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Full Length Research Paper

Analysis of fuelwood utilisation and existing reforestation strategy on local biodiversity in Northern Plateau State, Nigeria

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Unsustainable fuel wood utilisation and poorly articulated habitat reforestation strategy could pose serious threats to the survival of animal species. However, few areas have provided the opportunity to compare the twin effects of these factors on local biodiversity which may be useful for shaping conservation strategies at local levels. Thus, this study examined utilization patterns of plant species used for fuelwood in five Local Government Areas of Plateau State, Nigeria and the extent of avian and insect diversity that they support in natural habitats in comparison to the exotic *Eucalyptus camaldulensis* used in the reforestation of mined areas in the state. Pattern of fuel wood utilisation was obtained through direct survey of fuel wood markets. Biodiversity survey was also carried out to determine avian and insect visit rates, species richness and diversity on the three most utilised plant species (*Parkia biglobosa*, *Syzygium guineense* and *Terminalia macroptera*) and the exotic *E. camaldulensis*. Fuel wood utilisation appeared to involve a wide range of plant species. Most utilised plant species also supported higher local biodiversity as compared to the exotic *E. camaldulensis* suggesting that future reforestation in the area could achieve a wider ecological significance if some native plant species are considered.

Keywords: Fuel wood, reforestation, biodiversity, birds, insects.

INTRODUCTION

Unsustainable fuel wood utilisation and poorly articulated habitat reforestation strategy could pose serious threats to the survival of animal species. Fuel wood collection could lead to deforestation, landscape degradation as well as gradual local extinction of flora and possibly

dependent fauna (Negi et al., 2018; Sambe et al., 2018; Madaki and Sayok, 2019). Poorly articulated reforestation project on the other hand, could distort ecosystem balance especially when candidate plant species is of little or no benefit to local fauna.

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However, examples that showcase specific ecological roles rendered by human threatened flora and examine candidate plant species utilised in reforestation projects at local levels are lacking despite their importance for shaping conservation and environmental management strategies. However, this is because few areas are available that gives the opportunity to exploit these two effects simultaneously.

Globally, fuel wood utilisation is occurring at an alarming rate with consumption reported to have grown from 1854 to 1860 million m³ between 2012 and 2016 with at least one in three households globally depending on fuel wood for domestic energy needs either for cooking or heating (Singh et al., 2021). In Nigeria, fuel wood consumption rate is also quite high and widespread (Ekhuemelo et al., 2017; Salihu, 2019) even within protected areas (Chaskda and Fandip, 2017); annual consumption is estimated to reach about 156 million metric tons; Muazu and Oguijuba (2020) reported that 72.2% of households in Nigeria use fuelwood up to thrice a day for domestic energy needs. Communal bushes and forests often constitute the major source of fuel wood for both urban and rural dwellers (Abdulrashid and Ibrahim, 2018; Abdul-Hamid et al., 2020). This is buttressed by a study on community patterns of fuelwood exploitation by Abdulrashid and Ibrahim (2018) which was collaborated by Abdul-Hamid et al. (2020) in a study that evaluated fuelwood consumption patterns in northern parts of Nigeria where both fuelwood supplied and consumed were shown to be sourced from the same local environment. These patterns could have attendant consequences on dependent local fauna as well as decrease plant diversity and lead to soil erosion (Madaki and Sayok, 2019).

This situation is compounded on the Jos-Plateau, Nigeria where the additional effects of fuel wood consumption and previous tin mining activities have left a widely degraded landscape. Thus, to reclaim mined areas, reforestation using the exotic *Eucalyptus camaldulensis* had been carried out till 1985 covering less than 1% of about 300 km² of mined area (Alexander, 1990). This was done without due consideration to the needs of local animal species existing in the area but mainly based on the fast growth rate of the plant.

Thus, this study examined plant species utilised for fuelwood in five Local Government Areas of northern Plateau State, Nigeria and the extent of avian and insect diversity that they support in natural habitats in comparison to the exotic *E. camaldulensis* used in the reforestation sites. This was with a view to recommend effective future reforestation strategy that may enhance the conservation of animal species in the area.

MATERIALS AND METHODS

Study site

This study was conducted in five Local Government Areas in the

northern senatorial zone of Plateau State, Nigeria. These include: Jos-north, Jos-south, Jos-east, Barkin Ladi and Bassa Local Government Areas (Figure 1). These LGAs were chosen to obtain a representative sample of both rural and urban areas. The Jos environment has suffered environmental degradation as a result of tin mining activities in the past. This has left the landscape dotted with mining ponds (Alexander, 1990). Available natural habitats in this area are under pressure as a result of agricultural activities and fuelwood collection.

Determination of plant species utilised for fuelwood

This was carried out between August and December, 2006. It involved visit to twenty five (25) fuelwood markets, five each in the five selected LGAs. At each market, 10-bundles of fuelwood consisting of between 10 and 20 wood pieces (the form in which fuel wood was sold in the area) were randomly selected. From each bundle, five wood pieces (totalling 1250 wood pieces across the 25 markets) were further selected randomly and identified to species level using plant identification guide (Arbonnier, 2002).

Biodiversity survey

The top three plant species utilised for fuel-wood (that is, *Terminalia macroptera*, *Parkia biglobosa* and *Syzygium guineense*, based on survey conducted earlier) and *E. camaldulensis* (used previously to reclaim mined areas) were sampled for bird species visits and insect species presence. These were done between January and June, 2007. Twenty individual plants were sampled for each plant species; 10 individuals each at Amurum Forest Reserve (9° 53'N, 8° 59'E) and Kurra-Falls Forest (09° 23'N, 08° 42'E) to achieve a wider determination of the ecological functions of the study plants across available major natural habitats in the study area.

Bird sampling

Bird survey was carried out by positioning a telescope (Kamakura) within a range of 10 to 30 m to focal plant (depending on density of vegetation at the area). A period of 30 min was spent recording avian visits. Avian identification guide (Borrow and Demey, 2001) was used to confirm sighted individuals.

Insect sampling

Insect samples were obtained by enclosing plant branches (two randomly selected branches per plant) into a 25 × 65 cm net (diameter × length); this was shaken vigorously 10-times and net content emptied into plastic bags, trapped insects were preserved in ethanol solution (70% ethanol, 10% glycerine and 20% distilled water). These were later identified and enumerated in the laboratory using insect identification keys (Borrer et al., 1989; Shattuck, 2000; Castner, 2000).

Analysis

The SPSS Statistical Package Version 17.0 was used for data analysis. Both descriptive and non-parametric statistics were used to analyse data obtained from the study. Kruskal Wallis test was used to test for any significant differences in the number of avian visitors to the four plant species studied. Both avian and insect diversity indices across plant species were determined using the Shannon-Weiner diversity index (H) with the formula:

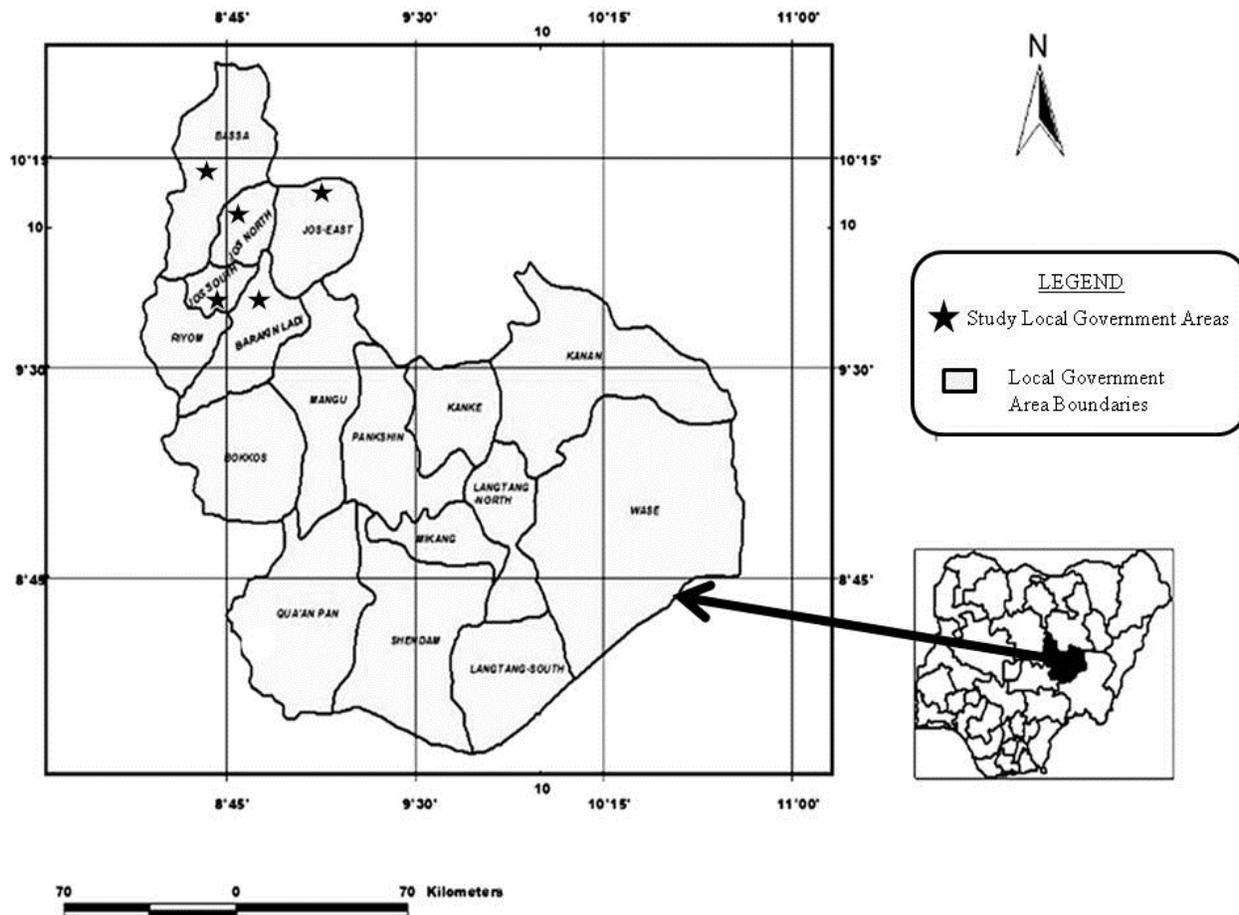


Figure 1. Map of Plateau State, Nigeria showing the location of Local Government Areas where study was conducted.

$$H = \sum (p_i) |\ln p_i|$$

where H= the Shannon diversity index, P_i = fraction of the entire population made up of species i , S = numbers of species encountered, and Σ =sum of species 1 to species S , where the index tend towards 0, indicates less diversity.

