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Forest Structure and Climate Change Mitigation Potential: A Case of Wilolesi and Ikonongo Forested Hills in Iringa Municipality, Tanzania

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Abstract

Vegetation plays major roles in carbon storage and ecosystem functioning by modifying the rate of carbon fluxes thereby mitigating climate change. However, the focus of assessing the potentials for different vegetation on climate change mitigation has for so long been conducted outside cities, towns and municipalities. This study was conducted in Wilolesi and Ikonongo hills located in Iringa as representative of the Municipality forested hills in Tanzania to assess vegetation structure and their potential for climate change mitigation. Random sampling technique was employed to establish 20 rectangular plots of 20 m x 40 m (0.08 ha) in each hill to determine plant species composition, richness, diversity, vegetation structure and above ground carbon (AGC). R-statistical software was used to compute Shannon-Wiener diversity indices, species richness and the above ground carbon. Results indicated high species diversity ranging from 3.5 to 4.1 for Ikonongo and Willolesi hills, respectively based on Shannon-Wiener diversity index (H'). We recorded 255 plant species (114 tree species, 51 shrub species, 2 sedge species, 66 herb species, 15 grass species and 7 climbers) in 60 families. Based on Important Value Index (IVI), *Brachystegia spiciformis* Benth (10.435) and *Julbernardia globiflora* Benth (4.555) were important species in Wilolesi and Ikonongo forested hills. There was a significant difference on the AGC between Ikonongo (3.12 t/ha) and Wilolesi (8.33 t/ha) (t = 1.83, p = < 0.004). Results have an implication for dedicating more efforts on the management of forest landscapes for biodiversity conservation, climate change mitigation and provision of other ecosystem services. It is recommended that there should be detailed study for all forested hills in Iringa Municipality for proper forest management initiatives.

Keywords: Climate change mitigation potential; forest structure; forested hills.

Introduction

Tanzania is endowed with vast forest resources with great potential for climate change mitigation and other ecosystem services (Millennium Ecosystem Assessment 2005). The wide range of natural resource products for subsistence is due to presence of unique environmental and biodiversity values (Deb et al. 2008, Sangha et al. 2015, Munishi et al. 2016). Atmospheric carbon has become an important concern for sustainable management of tropical forests, aiming to mitigate climate change through reduced deforestation and forest degradation (Bazezew et al. 2015, Tolotti et al. 2015). Sustainable forest management will not only improve carbon sequestration and socio-economic development, but also reduce the rate of biodiversity loss (Díaz et al. 2006).

Plant diversity has the potential to modify the rate of carbon fluxes and mitigate effects of climate change (Shirima et al. 2015). For example, miombo woodland is a potential vegetation type for climate change mitigation through carbon sequestration (Campbell et al. 2007). Sustainable management of these potential ecosystems will improve biodiversity outcomes, reduce carbon emissions and provide a source of income through other environmentally friendly activities such as commercial beekeeping (Campbell et al. 2007). Lack of proper knowledge on sustainable forest management is jeopardizing the efforts of poverty reduction and potential habitat for honeybees while increasing carbon emissions (Campbell et al. 2007, Chirwa et al. 2017, Shirima et al. 2015).

Iringa Municipality has potential forested hills that provide ecosystem services. However, the population of Iringa Municipality is growing at an annual rate of 1.6% (United Republic of Tanzania 2013). This is alarming as the demands for settlement, land for agriculture and other development will also increase, thus increasing the rates of forest degradation. Such on-going degradation impairs the quality of ecosystem services provided by the forested hills (Bangamwabo 2009, Fisher et al. 2011, Kim et al. 2015). Forest degradation can make forests sources of greenhouse gases by emitting carbon dioxide to the atmosphere through burning or other ways of vegetation destruction (Houghton2012). When forests are well managed and protected, they can act as “sinks” removing carbon dioxide from the atmosphere and storing it as carbon (Shirima et al. 2011, Herold et al. 2012, Marshall et al. 2012, Tolotti et al. 2015).

