo species coverage and distribution across zones and regions, land use and vegetation types in Tanzania are indicated in Tables 6-9. Bambusa species leading in supply of ESV by 51.4% equivalent to 20.37 Trillion TZS $year^{-1}$. Southern and Southern highland zones leads in ESV supply by 78.2% accounted to 31 Trillion TZS $year^{-1}$. ESV supply in various land use types indicates production and protection forests together with wildlife protected areas supply a total of 62.9% of ESV equivalent to 24.93 Trillion TZS $year^{-1}$ followed by shifting cultivation, agriculture and grazing land which supply a total of 30.9% of ESV equivalent to 12.25 Trillion TZS $year^{-1}$. However, woodland, cultivated land and forest are vegetation types that leads in ESV supply accounted to 65.9% (26.12 Trillion TZS $year^{-1}$), 12% (4.76 Trillion TZS $year^{-1}$) and 10% (3.96Trillion TZS $year^{-1}$) respectively.

Table 6: ESV of bamboo species in Tanzania.

Species name	ESV (Trillion TZS year–1)	Percentage (%)
Bamboo spp.	2.74	6.9
Bambusa bambos	6.54	16.5
Bambusa multiplex	0.63	1.6
Bambusa nutans	0.67	1.7
Bambusa spp.	4.32	10.9
Bambusa vulgaris	8.21	20.7
Dendrocalamus nutans	1.07	2.7
Dendrocalamus strictus	0.75	1.9
Oreobambos buchwaldii	0.44	1.1
Oxytenanthera abyssinica	5.83	14.7
Yushania alpina	8.44	21.3
Total	39.64	100

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Table 7: ESV of bamboo species across zones and regions of Tanzania.

Zone	Regions	ESV (Trillion TZS year–1)	Percentage (%)
Southern zone	Lindi, Mtwara and Ruvuma	24.62	62.1
Southern highland zone	Iringa, Njombe and Mbeya	6.38	16.1
Western zone Table	Kigoma and Katavi	4.95	12.5
Eastern zone	Morogoro	3.01	7.6
Northern zone	Arusha	0.67	1.7
Total		39.64	100

Table 8: ESV of bamboo species across land use types in Tanzania.

Land use type	ESV (Trillion TZS year^{-1})	Percentage (%)
Production forest	16.56	41.77
Protection forest	3.81	9.6
Wildlife protected areas	4.56	11.51
Shifting cultivation	4.52	11.4
Agriculture	7.61	19.21
Grazing land	0.12	0.3
Built up areas	0.63	1.6
Water body/wetland	1.59	4
Others	0.24	0.61
Total	39.64	100

Table 9: ESV of bamboo species distribution across vegetation types in Tanzania.

Vegetation type	ESV (Trillion TZS year–1)	Percentage (%)
Forest	3.96	10
Woodland	26.12	65.9
Bushland	1.19	3
Grassland	1.59	4
Cultivated land	4.76	12
Open land	0.04	0.1
Water	0.4	1
Other vegetation type	1.59	4
Total	39.64	100

Economic Value of Ecosystem Functions of Bamboo in Tanzania

Water conservation and carbon fixation and oxygen release account 80.5% of ecosystem functions (EF) of bamboo in Tanzania amounted 31.93 trillion TZS year^{-1} as shown in Table 10. The distribution of economic values of ecosystem functions (EF) of bamboo species coverage and distribution across zones and regions, land use and vegetation types in Tanzania are indicated in Tables 11-14. Yushania alpine and Bambusa vulgaris are leading bamboo species that hold high percentage of ecosystem functions of 21.3% and 20.7% respectively compared to other species as indicated in Table 11. Bambusa species contribute a total 51.4% of EF amounted 11.01 Trillion TZS year^{-1} for water conservation, 5.4 Trillion TZS year^{-1} for carbon fixation and oxygen release, 1.5 Trillion TZS year^{-1} for soil conservation, 0.56 Trillion TZS year^{-1} for nutrients accumulation and 1.91 Trillion TZS year^{-1} for biodiversity conservation. Southern and Southern highland zones leads in contribution of EF by 78.2% amounted 16.75 Trillion TZS year^{-1} for water conservation, 8.22 Trillion TZS year^{-1} for carbon fixation and oxygen release, 2.28 Trillion TZS year^{-1} for soil conservation, 0.84 Trillion TZS year^{-1} for nutrients accumulation and 2.91 Trillion TZS year^{-1} for biodiversity conservation. Production and protection forests together with wildlife protected areas were leading land use types contributing EF for a total of