RESULTS

Plants species utilised for fuelwood

A total of 58 plant species divided across 23 plant families were recorded during market survey across the five study LGAs in Plateau State. The three most common fuelwood plant species were *Parkia biglobosa* (Mimosoideae), *Terminalia macroptera* (Combretaceae) and *Syzygium guineense guineense* (Myrtaceae), respectively (Table 1).

Bird species on fuel-wood plant species and *E. camaldulensis*

A total of 142 individual birds spread across 36 bird

species and 11 families were recorded during this aspect of the study. Number of avian visitors to the four studied plant species varied significantly (Kruskal Wallis test; $\chi^2 = 46.157$, $df = 3$, $P < 0.001$) with 87 individuals (that is, 61.3% of 142) recorded on *P. biglobosa*, 22 (15.5%) on *S. guineense guineense*, 17 (12.0%) on *T. macroptera* and 16 (11.3%) on *E. camaldulensis*. Bird species visit rates per plant, bird richness and diversity were the highest on indigenous fuelwood plant species in comparison to the exotic *E. camaldulensis* used in reforested mined areas (Tables 2 and 3).

Insect species on fuelwood plant species and *E. camaldulensis*

Individual insects (739) were sampled on the four studied plants. These were divided across 39 families of insects spread across 12 insect orders. *S. guineense guineense* had the highest number of insect families recorded (representing 35.1%), while *E. camaldulensis* supported the least number of insects (9.5%) during the period of this study (Tables 4 and 5).

Table 1. Fuel-wood plant species recorded at fuel-wood markets in Jos and its environment (August - December 2006).

S/N	Fuelwood plant species (scientific names)	Mean number/market (\pm SD)	n	Total (%)
1	<i>Acacia ataxacantha</i>	0.28 \pm 0.50	7	0.6
2	<i>Acacia gourmaensis</i>	0.04 \pm 0.00	1	0.1
3	<i>Acacia macrostachya</i>	0.80 \pm 0.00	20	1.6
4	<i>Acacia mellifera</i>	0.08 \pm 0.00	2	0.2
5	<i>Acacia sieberiana</i>	0.48 \pm 1.14	12	1.0
6	<i>Albizia zygia</i>	1.8 \pm 1.21	45	3.6
7	<i>Alchornea cordifolia</i>	0.08 \pm 0.00	2	0.2
8	<i>Annona senegalensis</i>	1.88 \pm 1.51	47	3.8
9	<i>Annona squamosa</i>	0.16 \pm 0.58	4	0.3
10	<i>Anogeissus leiocarpus</i>	2.76 \pm 1.32	69	5.5
11	<i>Bombax costatum</i>	0.44 \pm 0.96	11	0.9
12	<i>Canarium</i> species	0.08 \pm 0.00	2	0.2
13	<i>Canthium cornelia</i>	0.04 \pm 0.00	1	0.1
14	<i>Carissa edulis</i>	0.44 \pm 0.44	11	0.9
15	<i>Cola laurifolia</i>	0.08 \pm 0.00	2	0.2
16	<i>Combretum fragrans</i>	2.32 \pm 1.46	58	4.6
17	<i>Combretum molle</i>	0.64 \pm 0.52	16	1.3
18	<i>Combretum tomentosum</i>	0.44 \pm 0.75	11	0.9
19	<i>Dichrostachys cinerea</i>	0.76 \pm 0.79	19	1.5
20	<i>Ekebergia senegalensis</i>	0.08 \pm 0.00	2	0.2
21	<i>Erythrophleum suaveolens</i>	0.92 \pm 1.83	23	1.8
22	<i>Euphorbia kamerunica</i>	0.08 \pm 0.00	2	0.2
23	<i>Ficus asperifolia</i>	0.68 \pm 0.55	17	1.4
24	<i>Ficus cordata</i>	0.20 \pm 0.50	5	0.4
25	<i>Ficus ovate</i>	1.20 \pm 1.33	30	2.4
26	<i>Ficus polita</i>	0.04 \pm 0.00	1	0.1
27	<i>Flueggea virosa</i>	0.04 \pm 0.00	1	0.1
28	<i>Guibourtia copallifera</i>	0.20 \pm 0.58	5	0.4
29	<i>Harungana madagascariensis</i>	0.08 \pm 0.00	2	0.2
30	<i>Holarrhena floribunda</i>	1.72 \pm 1.21	43	3.4
31	<i>Hymenocardia acida</i>	0.44 \pm 0.41	11	0.9
32	<i>Isobertlinia doka</i>	0.52 \pm 1.47	13	1.0
33	<i>Jasminum dichotomum</i>	0.44 \pm 0.96	11	0.9
34	<i>Khaya senegalensis</i>	0.08 \pm 0.00	2	0.2
35	<i>Lantana camara</i>	0.32 \pm 0.52	8	0.6
36	<i>Mangifera indica</i>	0.56 \pm 1.91	14	1.1
37	<i>Manilkara multinervis</i>	0.32 \pm 1.15	8	0.6
38	<i>Ochnella alba</i>	0.52 \pm 0.67	13	1.0
39	<i>Pachystela pobeguianiana</i>	0.56 \pm 1.00	14	1.1
40	<i>Parkia biglobosa</i>	5.92 \pm 1.76	148	11.8
41	<i>Phyllanthus muellerianus</i>	0.12 \pm 0.71	3	0.2
42	<i>Piliostigma thonningii</i>	0.60 \pm 0.87	15	1.2
43	<i>Psidium guajava</i>	0.16 \pm 1.41	4	0.3
44	<i>Rhus natalensis</i>	0.60 \pm 0.71	15	1.2
45	<i>Santaloides afzelii</i>	0.08 \pm 0.00	2	0.2
46	<i>Sarcocephalus latifolius</i>	0.92 \pm 1.01	23	1.8
47	<i>Senna siamea</i>	0.16 \pm 0.58	4	0.3
48	<i>Steganotaenia araliacea</i>	0.04 \pm 0.00	1	0.1
49	<i>Swartzia madagascariensis</i>	0.08 \pm 0.00	2	0.2
50	<i>Syzygium guineense guineense</i>	3.08 \pm 0.89	77	6.2
51	<i>Tamarindus indica</i>	1.44 \pm 1.48	36	2.9

Table 1. Contd.

52	<i>Tapinanthus dodoneifolius</i>	0.08 ± 0.00	2	0.2
53	<i>Terminalia brownii</i>	0.76 ± 1.80	19	1.5
54	<i>Terminalia macroptera</i>	3.80 ± 1.22	95	7.6
55	<i>Terminalia mollis</i>	1.40 ± 1.16	35	2.8
56	<i>Uvaria chamae</i>	0.44 ± 1.33	11	0.9
57	<i>Vitellaria paradoxa</i>	0.32 ± 0.82	6	0.5
58	<i>Vitex madiensis</i>	0.16 ± 0.58	4	0.3
59	<i>Eucalyptus camaldulensis</i>	5.92 ± 1.76	148	11.8
	Unknown	1.32 ± 1.36	35	2.8
	Total		1250	100

**Eucalyptus* was treated separate from the other species being an exotic used in reforestation of mined areas and the subject of ecological comparison with the top three local plant species.

Table 2. Estimates of abundance, richness and diversity of bird species across fuel-wood plant species and *Eucalyptus camaldulensis*.

Plant species	Mean avian visit per half hour per plant (± SD)	Avian species richness	Simpson's diversity index
<i>Parkia biglobosa</i>	2.00 ± 0.391	14	10.00
<i>Syzygium guineense guineense</i>	1.00 ± 0.486	8	6.25
<i>Terminalia macroptera</i>	0.75 ± 0.509	9	11.11
<i>Eucalyptus camaldulensis</i>	0.80 ± 0.507	6	4.76

DISCUSSION

Previous studies have recognised the magnitude of anthropogenic tendencies on natural habitats (Chaskda and Fandip, 2017; Sambe et al., 2018; Madaki and Sayok, 2019). For example, rate of fuelwood utilization across different geographic regions globally and locally have been well documented (Ekhuemelo et al., 2017; Baqir et al., 2018; Negi et al., 2018; Gioda, 2019; Salihu, 2019). However, to gain a better understanding of the effects of man-made factors on natural habitats, the importance of integrated studies that explore community specific resource usage patterns and its implications on local fauna cannot be overemphasized. This is important as the nature and scale of habitat disturbance should vary from one community to another therefore suggesting community specific approach. Such a measure will provide conservation stakeholders with the knowledge of specific problem areas and therefore ways of tackling them.

This study, revealed a total of 58 plant species being utilized by communities in the northern senatorial zone of Plateau State as source of energy. This high number of utilised plant species suggests extraction as being random and possibly based on availability within the local environment. The top three plant species in order of utilisation (excluding the exotic *E. camaldulensis* which is the subject of ecological comparison in this study) include *P. biglobosa*, *T. macroptera* and *S. guineense guineense*.

These plant species when compared with *E. camaldulensis* employed in the reforestation of mined areas in the state differed significantly in visit rates, species richness and diversity of birds and insects; avian visit rate, species richness and diversity favoured *P. biglobosa* while insect families and abundance were harboured more on *S. guineense guineense*. *E. camaldulensis* had the least faunal presence. The importance of *P. biglobosa* as an ecologically important resource for local wildlife particularly insects and bats has been previously acknowledged (Lassen et al., 2017). However, this study has in addition broadened this ecological importance to also include avian species. These findings have a wide range of implications, for example, though the aim of 'greening the environment' by planting *E. camaldulensis* might be achieved, in terms of sustenance of local fauna; however, the plant performed poorly as it was the least utilised by animals (birds and insects) in the study area. This situation is further being compounded by the gradual decimation in form of fuel wood usage of the most utilised local flora. These factors could distort ecological stability at local scale. For example, a number of the bird species recorded on indigenous plants are nectar feeding and pollinating birds; these include variable sunbird, scarlet-chested sunbird, pygmy sunbird and green headed sunbird which were actually observed to have shown their quest for nectar on the host plants. Other birds observed in this study were insectivores and dependent on the study

Table 3. Distribution of bird species across study plant species (√ = implies bird species recorded on plant species).