The forested hills of Iringa Municipality act as lungs that absorb carbon emissions resulting from different kinds of developments such as expansion of agricultural land, increased settlements and automobile emissions. However, information on the vegetation structures of these hills and their potential for climate change mitigation is not readily available. The present project was therefore conducted to obtain baseline information on vegetation structures and the potential for climate change mitigation in Wilolesi and Ikonongo forested hills of Iringa Municipality. The collected information is important for planning of proper management interventions that would be required in climate change mitigation and preparation of carbon and biodiversity monitoring initiatives.

Materials and Methods

Description of the study area

This study was conducted in Wilolesi and Ikonongo forested hills located in Iringa Municipality, Tanzania (Figure 1). The Municipality stretches along a hilltop overlooking the Ruaha River to the south, and spreads along ridges and valleys to the north. It lies on a plateau that ranges from 1,500 m to 2,500 m above sea level between latitude 7^{o}77’ South of the Equator and longitude 35^{o}69’ East of the Greenwich Meridian covering an area of 331 square kilometres (United Republic of Tanzania 2013).

Sampling design and data collection

Random sampling approach was employed in each forested hill, whereby nested plots of 20 m by 40 m (0.08 ha) were randomly established in each forested hill. The minimum distance from one plot to another was 200 m. Global position system (GPS) map 64s was used to identify plots by their coordinates. Tree species with diameter at breast height (dbh) ≥ 5 cm were measured within the entire plots of 20 m by 40 m; shrubs and regenerants were counted within the 5 m by 5 m plots, and herbs and grass cover were assessed within 2 m by 2 m plot. All trees and regenerants were identified by their botanical names at species level at the fields. Heights of all measured trees were taken using a pole of known height for accurate carbon assessment. Regenerants were counted and identified to determine the potential regeneration of the studied forested hills. Other life forms such as shrubs, herbs, grasses and sedges were also enumerated and identified.

Figure 1: Study area (Source: Google Earth).

Data analysis

Plant species composition was given a list of different identification. Shannon-Wiener Diversity Index was computed using Vegan package in R software. Plant species life forms were identified and counted basing on the ability to occupy both Ikonongo and Wilolesi hills.

Above ground tree carbon was estimated for each stem with a new improved biomass allometric equation, which is applicable to the tropical ecosystems, assuming 50% of biomass is carbon (Chave et al. 2014). Biomass was calculated in metric tons including heights of trees to avoid an overestimation when using dbh only (Marshall et al. 2012). Wood specific gravity (WSG) was estimated as the mean value for each species from a database of 2961 records from 844 species (Zanne et al. 2009). Where WSG data for specific species were not available, the mean value for all records of the nearest taxonomic unit (genus or family) was taken, and, where these were also not available, the mean of all remaining taxa in the same plot was taken. The use of WSG was found to be more efficient in calculating above ground tree biomass using the equation $B = 0.0559 \times (WD \times D^2 \times Ht)$ as suggested by Chave et al. (2014) where B = biomass, WD = wood density (WSG), D = diameter at breast height (cm), and Ht = height (m).

Other three allometric equations were used, whereby two of them were developed in Tanzania, and one was developed in dry tropical forests (Table 1). Two allometric equations utilise all required parameters (i.e. tree height, diameter at breast height and wood specific gravity) to make carbon estimates more robust (Chave et al. 2005, Chave et al. 2014), and one allometric equation utilises tree height and diameter, leaving aside wood specific gravity (Malimbwi et al. 1994). Only one equation used diameter at breast height.

Table 1: Allometric models that are used to estimate above ground tree carbon content

Author	Allometric equation	Source Country	Notes
Chave et al. (2014)	$B = 0.0559 * (WD \times D^2 * Ht)$	Tropical forests	For all vegetation types
Chave et al. (2005)	$B = 0.112 * (WD * D^2 * Ht)^{0.916}$	Tropical Dry Forest	Not miombo specific
Chamshama et al. (2004)	$B = 0.0625 * D^{2.553}$	Tanzania	Miombo
Malimbwi et al. (1994)	$B = 0.06*D^{2.012}* Ht^{0.71}$	Tanzania	Miombo

B = Biomass, WD = Wood density/Wood specific gravity, D = Diameter at breast height, and Ht = Tree height).