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62.9% amounted 13.47 Trillion TZS year^{-1} for water conservation, 6.61 Trillion TZS year^{-1} for carbon fixation and oxygen release, 1.83 Trillion TZS year^{-1} for soil conservation, 0.68 Trillion TZS year^{-1} for nutrients accumulation and 2.34 Trillion TZS year^{-1} for biodiversity conservation followed by shifting cultivation, agriculture and grazing land contributing a total of 30.9% of EF amounted 6.62 Trillion TZS year^{-1} for water conservation, 3.25 Trillion TZS year^{-1} for carbon fixation and oxygen release, 0.9 Trillion TZS year^{-1} for soil conservation, 0.33 Trillion TZS year^{-1} for nutrients accumulation and 1.15 Trillion TZS year^{-1} for biodiversity conservation. However, woodland, cultivated land and forest are vegetation types that leads in EF contribution by 65.9%, 12% and 10% respectively, amounted in Trillion TZS year^{-1} for water conservation (14.12, 2.57 and 2.14); carbon fixation and oxygen release (6.93, 1.26 and 1.05); soil conservation (1.92, 0.35 and 0.29); nutrients accumulation (0.71, 0.13 and 0.11) and biodiversity conservation (2.45, 0.45 and 0.37).

Table 10: Economic value of ecosystem functions (EF) of bamboo in Tanzania.

Ecosystem Functions	EF(Trillion TZS year–1)	Percentage
Water conservation	21.42	54
Carbon fixation & oxygen release	10.51	26.5
Soil conservation	2.91	7.3
Nutrients accumulation	1.08	2.7
Biodiversity conservation	3.72	9.4
Total	39.64	100

Table 11: EF of bamboo species in Tanzania.

Species name	EF (Trillion TZS year–1)					
	WC	CF & OR	SC	NA	BC	Total
Bamboo spp.	1.48	0.73	0.2	0.07	0.26	2.74
Bambusa bambos	3.53	1.73	0.48	0.18	0.61	6.54
Bambusa multiplex	0.34	0.17	0.05	0.02	0.06	0.63
Bambusa nutans	0.36	0.18	0.05	0.02	0.06	0.67
Bambusa spp.	2.33	1.15	0.32	0.12	0.41	4.32
Bambusa vulgaris	4.43	2.18	0.6	0.22	0.77	8.21
Dendrocalamus nutans	0.58	0.28	0.08	0.03	0.1	1.07
Dendrocalamus strictus	0.41	0.2	0.06	0.02	0.07	0.75
Oreobambos buchwaldii	0.24	0.12	0.03	0.01	0.04	0.44
Oxytenanthera abyssinica	3.15	1.54	0.43	0.16	0.55	5.83
Yushania alpina	4.56	2.24	0.62	0.23	0.79	8.44
Total	21.42	10.51	2.91	1.08	3.72	39.64

WC= Water conservation, CF&OR= Carbon fixation & oxygen release, SC= Soil conservation, NA= Nutrients accumulation, and BC= Biodiversity conservation.

Table 12: EF of bamboo species across zones and regions of Tanzania.

Zone	EF (Trillion TZS year–1)					
	WC	CF & OR	SC	NA	BC	Total
Southern zone	13.3	6.53	1.81	0.67	2.31	24.62
Southern highland zone	3.45	1.69	0.47	0.17	0.6	6.38
Western zone Table	2.68	1.31	0.36	0.13	0.46	4.95
Eastern zone	1.63	0.8	0.22	0.08	0.28	3.01
Northern zone	0.36	0.18	0.05	0.02	0.06	0.67
Total	21.42	10.51	2.91	1.08	3.72	39.64

WC= Water conservation, CF&OR= Carbon fixation & oxygen release, SC= Soil conservation, NA= Nutrients accumulation, and BC= Biodiversity conservation.