S/N	Common name	Scientific name	<i>Terminalia macroptera</i>	<i>Syzygium guineense guineense</i>	<i>Parkia biglobosa</i>	<i>Eucalyptus camaldulensis</i>
1	Adamawa turtle dove	<i>Streptopelia hypopyrrha</i>			√	√
2	Black crowned tchagra	<i>Tchagra senegalus</i>			√	
3	Black-billed wood dove	<i>Turtur abyssinicus</i>			√	
4	Bronze mannikin	<i>Lonchura cucullata</i>	√			
5	Cinnamon-breasted rock bunting	<i>Emberiza tahapisi</i>			√	
6	Common bulbul	<i>Pycnonotus barbatus</i>	√	√	√	√
7	Common white throat	<i>Sylvia communis</i>	√	√	√	
8	Familiar chat	<i>Cercomela familiaris</i>	√		√	
9	Green-headed sunbird	<i>Cyanomitra verticalis</i>		√		
10	Grey backed camaroptera	<i>Camaroptera brachyura</i>			√	
11	African Grey hornbill	<i>Tockus nasutus</i>			√	
12	Grey-headed sparrow	<i>Poicephalus suahelicus</i>	√			
13	Laughing dove	<i>Streptopelia senegalensis</i>			√	√
14	Little weaver	<i>Ploceus luteolus</i>	√		√	
15	Mocking cliff chat	<i>Thamnolaea cinnanomeiventris</i>			√	
16	Northern black flycatcher	<i>Melaenornis edolioides</i>			√	
17	Northern red bishop	<i>Euplectes franciscanus</i>	√	√	√	
18	Pale flycatcher	<i>Bradornis pallidus</i>			√	
19	Pied flycatcher	<i>Ficedula hypoleuca</i>	√			
20	Pygmy sunbird	<i>Muscicapella hodgsoni</i>		√		
21	Red billed hornbill	<i>Tockus erythrorhynchus</i>			√	
22	Yellow fronted tinkerbird	<i>Pogoniulus chrysoconus</i>			√	
23	Red throated bee-eater	<i>Merops bullocki</i>			√	
24	Red-cheeked cordon bleu	<i>Uraeginthus bengalus</i>	√	√	√	
25	Rock firefinch	<i>Lagonosticta sanguinodorsalis</i>			√	
26	Rock loving cisticola	<i>Cisticola aberrans</i>			√	
27	Scarlet-chested sunbird	<i>Chalcomitra senegalensis</i>			√	√
28	Short winged cisticola	<i>Cisticola brachypterus</i>			√	
29	Spotted flycatcher	<i>Muscicapa striata</i>			√	
30	Tawny flanked prinia	<i>Anthus campestris</i>			√	
31	Variable sunbird	<i>Cinnyris venustus</i>	√	√	√	√
32	Village weaver	<i>Ploceus cucullatus</i>			√	
33	Whinchat	<i>Saxicola rubetra</i>			√	
34	Wood warbler	<i>Phylloscopus sibilatrix</i>			√	
35	Yellow crowned gonolek	<i>Laniarius barbarus</i>			√	
36	Yellow fronted canary	<i>Serinus mozambicus</i>		√	√	

Table 4. Estimates of abundance, richness and diversity of insect species across fuel-wood plant species and *Eucalyptus camaldulensis*.

Plant species	Mean insect abundance/branch (\pm SD)	Number of insect families	Simpson's diversity index
<i>Parkia biglobosa</i>	10.78 \pm 4.85	18	1.92
<i>Syzygium guineense guineense</i>	4.18 \pm 1.78	26	12.50
<i>Terminalia macroptera</i>	3.00 \pm 0.74	23	4.17
<i>Eucalyptus camaldulensis</i>	0.53 \pm 1.08	7	0.40

Table 5. Distribution of insect families found on fuel wood plant species and *Eucalyptus camaldulensis* (\checkmark = implies insect family recorded on plant species).

S/N	Insect families	<i>Parkia biglobosa</i>	<i>Syzygium guineense guineense</i>	<i>Terminalia macroptera</i>	<i>Eucalyptus camaldulensis</i>
1	Acanaloniidae				\checkmark
2	Acrididae	\checkmark	\checkmark	\checkmark	
3	Alydidae	\checkmark	\checkmark	\checkmark	
4	Apidae		\checkmark		
5	Aradidae				\checkmark
6	Blattidae		\checkmark	\checkmark	
7	Brachonidae		\checkmark	\checkmark	
8	Bruchidae	\checkmark		\checkmark	\checkmark
9	Buprestidae	\checkmark			
10	Calliphoridae	\checkmark	\checkmark	\checkmark	
11	Cercopidae	\checkmark	\checkmark	\checkmark	
12	Chalcididae		\checkmark	\checkmark	
13	Chrysididae		\checkmark	\checkmark	
14	Chrysopidae			\checkmark	
15	Cicadellidae	\checkmark	\checkmark	\checkmark	
16	Cicadidae	\checkmark	\checkmark	\checkmark	\checkmark
17	Coccinellidae		\checkmark		
18	Conopidae	\checkmark			
19	Curculionidae	\checkmark	\checkmark	\checkmark	\checkmark
20	Cynipidae	\checkmark	\checkmark	\checkmark	
21	Dermestidae			\checkmark	
22	Drosophilidae			\checkmark	
23	Formicidae	\checkmark	\checkmark	\checkmark	
24	Mantidae		\checkmark		
25	Meloidae		\checkmark		
26	Membracidae	\checkmark	\checkmark	\checkmark	
27	myrmeleontidae		\checkmark		
28	Nabidae	\checkmark		\checkmark	
29	Pentatomidae		\checkmark	\checkmark	
30	Perlodidae	\checkmark			
31	Polistinae				\checkmark
32	Pyrrhocoridae	\checkmark		\checkmark	
33	Reduviidae		\checkmark		
34	Scarabaeidae		\checkmark		
35	Scutelliridae	\checkmark	\checkmark	\checkmark	
36	Staphylinidae				\checkmark
37	Tenebrionidae	\checkmark	\checkmark	\checkmark	
38	Tephritidae		\checkmark		

Table 5. Contd.

39	Tingidae		√		
	Total (families)	18	26	23	7

plants as foraging substrate; these include birds like the northern black flycatcher, common bulbul and migratory passerines such as the common whitethroat and pied flycatcher.

The high numbers of *E. camaldulensis* recorded at fuelwood markets also suggest it to be one of the preferred fuel wood plants which thus points to a bleak future for areas where *E. camaldulensis* was used to reclaim mined areas particularly when utilisation becomes unsustainable. The use of the plant to reclaim mined areas has been attributed to its fast growth rates and drought resistance; therefore, reducing the long term cost of sustaining such projects (Alexander, 1990; Saadaoui et al., 2017; Zaiton et al., 2018). The plant's usage in reforestation is also attributable to its very valuable nature in the prompt solutions necessary for combating erosion and desertification (Zaiton et al., 2018). However despite these benefits, *E. camaldulensis* has also been shown to cause soil deterioration, thus, plants such as *Acacia albida* was previously suggested to have been used in its place in the reclaimed areas where this study was carried out (Alexander, 1990).

Conclusion

It is obvious from this study that if the needs of local fauna must be met effectively, then future reforestation strategy of the mined areas should incorporate indigenous plant species. This is because these plants apart from serving the energy demands of the populace are also a major support for the sustenance of local biodiversity as has been demonstrated in this study using both birds and insects.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Is *Faurea rochetiana* a potential candidate for Dendroclimate studies? Wood samples from semi-arid woodlands of southern Ethiopia

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Sustainable management of economically and ecologically important tree species such as *Faurea rochetiana* merely depend on acquiring reliable information on growth dynamics and structure in response to the changing climate. Formation of the growth ring boundaries is pre-requisite for conducting several dendroclimatology studies. Hence, the objective was to verify the formation of growth ring boundaries of *F. rochetiana*. Fifteen sample discs were examined for macroscopic and microscopic wood anatomy features and compared with IAWA list of microscopic features of hardwood identification for wood anatomy characterization. The result revealed that the studied tree had indistinct growth ring boundaries. Consequently, the studied tree is not a potential candidate for further dendroclimate studies.

Key words: Wood anatomy, growth ring, South Omo, *Faurea rochetiana*.

INTRODUCTION

Ethiopian dry forests are habitats for many endemic plants and animal species which has a varied ecological, social and economic importance (Lemenih and Bongers, 2011, Worku et al., 2011). Despite, these forest resources are being highly destroyed due to agricultural expansion, human-made fire and illegal harvest of woods, over grazing and climate change related threats (Atmadja et al., 2019, Lemenih and Kassa, 2011). For instance climate change has a considerable effects on includes growth rates and dynamics of many plant community, composition, and distribution of plant populations (Siyum, 2020). Moreover, human induced activities such as free grazing and fire can also cause recruitment failure and emerged seedlings suppression

(Tolera, 2013; Tsegaye et al., 2009). As a result several measures have begun to restore the degraded forest land of the country Lemenih and Kassa (2014) through sustaining the remnant forest and planting of ecologically and economically important tree species such as *Faurea rochetiana*. Side-by-side conserving and adopting regulated use of the existing forest with appropriate silvicultural practices such as: planned logging, maintaining the health and quality etc. are urged critical (Lemenih and Bongers, 2011). Despite, for devising successful strategies for these forest resources, acquiring reliable data on for instance growth rates, population structure and, the climate-growth relationship is important (Rozendaal and Zuidema, 2011; Worbes et al., 2003).

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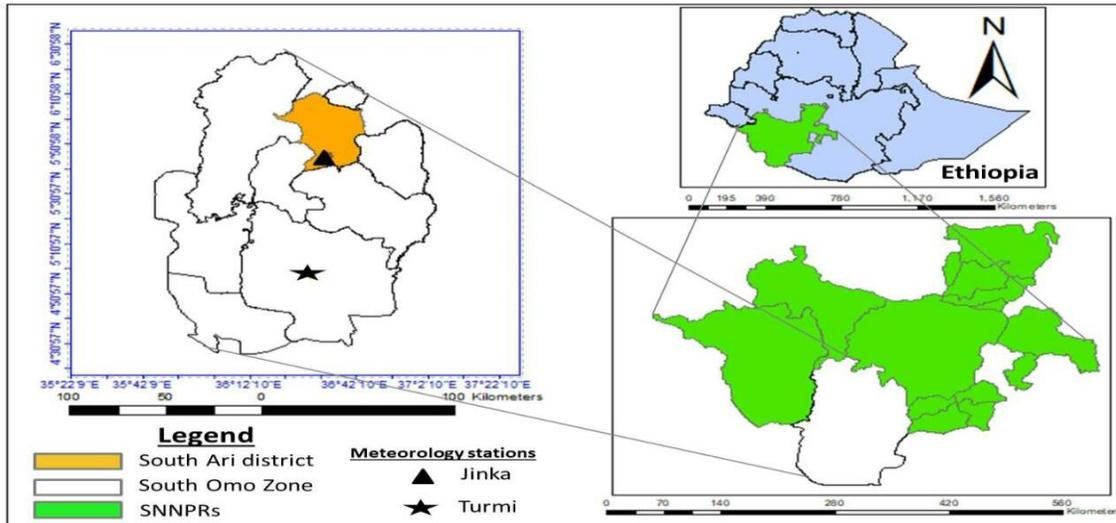


Figure 1. Location of the study area.