Results and Discussion

Vegetation structure, species composition, richness and diversity

The mean stand density was 1582 ± 238.04 stems ha^{-1} in both forested hills. Stems ranged from 1435 in Ikonongo forested hill to 1729 stems ha^{-1} in Wilolesi forested hill. The mean diameter for both forested hills was 7 ± 3 cm ranging from 5 cm to 38 cm whereby most trees were found within the smaller diameter classes (5 to 8 cm). The mean basal area for both hills was estimated at 7.3 ± 1.6 m^2 ha^{-1} and, in the forested hills, ranged from 4.1 m^2 ha^{-1} in Ikonongo forested hill to 10.5 m^2 ha^{-1} in Wilolesi. The dominance of small trees (5 to 8 cm) indicates that the forests are regenerating following exploitation by human beings and not fire because species like *Pseudolachnostylis maprouneifolia*, *Pterocarpus angolensis* and *Diplorhynchos condylocarpon* would prevail (Backéus et al. 2006).

The general plant species diversity for Ikonongo and Wilolesi forests was 4.9 based on the Shannon-Wiener diversity index. A total of 255 plant species (114 tree species, 51 shrub species, 2 sedge species, 66 herb species, 15 grass species and 7 climbers) in 60 different families were identified in Wilolesi and Ikonongo forested hills (Figure 2). Families that depicted high numbers of occurrences were Leguminosae, Rubiaceae, Compositae, Poaceae, Malvaceae, Phyllanthaceae, Lamiaceae and Euphorbiaceae (Appendix 1).

The top 10 plant species which ranked high in the study areas basing on the frequency of occurrence were *Julbernardia globiflora* (Benth.), *Brachystegia spiciformis* (Benth), *Lannea schimperi* (Hochst. ex A. Rich.) Engl, *Combretum molle* R. Br. ex G. Don, *Brachystegia bussei* Harm, *Faurea saligna* Harv, *Brachystegia boehmii* Taub, *Dalbergia nitidula* Welw. ex Baker, *Brachystegia manga* De Wild and *Ochna holstii* Engl. In both sites, *Julbernardia* and *Brachystegia* as the genera of miombo were observed, and the genus *Isoberlinia* was absent (Kowero et al. 2003).

The total number of species encountered in Wilolesi and Ikonongo forested hills suggests that the two hills have a wide diversity of plant species, which is portrayed by the obtained estimates in the study area. Shannon diversity index (H') was found to be > 3.5 in the two hills. H' usually does not exceed 5, although this maximum value varies depending on the type of the biological community sampled and the sampling approach applied including size of sample units. In this study, data were collected by using 40 m x 20 m plots. A threshold value of 2 for H' has been mentioned as a minimum value, above which an ecosystem can be regarded as medium to highly diverse. This means that the project area is highly diverse as H' values exceeded 3.5 for both sites. However, diversity of tree species only ranged from 2.3 in Ikonongo hill to 2.6 in Wilolesi hill basing on the Shannon-Wiener diversity index (H'). The total numbers of tree species in Wilolesi and Ikonongo forested hills were 95 and 75, respectively. This number of tree species in miombo Woodland has been also observed in other areas with the same vegetation type (Luoga et al. 2002).

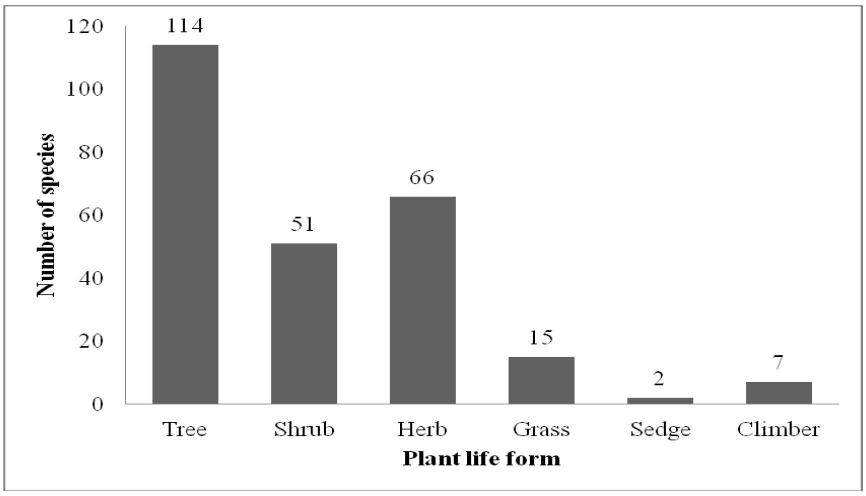

Figure 2: Number of species in different plant life forms.