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Table 13: EF of bamboo species across land use types in Tanzania

Land use type	EF (Trillion TZS year−1)					
	WC	CF & OR	SC	NA	BC	Total
Production forest	8.95	4.39	1.22	0.45	1.55	16.56
Protection forest	2.06	1.01	0.28	0.1	0.36	3.81
Wildlife protected areas	2.47	1.21	0.34	0.12	0.43	4.56
Shifting cultivation	2.44	1.2	0.33	0.12	0.42	4.52
Agriculture	4.11	2.02	0.56	0.21	0.71	7.61
Grazing land	0.06	0.03	0.01	0	0.01	0.12
Built up areas	0.34	0.17	0.05	0.02	0.06	0.63
Water body/wetland	0.86	0.42	0.12	0.04	0.15	1.59
Others	0.13	0.06	0.02	0.01	0.02	0.24
Total	21.42	10.51	2.91	1.08	3.72	39.64

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WC= Water conservation, CF&OR= Carbon fixation & oxygen release, SC= Soil conservation, NA= Nutrients accumulation, and BC= Biodiversity conservation.

Table 14: EF of bamboo species across vegetation types in Tanzania.

Vegetation type	EF (Trillion TZS year−1)					
	WC	CF & OR	SC	NA	BC	Total
Forest	2.14	1.05	0.29	0.11	0.37	3.96
Woodland	14.12	6.93	1.92	0.71	2.45	26.12
Bushland	0.64	0.32	0.09	0.03	0.11	1.19
Grassland	0.86	0.42	0.12	0.04	0.15	1.59
Cultivated land	2.57	1.26	0.35	0.13	0.45	4.76
Open land	0.02	0.01	0	0	0	0.04
Water	0.21	0.11	0.03	0.01	0.04	0.4
Other vegetation type	0.86	0.42	0.12	0.04	0.15	1.59
Total	21.42	10.51	2.91	1.08	3.72	39.64

WC= Water conservation, CF&OR= Carbon fixation & oxygen release, SC= Soil conservation, NA= Nutrients accumulation, and BC= Biodiversity conservation.

Discussions

Bamboo covers 2.13 % of land in Tanzania main land with its ESV per year was 27.6% of GDP for the year 2020. The World Bank ranked Tanzania's economy as 74th country out 217 countries with GDP amounted 143.73 trillion TZS for the year 2020 (using 3rd December, 2021 conversion rate). Thus, the major functions of ecosystem services is to improve and sustain human wellbeing and welfare in terms of goods and services supplied by ecosystems, then, bamboo have shown the promising one. The bamboo coverage and ESV supplied shows its huge contribution to humans compared to the GDP of the country. These findings imply that, integrating bamboo into development agendas and programs through its economic and ecological recognition can be catchy in contribution to sustainable development. Indigenous bamboo species in Tanzania contributes 37.1% of ESV compared to 62.9% of exotic species amounted to 14.71 Trillion TZS year^{-1} and 24.93 Trillion TZS year^{-1} for indigenous and exotic species respectively. Thus, promoting bamboo farming is socially, economically and ecologically rewarding activity.

Conclusion and Recommendations

Conclusion

Countries across Africa and around the globe are increasingly recognizing the critical importance of natural capital to achieve sustainable development goals. Understanding human dependence on flora and the benefits flora provide serves both economic and conservation objectives. This study assessed economic value of ecosystem services of bamboo in Tanzania at

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various scales, from species distribution, across zones and regions, on land use types, and across vegetation types. This information can form a strong basis for bamboo management at regions, zones and national levels to support an integrated approach to flora species conservation for combating climate change and improve human wellbeing and welfare. This study highlights the relevance of green lands to diverse constituencies as a means to ensure sustainable future of Tanzania.

Recommendations

Key actors of flora conservation in Tanzania shall ensure that:

a) Bamboo is included in carbon trade as it has higher carbon sequestration capacity compared to tree species

b) Encourage households to cultivate bamboo species in farm plots for easy assessment of its values

c) Advise households to cultivate bamboo species that are economically and ecologically rewarding includes Yushania alpine, Bambusa vulgaris, Bambusa bamboos, and Oxytenanthera abyssinica

d) Prioritize the use of bamboo as alternative to other tree species for all socio-economic activities that requires the use of tree for timber, furniture, building poles and others

e) Improve innovation to timber vocational training colleges to customize the use of bamboo so as to safeguard tree species that takes several years of maturity

Compliance with Ethical Standards

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