Despite, annual growth ring boundaries is a pre-requisite, tree rings can generate reliable data and useful information that helps to sustainably manage forest resources (Gebrekirstos et al., 2008). Thus, a study was conducted to verify whether *F. rochetiana* form annual growth ring boundaries. The objective of this study is to characterize the macroscopic and microscopic wood anatomic features of *F. rochetiana*, so that it is potential for further dendroclimate studies can be checked out?

METHODOLOGY

The study species

F. rochetiana is a tree which belongs to the family Proteaceae, it is an untidy small tree up to 8 m in height (Orwa et al., 2009; Raynes, 2007). *F. rochetiana* well known in the study area with the local name called “Qelshi” (local language-Arigna). It is distributed in the scattered fashion along the stream banks of the south-western periphery of the Kure natural forest. The wood is hard and durable for making different farm implements, furniture and house construction (Raynes, 2007). The charcoal and firewood from this tree are highly preferred by the surrounding community due to high calorific potential. Consequently, the tree population has been declined drastically during the last three-to-four decades.

Description of the study area

Sample discs were sampled from Kure secondary forest which laid with elevation ranges of 850-1200 masl. The forest located in *Combretum-Terminalia* woodlands of South Omo Zone, South-western Ethiopia (Figure 1). The study site has a bi-modal rainfall pattern with a shorter rainy season from March-May and longest rainy season from August-November. Twenty years (1996- 2015) of climate data is acquired from Jinka meteorology station. The total annual rainfall recorded was 272.4 ± 250.7 mm, while the annual mean minimum and maximum temperatures was $16.3 \pm 0.9^\circ\text{C}$ and $27.7 \pm 1.4^\circ\text{C}$.

Sampling method and sample collection

The field campaign was conducted between January and February of 2016. Systematic random sampling design was employed to choose representative trees from the forest. Hence, three transect lines laid out every 2000 m interval and 400 m^2 quadrants were established every 1000 m along transects. Stem discs deliver more information than increment cores especially while dealing with the new species (Brienen and Zuidema, 2005). Similarly, for the current study fifteen trees were felled, totally fifteen stem discs (that is, one disc per tree and sample plot) were taken above ground at 30- 50 cm from the ground (Therrell et al., 2007). The transverse surfaces of the stem discs were sanded gradually using sandpaper with grit size of (60-600). This process was found enough to reveal the cellular structure of wood under low magnification (Tolera, 2013). Six Micro-thin sections were prepared from the transversal section using a sliding microtome and stained with a mixture of Safranin-astrablue for anatomical investigation. The anatomical investigation was carried out under a light microscope. Samples were investigated both microscopically and macroscopically to detect which wood anatomic feature is responsible for the possible growth ring boundaries (Verheyden et al., 2004). Comparisons of ring boundary anatomical features were conducted with IAWA list of microscopic features of Hardwood identification (Ruffinatto et al., 2015, IAWA Committee, 1989).

RESULTS AND DISCUSSION

Wood anatomy characteristics of *F. rochetiana*

The cross-section of the studied tree had light brown color with fine texture and it is easily visible with naked eyes. Despite, the color variation has occurred especially for untreated wood samples along with the time (IAWA Committee, 1989). The growth ring boundary of *F. rochetiana* was characterized as indistinct. The vessels are solitary and clustered with a tendency of tangential arrangement. The rays were visible with a simple lens from traverse section and relatively wider with aggregates

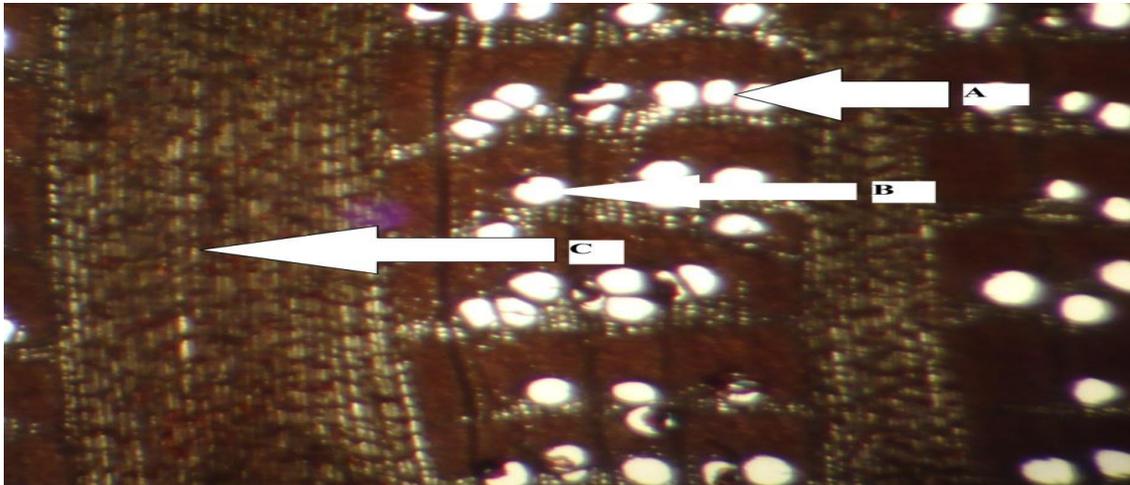


Figure 2. Cross - section of *Faurea rochetiana*. A- Tangential orientations of vessels with the tangential multiple. B- Solitary vessels. C- Radial orientation of rays with an aggregate. The cross-sectional pictures were captured with magnification scales of 20X.

cells. The tree forms multi-seriate axial parenchyma bands sometimes broken or sometimes continuous from ray to ray and it is arranged in arcs perpendicular to the rays (festooned) (Figure 2).

Many genera have similar macroscopic features and hence, easy to establish to which family it likely belongs. Though, more species are distinguished with microscopic features rather than macroscopic ones (IAWA Committee, 1989). Similarly, the present tree shown similar feature with other tree species within the *Faurea* genus such as *F. discolor*, *F. macnaughtoni*, *F. saligna* and *F. speciosa* (Chattaway, 1948). The observed microscopic features of the current study are shown similarity with the typical characteristics of trees from Proteaceae family.

Conclusion

For successful dendroclimatology studies trees with annual growth ring boundary are desirable. *F. rochetiana* is not a potential candidate for climate-growth relationship studies with annual resolution due to the indistinct growth ring boundaries. However, this study switches further studies that enable the studied tree species used as an environmental proxy through employing different techniques. For instance, Verheyden (2004) had verified *Rhizophora mucronata* as a potential source for investigating environmental changes through characterizing growth rings by considering vessel density in early and late woods.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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Full Length Research Paper

Rangeland rehabilitation using micro-catchments and native species in Turkana County, Kenya

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Turkana County is prone to perturbations and famine owing to the prevailing climatic conditions. Due to degradation through natural and anthropogenic activities such as charcoal burning; over time, existing woodlands have been degraded, necessitating rehabilitation. Several drylands adapted plant species studied over the years for the response to the needs of the communities were identified and isolated through a survey. The species identified to be most useful to the communities included *Cenchrus ciliaris*, *Tamarindus indica*, *Salvadora persica*, *Moringa oleifera*, *Aloe turkanensis*, *Acacia senegal*, *Acacia tortilis*, *Acacia mellifera*, *Cordia sinensis*, *Adenia obesum*, *Dobera glabra*, *Parkinsonia aculeata* and *Balanites aegyptiaca*. The final species planted were *A. mellifera*; *A. senegal*; *A. tortilis*; *Adenium obesum*; *B. aegyptiaca*; *C. sinensis*; *D. glabra*; *P. aculeata*, *S. persica* and *Melia volkensii* were introduced for observation on performance. This study's objectives were to determine the effectiveness of micro-catchments in rangeland rehabilitation and to compare species performance to appraise the species highly adaptable to the environment. This offered an opportunity to demonstrate climate-smart technologies regarding rangeland rehabilitation. The methodology was adapted from proving phase provenance trials using nested intensity design to give the best measurements that measure native and exotic plant species. The site was in Ekalees 10 km off Lodwar -Kerio road, Lodwar. Micro-catchment was used as a treatment where a similar number of species of the same age were grown with micro catchments and others without micro-catchments. The major result of this study was found in the site with micro-catchments having higher mean heights and root collar diameters for each species tested. The results indicated the usefulness of micro-catchments, especially in arid and semi-arid areas, as well as showing the performance of selected native species performance in the natural ecosystem.

Key words: Water harvesting, land restoration, climate-smart technology, native species.

INTRODUCTION

Land degradation and deforestation in the rangelands is a serious challenge, currently recognized as a major

threat to the wellbeing of range inhabitants and the environment (Yirdaw et al., 2017). According to the report

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by the Millennium Ecosystem Assessment (2005), 10-20% of the drylands globally are highly degraded. This degradation is mainly caused by natural and anthropogenic factors resulting in loss of biodiversity, soil degradation, increased greenhouse gases, and periodic stresses of extreme and persistent climatic events (World Meteorological Organization, 2005). In lieu of climate change, the arid and semi-arid lands (ASALs) of Kenya are highly characterized by scattered vegetation, low and erratic rainfall, high evapotranspiration, and shallow soils with low water holding capacity (Mwamburi and Musyoki, 2010), thus favouring pastoral production systems. According to Kigomo and Muturi (2013), rangeland degradation and deforestation continue to threaten the survival of indigenous plant communities, which entirely depend on the scarce and diminishing natural resource base.

Pastoralists in ASALs of Kenya continue to face myriad challenges due to rangeland degradation, unpredicted weather patterns, and land mismanagement, thus threatening the sustainability of land-based production systems (Mganga et al., 2015). Turkana County, which is one of Kenya's driest counties, experiences low and unpredictable rainfall, frequent droughts and flooding, and in most instances, prone to perturbations and famine (CIDP, 2018). Despite the challenges, Turkana pastoralists have used traditional land management practices such as delineation of seasonal grazing areas and periodic movement, which facilitated the resilience of range resources to conserve natural resource bases (Barrow and Mlengi, 2003; Kidake et al., 2016). Nonetheless, these practices have currently collapsed owing to the changing dynamics of land use and socio-economic factors (Gaur and Squires, 2017).