Species accumulation curve

The species accumulation curve (Figure 3) shows sampling efforts used in this study were sufficient to cover much, but not all, of the variations and species diversity of the study area. At 30 plots, the graph did not reach its asymptotic level, but it was starting to converge, implying that any further increase of sample size would be expected to lead to inclusion of additional rare species. Although the graph did not reach its asymptotic level, it still indicates the employed sampling efforts were quite enough to capture the variations of plant biodiversity of the study area. The results are very useful for characterising the species diversity and relationships between species and sites.

Species Important Value Index

The ranking of species by Important Value Index (IVI) indicates that *Brachystegia spiciformis* Benth and *Julbernardia globiflora* Benth were the most important species in Wilolesi and Ikonongo forested hills (Appendix 1), which is consistent with other studies in miombo woodlands (Shirima et al. 2011). Therefore, based on their IVIs, species with higher importance in terms of their abundance, frequency and dominance in Wilolesi and Ikonongo forested hills are shown in Table 2. These species should be given a due consideration for conservation to maintain the structures and ecological functioning of the forest ecosystem. However, ongoing threats from human encroachments in the forests, endanger the sustainability of the plant species in the two hills (Plate 1).

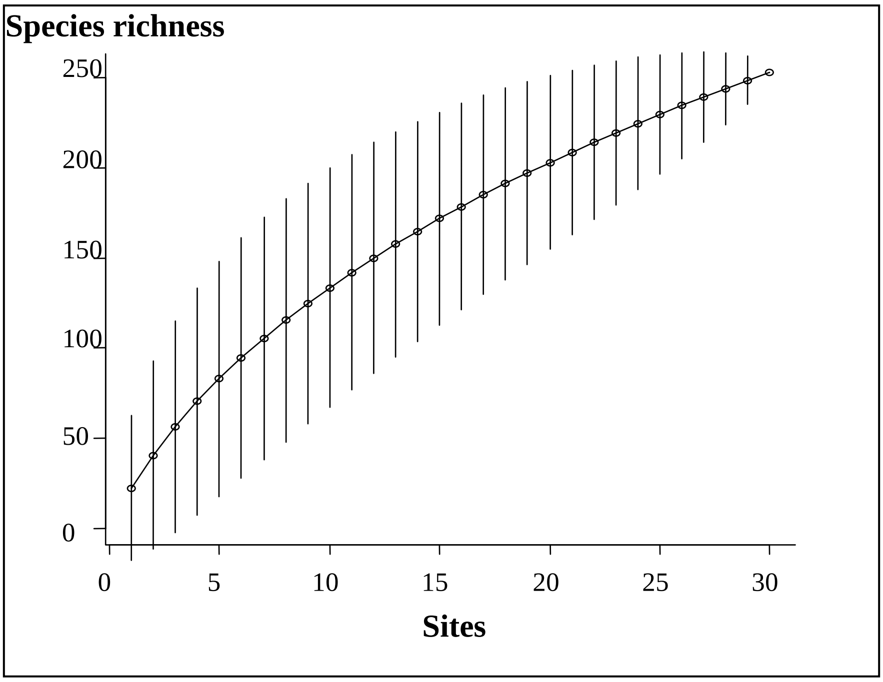

Figure 3: Species accumulation curve for flora composition in the study area.

Table 2: Important Value Index (IVI) of the most important species in the study area

SN	Latin name	IVI
1	*Brachystegia spiciformis* Benth	10.435
2	*Julbernardia globiflora* Benth	4.555
3	*Brachystegia bussei* Harm.	4.425
4	*Brachystegia boehmii* Taub	2.053
5	*Brachystegia manga* De Wild	1.412

Above ground tree carbon

The overall findings showed that both Wilolesi and Ikonongo forested hills had an average of 5.99 t/ha of above ground carbon stock ranging from 3.12 t/ha in Ikonongo hill to 8.33 t/ha in Wilolesi hill (Table 3). This implies that Wilolesi forested hill contains significantly higher above ground carbon (AGC) than Ikonongo forested hill (t = 1.83, p = < 0.004). This is contributed by historical management interventions related to time in which the majority settled around the forested hills. Wilolesi hill is being bordered by Mkwawa University College of Education and its nearness to the Municipal Council Headquarters could also add to its security towards encroachments and hence unplanned management, while Ikonongo is still vulnerable to encroachments despite some efforts from the community bee keeping group to manage the forest as a habitat for honey bees.

Table 3: Average above ground biomass (AGB) and above ground carbon (AGC) in tC/ha estimated using different allometric equations

Equation used	Location				Grand total	
	Ikonongo hill		Wilolesi hill			
	AGB	AGC	AGB	AGC	AGB	AGC
$B = 0.112 * (WD * D^2 * Ht)^{0.916}$	8.32	4.16	19.28	9.64	14.34	7.17
$B = 0.0559 * (WD \times D^2 * Ht)$	6.24	3.12	16.67	8.33	11.97	5.99
$B = 0.0625 * D^{2.553}$	6.25	3.12	22.07	11.03	14.94	7.47
$B = 0.06*D^{2.012}* Ht^{0.71}$	6.75	3.38	16.90	8.45	12.33	6.17

The estimated carbon storage in this study is lower than that reported in Tanzania's miombo by Shirima et al. (2011) and Shirima et al. (2015). This may be influenced by their studies being conducted in mature miombo woodland while this study was conducted in regenerating (recovering) miombo. Carbon range obtained in this study is similar to what has been obtained by other researchers for regenerating trees (5–6 years) (Kweka et al. 2015). Carbon stock of certain vegetation is influenced by the size of the available trees. Vegetation consisting of tree species with large diameter have a higher biomass carbon than that with small diameter as in this study.

Status of forest degradation

Wilolesi and Ikonongo forested hills are significant landscapes for biodiversity conservation, climate change mitigation and ecosystem services. They are, however, increasingly threatened by continuous degradation through small scale agriculture, settlement development, quarrying, and fuel wood extractions. The adjacent communities have developed the habits of entering secretly into the forests to cut trees and pick them as dead woods when dry (Plate 1). This is because of the presence of the by-laws, which prohibit the use of fresh trees by the communities, even though its implementation is questionable.

Felled tree

Settlement in the hill

Farming in the hill

Plate 1: Indicators of forest degradation.

Other existing biodiversity in Wilolesi and Ikonongo forested hills

While working on tree measurements, the field team was able to identify some of the existing fauna along the transect lines, which included small mammal (rat), orange headed agama lizard (*Agama agama*) and tortoise, as indicated in plate 2. Other fauna in the study area were different species of invertebrates, including beetles and butterflies. Invertebrates constitute functionally significant components of terrestrial biodiversity and are important indicators of environmental conditions. Despite their critical roles in the functioning of ecosystems, invertebrates are constantly neglected in conservation planning and management (McGeoch et al. 2002).

Rat

Orange headed agama lizard

Tortoise

Ridged seed beetle

Gaudy commodore butterfly

Plate 2: Different fauna species found in Wilolesi and Ikonongo hills.

Conclusion and Recommendations

Wilolesi and Ikonongo forested hills are recovering from previous degradation making them very potential for carbon sequestration and hence climate change mitigation. It is very important to strengthen the management of the two hills and other Municipality forested hills in order to recover their lost carbon stocks and biodiversity and restore the flow of various ecosystem services. When the Municipality forested hills are sustainably managed, they can effectively support the mitigation of climate change by maintaining and increasing forest and tree cover thereby increasing carbon sequestration potentials.