Seventy percentage of the inhabitants of Turkana County are pastoralists depending largely on livestock and livestock products for their livelihood (CIDP, 2018; Watson and Binsbergen, 2008). These pastoralists have over the years sustainably used woodland resources through traditional practices and laws (Barrow and Mlengi, 2003; Muturi et al., 2014a), as the region is largely endowed with a diversity of native species. However, indigenous practices on natural resource management are breaking down as current policies favour sedentarization as an avenue of accelerated development in drylands. Afforestation and re-afforestation as an avenue of reversing land degradation in the ASALs faces several challenges, including moisture stress, termite infestation, animal damage, and competition from weeds (Mwamburi and Musyoki, 2010). The available woodland resources cannot sustainably meet the increasing demand for fuelwood, charcoal, and construction poles, thus exacerbating woodland degradation and reduction of both plant species diversity and density (Muturi et al., 2014a). This study also showed that degradation is even more serious around settled areas where the population has continued to grow

drastically. Forest cover in Turkana County is estimated to be 4.06% far below the recommended 10% forest cover, and about 50% of the landscape is highly degraded (CIDP, 2018). The vegetation cover is influenced by climate, topography, and soil structure, as rainfall increases with elevation (Wang et al., 2016). The vegetation cover comprises of scattered *Acacia tortilis*, *Salvadora persica*, *Dobera glabra*, *Cordia sinensis*, *Balanites orbicularis*, *Acacia senegal* and *Acacia reficiens*, which at the moment have decreased significantly paving the way for the succession of invasive species such as *Prosopis juliflora* (Turkana County Government, 2015). Most indigenous grasses such as *Cenchrus ciliaris* have disappeared, leaving most grazing areas bare (Mganga et al., 2015). Among the contributing factors to the loss of vegetation cover is the increased overgrazing and human pressure on the woodland vegetation for charcoal production and construction (Muturi et al., 2014a), thus creating conditions conducive to soil degradation, deforestation and desertification of the fragile environment (GoK, 2016; Lal, 2012). Muturi et al. (2014a) argue that woodlands have been degraded necessitating rehabilitation; hence such areas cannot be left for the natural regeneration process. There is, therefore, the need to beef up forestry in designated settlement areas to act as a buffer zone during dry season and cushion pastoralists from extreme weather conditions.

Forest and woodland restoration play a vital role in rehabilitating degraded and over-exploited areas (M'aty'as et al., 2013; Yirdaw et al., 2017). The government of Kenya and several non-governmental organizations have invested great effort and resources in afforestation and conservation of forests in the drylands to stabilize water supply and reduce soil erosion and desertification (GoK, 2016; Okeyo et al., 2020). However, water scarcity and high evapotranspiration rates in the rangelands have constrained these afforestation and re-afforestation measures. According to M'aty'as et al. (2013), the man-made forest has a high water consumption, which may lead to water scarcity and aridification, thus the need of well-thought technologies to achieve the goal environmental protection. Some rehabilitation measures to combat degradation and improve vegetation cover has successfully been undertaken in some areas (Kigomo and Muturi, 2013; Muturi et al., 2014a; Wairore, 2015), with most rehabilitation strategies being the establishment of the enclosure.

The use of water harvesting infrastructures and tree with high water use efficiency has not been exploited fully in re-afforestation of Kenya's drylands despite its documented importance in capturing and storing run-off water, thus improving soil moisture, speeding up tree establishment and deep root development (Ali et al., 2003; Glotzbach et al., 2011). Most native trees are well adapted to adverse climatic conditions with high

water use efficiency. However, water use efficiency can reduce if infiltration and water holding capacity is not addressed (Hatfield and Dold, 2019; Stroosnijder et al., 2012). A combination of these native species and the use of water harvesting technologies in Turkana County as a strategy for rehabilitation can significantly provide a platform for promoting regeneration of native plant species to improve forest and ground cover as well as improving communities' livelihoods (Castruita-Esparza et al., 2019; Jama and Zeila, 2005). Micro-catchments are rainwater harvesting structures that collect rainfall run-off and direct it to the planting hole, thus improving soil moisture and plant vigour (Haruna, 2014; Rahman et al., 2020). Thus, water harvested is made available to the tree long after the rains have stopped. There are different types of micro-catchments: V-shaped, W-shaped, circular, and semi-circular (Mullah et al., 1995; Mwamburi and Musyoki, 2010; Reijntjes, 1896). Thus, semi-circular micro-catchments were used in trials to rehabilitate some areas with much success and various community adaptation. In order to put the issue into a wider perspective, this paper sought to determine the effectiveness of micro-catchments and native tree species in rangeland rehabilitation and to compare species performance to appraise the species highly adaptable to the environment. This offered an opportunity to demonstrate climate smart technologies regarding rangeland rehabilitation.

MATERIALS AND METHODS

Study site

The experiment was conducted in a public plot of land in Ekalees (3.08465N 35.63903E), Turkana County, 10km off Lodwar-Kitale road. The area selected had deep sandy soils. The vegetation was scarce on the site, with only two species visible: *Balanites aegyptiaca* L. Drel and *A. tortilis*. The entire site was fenced with metal bars and barbed wire to secure the site from browse species and had security round the clock to secure the site.

Establishment of research plots

Within the Ekalees plot, a 38 m × 29 m experimental plot was established and fenced. Semi-circular micro-catchments with a spacing of 4 m × 4 m were then constructed within the fenced plot. Seedlings of mixed species that were propagated at Kenya Forestry Research Institute (KEFRI) tree nursery, Lodwar were planted in the plot with micro-catchment and adjacent area without micro-catchment. The treatment of the site was with micro-catchments, while control site was without micro-catchments. Trees were chosen based on their importance to the Turkana Community and their adaptations to arid and semi-arid environments. A similar number of species of the same age were planted. The tree species planted were: *A. tortilis*, *A. senegal*, *Acacia mellifera*, *D. glabra*, *Salvadora persica*, *Adenium obesum*, *Melia volkensii*, *C. sinensis*, and *Parkinsonia aculeata*. The site had received 4 mm of rain

immediately before planting in August 2015 and only 9 mm in 6 months (August 2015 - January 2016) was received at the site. Monitoring was subsequently undertaken to estimate the extent of regeneration.

Data collection

Baseline and monitoring data were collected from each experimental site. The height and the root collar diameter of all the trees planted were taken after six months, using the height pole and vernier calipers, respectively. The species count was done for the two sites, and also vegetation counts in the two sites according to Muturi et al. (2014). The design of a micro-catchment is a 1.5 m arc (Figure 1 and Plates 1 and 2).

Data analysis

Data on tree height and root collar diameter was keyed in and summarized in R statistical software where mean and percentages were generated and results illustrated in graphical charts. Differences were analysed with ANOVA and post-hoc Tukey HSD.

RESULTS

The boxplot shows the median height of species planted in micro-catchment and outside micro-catchment. Tree species planted in the micro-catchment shows a median height of 67.5 cm, while tree species planted outside micro-catchment show a median height of 35 cm. Most trees in the micro-catchment had height between 36 and 90 cm; and height as low as 10 cm and as high as 115 cm. Most tree species outside the micro-catchment had a height of between 24 and 56 cm; and height as low as 9 cm Figure 2.

The boxplot results show the median root collar diameter (RCD) of tree species planted inside the micro-catchment and outside micro-catchment. The median RCD of tree species inside the micro-catchment was 13.6 mm, while the median RCD of tree species planted outside micro-catchment was 5.5 mm. Most trees in the micro-catchment had RCD between 10 and 18.1 mm; and RCD as low as 3.5 mm and as high as 21.5 mm. Most tree species outside the micro-catchment had RCD of between 5 and 7 mm; and RCD as low as 3.5 mm and as high as 8.2 mm (Figure 3). The results of the assessment of the tree species planted using micro-catchments and without micro-catchment showed significant differences. The results showed that the mean height of trees planted with micro-catchment was higher (57.9 cm) compared to those planted without micro-catchments (39.6 cm). *A. senegal*, *A. mellifera*, *D. glabra* and *C. sinensis* in the micro-catchments had a higher mean growth in the heights of 95, 66.5, 31, and 79.4 cm respectively than those planted without micro-catchment at six months old. *Adenium obesum*, *Melia volkensii*, and

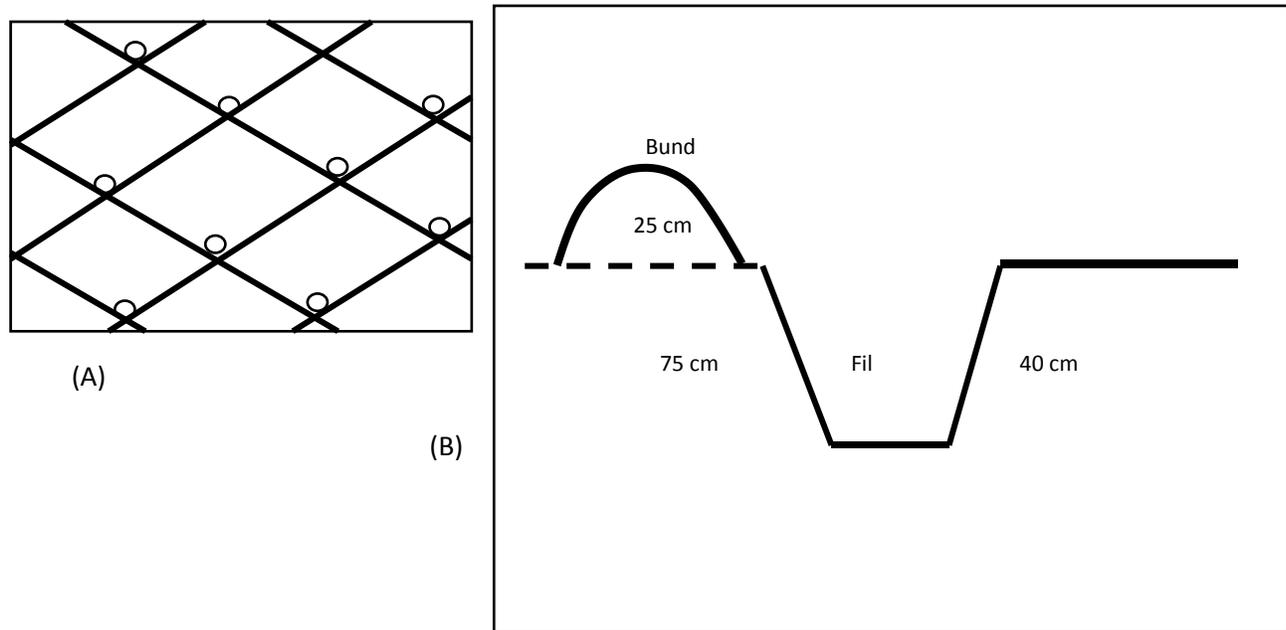


Figure 1. Micro-catchments in a plot (A) and a side view of bund and hole for trapping water in a micro-catchment (B).



(A)



(B)

Plate 1. Plant species in the micro catchment of fenced (A) and non-fenced (B) plots.

P. aculeata did not survive in sites without micro-catchments. *A. senegal* and *C. sinensis* in the site without micro-catchment were taller than other species because the species are well adapted to the environment (Figure 4). From the results in Figures 5 and 6, the percent increase in tree height of most species was directly proportional to the increase in DBH. *Salvadora persica* had the highest percent increase in height and the lowest increase in DBH. The heights of *Adenium obesum*, *Cordia sinensis*, and *Parkinsonia aculeata* increased by over 50% in the period between 6 months old and 2

years old. While the increase in DBH of *A. obesum* was slightly above 50%, the other species *S. persica*, *A. melifera*, *C. sinensis*, *A. senegal* and *P. aculeata* ranged between 7 and 32%.

The micro-catchment site had a higher species density compared to sites without micro-catchment. In the micro-catchment sites, *Cordia sinensis* had the highest density while *Acacia senegal* and *M. volkensii* had the lowest density. *M. volkensii*, *A. obesum* and *P. aculeata* were present in the micro-catchment and absent *in site* without micro-catchment (Table 1). The herbaceous density was



Plate 2. Area with micro-catchment and the abundance of vegetation.

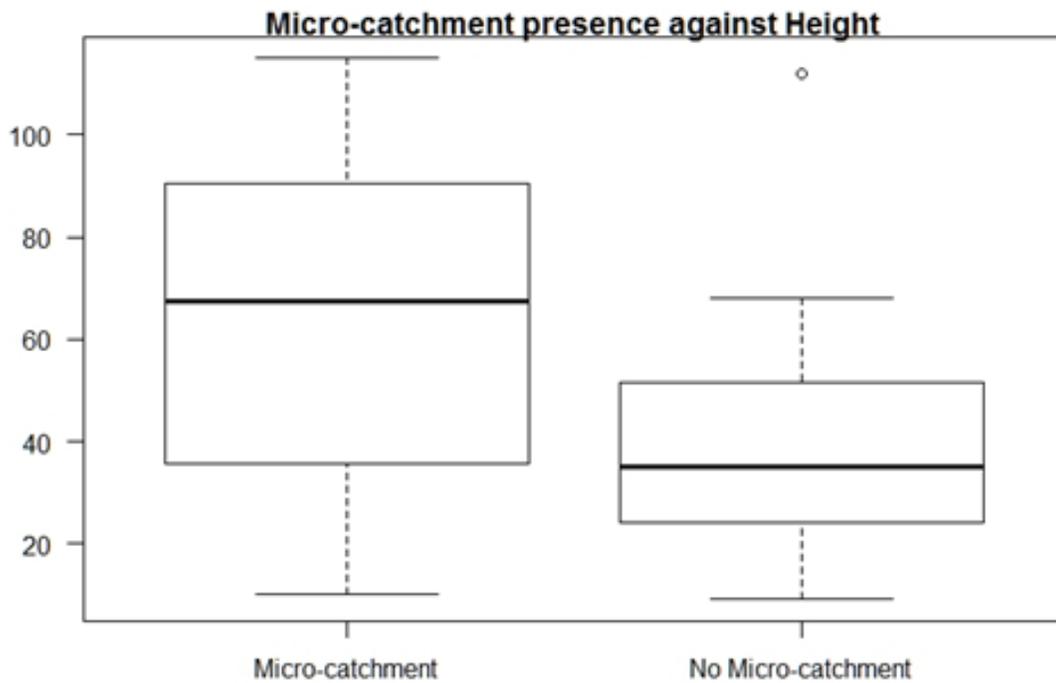


Figure 2. Boxplots showing tree species height comparison in micro-catchment and non-micro-catchment plots.

higher in sites with micro-catchment compared to sites without micro-catchment with 520,000 and 120,000

species per hectare. Sites without micro-catchment had only one herbaceous species (*Indigofera spinosa*) (Table 2).

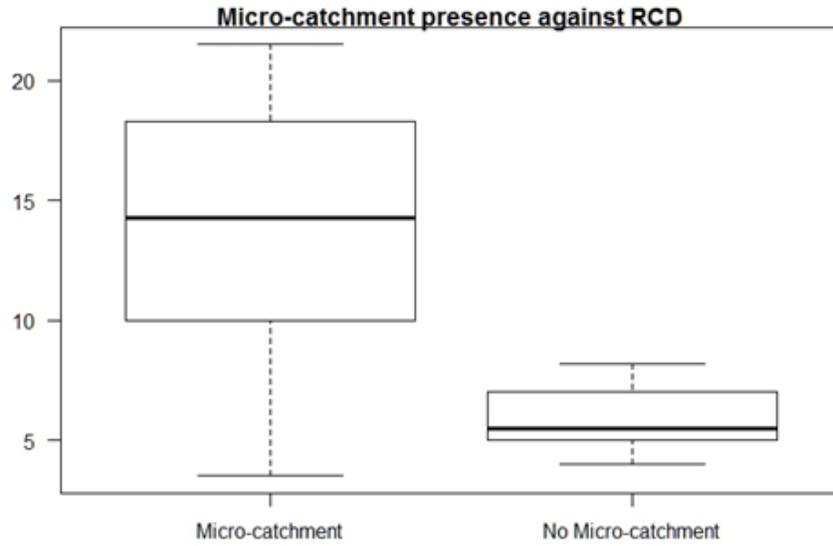


Figure 3. Boxplots showing tree species root collar diameter comparison in micro-catchment and non-micro-catchment plots.

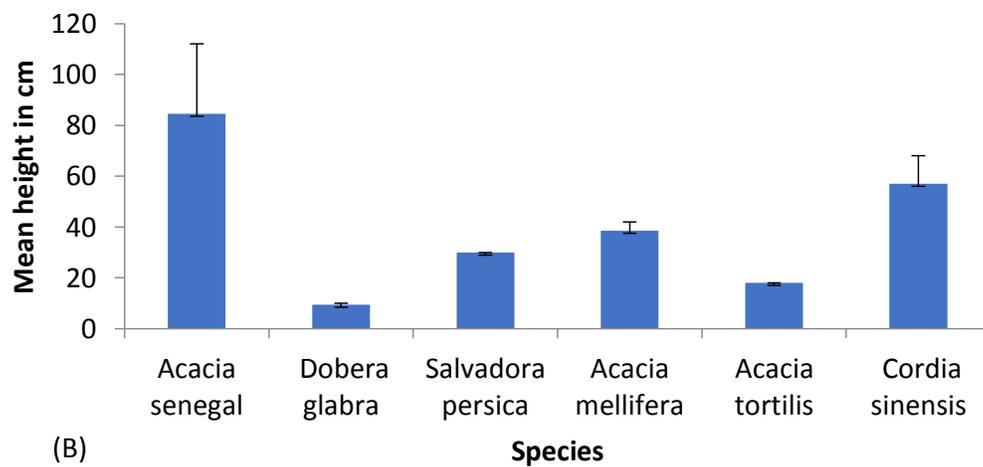
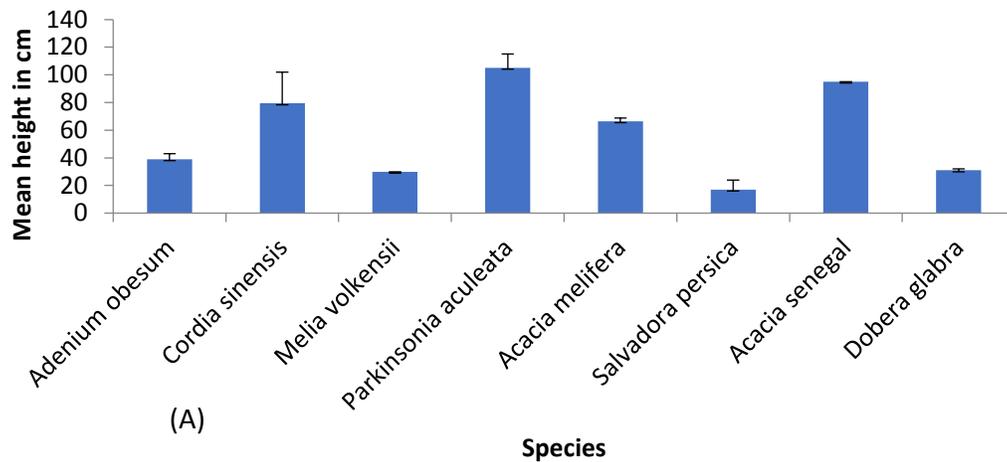


Figure 4. Mean heights of the plant species in (A) micro-catchment and (B) non-micro-catchment plots after six months of planting.

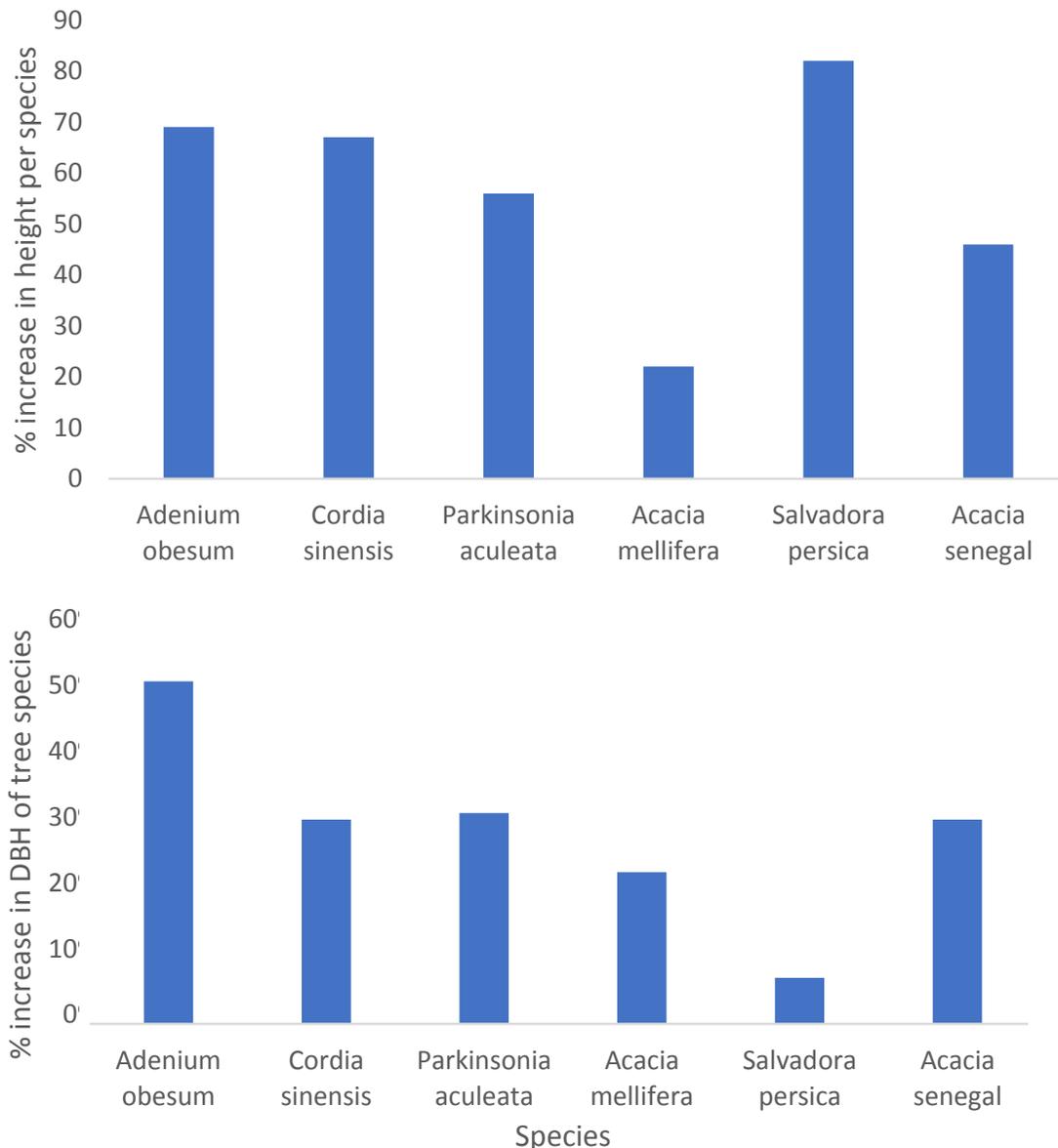


Figure 5. The percent increase in mean height and DBH of species in the site with micro-catchment after two years of establishment.