Acknowledgement

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Appendix 1: Important value index (IVI) for all tree species in Wilolesi and Ikonongo forested hills

SN	Latin Name	IVI
1	*Brachystegia spiciformis* Benth	10.435
2	*Julbernardia globiflora* Benth	4.555
3	*Brachystegia bussei* Harm.	4.425
4	*Brachystegia boehmii* Taub	2.053
5	*Brachystegia manga* De Wild	1.412
6	*Combretum molle* R. Br. ex G. Don	0.838
7	*Albizia glaberrima* (Schum. & Thonn.) Benth	0.560
8	*Lannea schimperi* Rich	0.557
9	*Uapaca kirkiana* Muell. Arg.	0.393
10	*Commiphora africana* Rich	0.348
11	*Burkea africana* Hook.	0.275
12	*Faurea saligna* Harv.	0.271
13	*Pericopsis angolensis* (Baker) Meeuwen	0.226
14	*Protea gaguedi* J.F. Gmel	0.224
15	*Pterocarpus tinctorius* Welw	0.209
16	*Commiphora edulis* (Klotzsch) Engl	0.187
17	*Albizia harveryi* Fourn	0.156
18	*Ficus vallis* Dugand	0.155
19	*Dalbergia nitidula* Welw. ex Baker	0.144
20	*Pseudolachnostylis maprouneifolia* Pax	0.131
21	*Albizia antunesiana* Harms	0.109
22	*Monotes africana* A. DC	0.108
23	*Rothmannia manganjae* (Hiern) Keay	0.107
24	*Zanthoxylum deremense* (Engl.) Kokwaro	0.104
25	*Morella salicifolia* (Hochst. ex A. Rich.) Verdc. & Polhill	0.102
26	*Monotes elegans* Gilg	0.095
27	*Pappea capensis* Eckl. & Zeyh	0.087

28	*Cremaspora triflora* (Thonn.) K. Schum	0.084
29	*Catunaregam spinosa* (Thunb.) Tirveng	0.082
30	*Strychnos angolensis* Gilg	0.077
31	*Rothmannia macrosiphon* (K. Schum. ex Engl.) Bridson	0.077
32	*Cussonia arborea* Hochst. ex A. Rich	0.076
33	*Parinari curatellifolia* Planch. ex Benth.	0.068
34	*Ormocarpum kirkii* S.Moore	0.059
35	*Ficus stuhlmannii* Warb	0.057
36	*Ochna holstii* Engl	0.055
37	*Abutilon mauritianum* (Jacq.) Medik	0.054
38	*Azanza garckeana* (F. Hoffm.) Exell & Hillc	0.053
39	*Searsia pyroides* (Burch.) Moffett	0.036
40	*Entada abyssinica* A. Rich	0.033
41	*Pterocarpus angolensis* DC	0.032
42	*Flueggea virosa* (Roxb. ex Willd.) Royle	0.027
43	*Ximenia caffra* Sond	0.025
44	*Ozoroa insignis* Delile	0.024
45	*Flacourtia indica* (Burm.f.) Merr	0.024
46	*Ochna ciliata* Lam	0.023
47	*Diospyros mespiliformis* Hochst. ex A.DC	0.023
48	*Erythrina abyssinica* Lam. ex DC.	0.022
49	*Bridelia scleroneura* Müll. Arg	0.021
50	*Euphorbia candelabrum* Trémaux ex Kotschy	0.021
51	*Strychnos spinosa* Lam	0.020
52	*Diospyros abyssinica* (Hiern) F.White	0.019
53	*Gardenia ternifolia* Schumach. & Thonn.	0.018
54	*Margaritaria discoidea* (Baill.) G.L. Webster	0.017
55	*Combretum zeyheri* Sond	0.016
56	*Vangueriopsis lanciflora* (Hiern) Robyns	0.014
57	*Ekebergia benguelensis* Welw. ex C.DC	0.013
58	*Diospyros fischeri* Gürke	0.011
59	*Cussonia spicata* Thunb	0.009
60	*Ziziphus mucronata* Willd	0.009
61	*Cussonia arborea* Rich	0.008
62	*Vachelia holstii* Taub	0.008
63	*Vangueria infausta* Burch	0.008
64	*Senna sp*	0.007
65	*Holarrhena pubescens* Wall. ex G. Don	0.007
66	*Maerua triphylla* A. Rich	0.007
67	*Garcinia buchananii* Baker	0.007
68	*Faurea rochetiana* (A. Rich.) Pic. Serm.	0.006
69	*Cussonia holstii* Harms ex Engl	0.004
70	*Heteromorpha trifoliata* (H.L. Wendl.) Eckl. & Zeyh	0.004
71	*Rothmannia engleriana* (K. Schum.) Keay	0.004