DISCUSSION

Effectiveness of micro-catchment in rangeland rehabilitation

The use of micro-catchment technology has been utilized to be able to increase the survivability of various afforestation initiatives in the drylands as it ensures speedy growth of trees and deep root development, thus minimizing mortality rate (Ali and Yazar, 2007; Haruna, 2014). This results from the fact that rainfall in arid and

semi-arid areas is unreliable, hence trees planted for afforestation or re-afforestation must have some drought-tolerant ability and tree properties for their sustainability (Muturi et al., 2014b).

The contrasting tree species height and presence in the site with and without micro-catchments attest to the effectiveness of micro-catchments in range rehabilitation. These results show proof of the technology to various afforestation initiatives that can be adopted by the local community to improve tree cover and livelihoods. The absence of some tree species planted in the site without

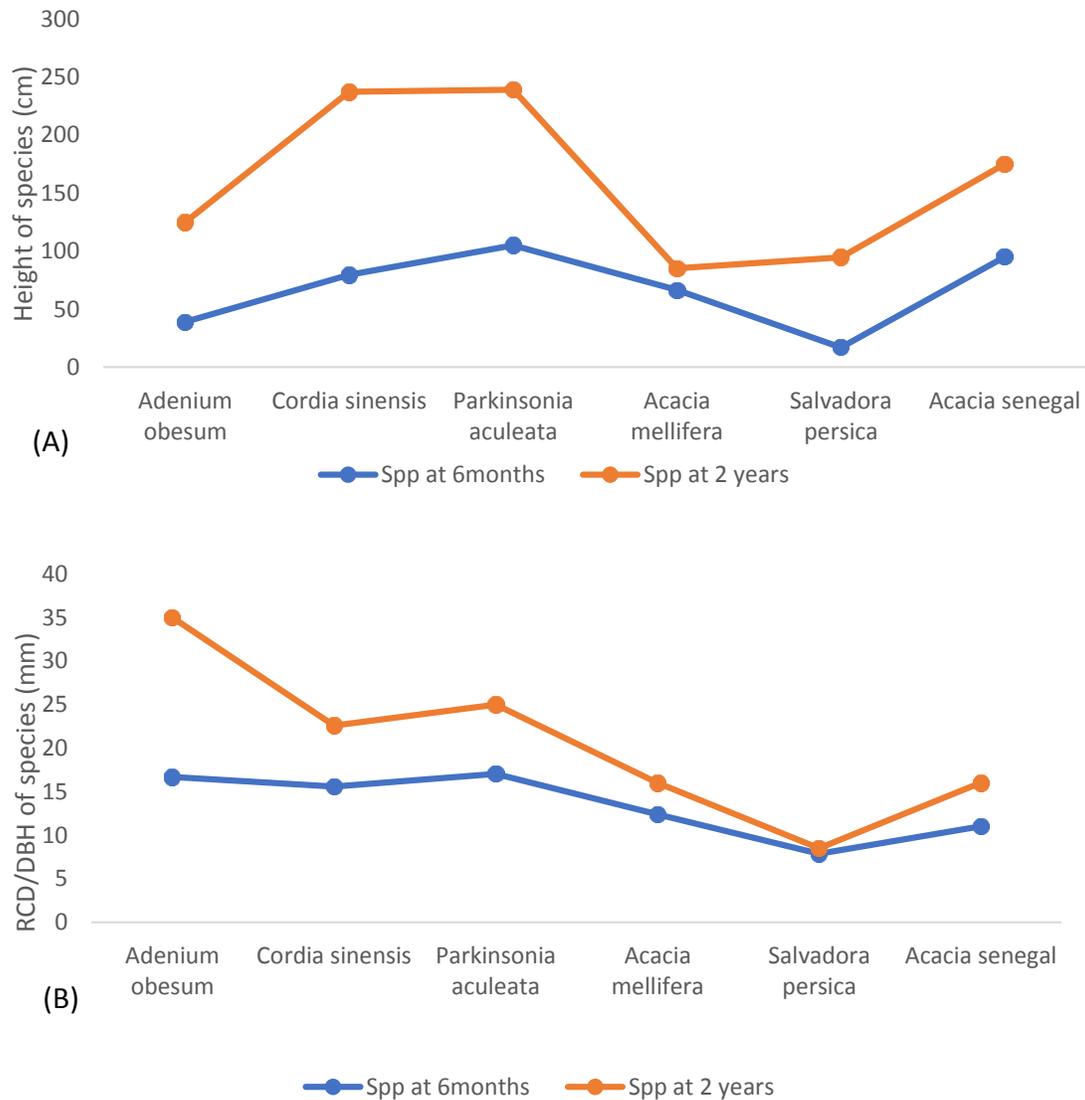


Figure 6. (A) Mean height of spp in micro-catchment, (B) Mean RCD/DBH of spp in micro-catchment at 6 months and 2 years old.

Table 1. Showing species counts in Ekaales with micro-catchments and without micro-catchments. This is total survival after 6 months.

Species	Micro-catchment	
	Yes	No
<i>Acacia mellifera</i>	4	2
<i>Acacia senegal</i>	1	2
<i>Acacia tortilis</i>	0	1
<i>Balanites aegyptiaca</i>	0	1
<i>Cordia sinensis</i>	18	2
<i>Adenium obesum</i>	4	0
<i>Dobera glabra</i>	2	2
<i>Melia volkensii</i>	1	0
<i>Parkinsonia aculeata</i>	2	0
<i>Salvadora persica</i>	4	1

Table 2. Species count in the quadrats in sites with and without micro-catchment.

	Species density/ m ²	Species /ha
Micro-catchment	52	520,000
No micro-catchment	12	120,000

micro-catchment shows the importance of water harvesting structures in areas with low and unpredictable rainfall. This is because the micro-catchment has a higher water collection efficiency and retains water, which could have been lost through run-off and made available to the tree long after the rains have stopped (Haruna, 2014). This technology can be applied in areas with an annual rainfall of 200 to 750 mm. The position of planting the tree should also be determined according to characteristics of the tree species and the soil type (Muturi et al., 2014a).

Species performance in the arid environment

The vegetation data shed light on the influence of micro-catchment on tree growth and survival in the harsh environment of Turkana County. Tree survival in the arid area under natural conditions is usually poor (Haruna, 2014). However, the use of micro-catchment proved to improve the successful establishment of indigenous tree species despite the limited amount of rainfall accompanied by high daily temperature (Mohammed and Mohamed, 2016). The survival rate of trees grown in micro-catchment was recorded to be high, hence the need to advocate for the use of micro-catchment to enhance water infiltration rate. The native plant species outperformed the exotic species in growth and survival. This is because the native species are well adapted to the local environmental conditions. The study also revealed poor long-term survival of exotic species, which in the course of experiment exhibited much stress, and the majority of them dying especially in sites without micro-catchment.

Plant growth occurs as a result of the mutual interaction of genetic structure and environmental conditions (Hrivnák et al., 2017; Yigit et al., 2016a). External factors prevail in the environment in which the plant is grown, this means, climatic and edaphic conditions play an extremely important role in plant growth. Morphological, anatomical, and phenotypic characteristics of plants come up as a result of the interaction of genetic structure and environmental conditions (Sevik et al., 2020a,b; Yucedag et al., 2019). Plants' reaction to environmental factors is closely related to their genetic structures (Yigit et al., 2016b). Since plants of the same species have different genetic structures, they can react to the same

growing conditions and stress conditions at different levels (Topacoglu et al., 2016; Guney et al., 2017; Sevik et al., 2019a,b,c). It is stated as a fact that there may be significant differences between the morphological and micro-morphological characteristics of plants grown in the same environment and belonging to the same species, as well as their growth performances (Sevik et al., 2017; Turkyilmaz et al., 2018a,b).

Morphological characteristics of plants, and hence their growth rate, are also under the influence of environmental factors. There are many factors such as precipitation, temperature, stress factors, light, air pollution, and soil structure which affect the morphological characteristics and development of plants (Cetin et al., 2018a,b; Aricak et al., 2020). In addition to ecological conditions, the studies conducted reveal that the factors such as pruning, hormone applications, spraying, shading, and fertilizing factors are also effective on plant morphological characteristics and development (Guney et al., 2016; Sevik and Cetin, 2016; Yigit et al., 2019). However, the reactions given to these conditions by plants are also shaped under the influence of genetic structure. Therefore, the first step of growing high-quality seedlings is the selection of suitable species and provenances with quality and suitable genetic material.

Herbaceous density

In areas with limited water resource availability, conservation of soil, and water to increase water availability is the only option to improve biomass production (Singh et al., 2013). Water harvesting technologies have a positive role in enhancing soil organic components, nutrients mobility, vegetation population, evenness, and growth (Singh et al., 2017). This is because water harvesting structures help in the conservation of soil and water, and promote herbaceous growth, thus facilitating the land restoration process. The high density of herbaceous species in sites with micro-catchment shows the importance of enclosing a rehabilitated area to allow vegetation to establish. High infiltration rate and low grazing pressure could be a contributing factor to high herbaceous species density. The presence of a single species in sites without micro-catchment (*I. spinosa*) is as a result of high grazing pressure; leading to suppression of decreased species

as well as low infiltration rate during the rainy season.

CONCLUSION AND RECOMMENDATIONS

Rehabilitation of degraded ASAL areas is possible if effective measures and technologies are employed. The results from the study show that the use of native species with proper water harvesting technologies can enhance tree survival and contribute to the rehabilitation of degraded areas. The use of micro-catchment can be adopted by the local communities in Turkana to improve forest and ground cover, thus improving livestock production and environmental conservation. The correct choice of plant species and domestication of young seedlings from domestic browsing species is important. Native species such as *A. senegal*, *A. mellifera*, *C. sinensis*, and *P. aculeata* are highly recommended for this region because of their fast growth, drought-tolerant ability and properties for their sustainability. Community training is necessary so as to encourage the practice of planting native plant species using micro-catchments as a rehabilitation strategy (Muturi et al., 2014a,b; Mwamburi and Musyoki, 2010).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Realising the net Impacts of International trade on carbon dioxide emissions for the sustainability of the environment in African countries

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The purpose of this study is to critically assess the relationship between international trade and carbon dioxide (CO₂) emissions to identify the key driving forces in Africa at different income levels. In examining the causal effects of net trade on CO₂ emission loads from 1960 to 2012 with a number of other anthropogenic driving forces, we employed a panel dataset, an augmented STIRPATN models and techniques of Generalised Least Squares to determine the quantitative magnitude impacts of net trade on CO₂ emissions. The results suggest that CO₂ emissions have statistical significant impact on net trade, population size, manufacturing sector and services sector. The final consumption expenditure (annual growth) cannot be used to explain CO₂ emission loads in Africa, as it is not statistically significant at all in different income levels. The estimated results indicate that, the average effect of net trade over CO₂ emissions, when the net trade changes across time and between countries increases by 1%, CO₂ emissions increases by about 1.02 and 2.24% for low income countries and middle income countries, respectively, when all the other predictors are constant.

Key words: International trade, population size, carbon dioxide emissions, net trade.

INTRODUCTION

Previous studies see the role of international trade as crucial to the explanation of increasing carbon dioxide (CO₂) emissions. International trade is regarded as an engine of growth as it provides much needed opportunity for technological transfer, investment and knowledge transfer among others.

The population trends in Africa have fuelled global concern, given its finite resources which engender increasing international trade relationship to complement the available resources within each member countries.

The continent has witnessed an explosive growth in human population and a steep increase in resource depletion and environmental problems. These trends have accelerated since 1960, fuelling the debate on the relationship between trade, population and environment impacts (Panayotou, 2000a, b).

In recent times, some studies have maintained that changes in the ecosystem are due to increasing international trade, population change, consumption patterns and human activities through the impacts on the

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distribution of affluence (income), institutional environment and poverty. Furthermore, the environmental problems trends in Africa can create pressures that overwhelm the continent's ability to plan and adapt. There is an increasing concern that a rapidly growing international trade relationship might be one of the key driving forces behind the rising (CO₂) emissions in the continent. CO₂ emissions are one of the key indicators of environmental impacts, contributing to Atmospheric Greenhouse Gas Emissions (AGHGEs) (Shi, 2003).

African continent accounts for only 3.7% out of the total carbon dioxide emissions per year (Canadell, et al., 2009). However, the rapid population growth in Africa suggests an increasing demand for energy such as combustion of wood for fuel- by deforestation and increasing use of kerosene (most households in sub-Saharan Africa still depends on the stove for cooking); emission of carbon monoxide by increasing use of generators because of incessant cut in power supply in some countries; generation of carbon monoxide by increasing use of vehicular movements that are not roadworthy in America and Europe; pollution and carbon monoxide, other used items such as refrigerators, deep freezers, television and chlorofluorocarbons emission.

The cement industry is expanding as new firms are established in most part of the continent to keep pace with population growth (PGH). All the resources are likely to rise which in-turn increases international trade relationship in line with population growth (PGH). The statistical estimates and projection, since 1960, shows an increasing trend of carbon dioxide emissions on the continent, and the suspicion that recent increase in international trade may be responsible. Thus, the comprehension of the continent's contributions and trends of anthropogenic carbon dioxide emissions and international trade are crucial to suggest ways to improve the operational effectiveness aimed at stabilizing the global carbon dioxide emissions.

Despite the important benefits, many previous studies have undergone, very few empirical analysis takes into account the issue of international trade with respect to carbon dioxide emissions. In addition, on a global scale increasing energy consumption has been linked to the renewed aggressive extraction of natural resources from Africa to meet rising demands of industrialized nations and emerging economies: such as Brazil, Russia, India, China and South Africa. Empirical analysis has not extended its reach to examine this gap regarding Africa. Therefore, this study intends to contribute to global trade-environment relationship by investigating empirically net trade as part of the driving forces of environmental impacts in Africa. By contrast, previous studies only examined population, affluence and technology as the key driving forces of environmental threats, since the theoretical framework was designed based on developed economies. The primary objective of the study is to

investigate the impacts of openness of the economies on carbon dioxide emissions in African countries at different per capita income levels.

This study is motivated by the desire to have a better understanding of the contributions and trends of anthropogenic carbon dioxide (CO₂) emissions in Africa that have dictated increasing trends since 1960 and to be able to predict future anthropogenic CO₂ emissions. The research also links trade-carbon dioxide emissions in terms of the measurement of the quantity of CO₂ emitted by the sustained increase of African countries trade relationship with the rest of the world in comparison to the emissions of other numerous human activities.

LITERATURE REVIEW

Net trade and CO₂ emissions

Dietz and Rosa (1994a) offer a comparative analysis of studies with the argument that single indicator of study and estimation based on it may be misleading due to the *Netherlands effect*. For example, Ehrlich and Holdren (1971a, 1972b) maintain that much of the environmental impact of a country may be displaced across its borders as a result of the mix between imports and exports and its place in the international division of labour.

This study pointed out that, the relationship between trade and environmental impacts can be controlled by considering imports and exports with high environmental consequences. However, this position is flawed because substitution within a social system is not taken into account. It is argued that, a country may have relatively low carbon dioxide emissions due to extensive use of nuclear hydroelectric power rather than fossil fuel. An obvious reference to the impacts of nuclear waste is reiterated by Dietz and Rosa (1994a). Their study pointed out that, the disposal of nuclear waste and the disruption of riparian ecosystems are environmental problems. It is suggested that an adequate environmental indicator should be taken into account the effects of net trade and the possibility of displacing impacts. Dietz and Rosa (1994a) suggested that, environmental impacts can be treated as latent variables while specific indicators such as carbon dioxide emissions, tropical wood imports or endangered species serve as observed indicators or proxies associated with the latent variables. In strict accordance with the world system theory, Shi (2003) asks whether the linkages between population and environmental impacts will be robust when the relationship between net trade and emissions is taken into account. This study argues that, changes in emissions across countries may be influenced by imports and exports of dirtier products such as fuel. It was examined the net trade-emission nexus by using non-trade output as a percentage of Gross Domestic Product

(GDP) as predictor.

It claimed that a large share of non-traded GDP may mean a smaller quantity of trade in dirtier industries. Thus, we expect that a country with relatively larger share of non-traded GDP will mitigate emissions than another whose share is relatively small.

Jorgenson (2009) investigated the transnational organization of production in the context of foreign direct investment and carbon dioxide emissions. The study used the method of fixed effects for a panel regression analysis of 37 less developing countries from 1975 to 2000, and examines the impact of secondary sector foreign investment on total carbon dioxide emissions and emissions per unit of production. The empirical findings suggest that, foreign direct investment in manufacturing has a positive relationship with both outcomes. The results also indicate that, the level of economic development and export intensity has a positive association with total emissions and emissions per unit of production.

The world systems theory perspective foregrounds the importance of human-ecology and political perspectives when examining anthropogenic carbon dioxide emissions. Roberts et al. (2003) applied the world system perspective to environmental impacts. The research sampled 154 countries and investigated their contribution to the global economy and their internal class and political forces to estimate on how these factors influence the quantity of CO₂ emissions per unit of economic output. The study concluded that semi-periphery and upper-periphery countries are the least efficient consumers of fossil fuels, consistent findings with Satterthwaite (2009).

Li et al. (2017) studied the effect of trade on fuel related mercury emissions to examine the aggregate energy consumption and environmental emissions. The literature employs a three-scale input-output analysis which accommodates variation in circumstances regarding local, domestic and international activities and evaluated the embodiment fluxes of fuel related mercury emissions in Beijing in 2010, given the mercury intensities for average national and world economies. The results found that international trade is a major contributor of Beijing environmental emissions (Beijing mercury emissions final fuel consumption were 7.79t in 2010, higher by about 3/4 of which is linked to domestic and openness of the economy).

However, the highest level of environmental emissions was due to massive infrastructural development in the capital city. The implication is that modernization is a driver-trigger in the analysis of environmental impacts. The specification used by Liu et al. (2015) is a system dynamic model to estimate energy consumption and carbon dioxide emissions in China for the period 2008 to 2020. Using macro-data, the literature clearly shows that CO₂ emissions per GDP amelioration by about 40 to 45%

of 2005 level could be attained in 2020 in China. Even though the structure conducted scenario simulation, to determine the impacts of economic growth rates on the energy consumption and carbon dioxide emissions, some vital variables such as population dimensions and technology were neglected in the determination of environmental impacts.

Consumption is not the only driving forces of environmental impacts. Xu and Lin (2015) analyzed the driver-trigger of carbon dioxide emissions in China's transport sector. A nonlinear inverted U-shaped curve was found to exist suggesting evidence of Environmental Kuznets Curve (EKC) in the sector, as in economic growth depending heavy on road and air transport in the early stage, but deepening on emission-free train-transport at the later stage due to the speed of technological progress at different times. Urbanization is also found to exhibit pattern of EKC. Zhang et al. (2014) used a PEMs method to collect 60 light-duty passenger vehicles (LDPVs) data on-road fuel consumption and CO₂ emissions for China. The study found about 30% gap between on-road fuel consumption and type-approval values. The results among many others, found diesel LDPVs to have 22% energy saving advantage against gasoline counterparts while the literature also reports a strong correlation between fuel consumption and average speed, that is, a reduction in traffic congestion has effect of mitigating distance-based fuel consumption. Loftus et al. (2015) carried out feasibility studies on global decarbonization argue that historical carbon intensity and energy intensity rates need to improve and normalized energy technology capacity deployment rates which are important benchmarking comparators to examine the relative feasibility of global decarbonization scenarios for decision makers.

Zhang and Choi (2013) explore the feasible application of the SBM-DEA approach for energy efficiency in China, showing that most regions in China are not efficient in environmental-friendly low energy carbon economy. However, considerable room for improvement is not ruled out. The study attributed environmental energy inefficiency to pure energy inefficiency, and research and development is therefore recommended for the future. Ouyang and Lin (2015) investigated the drivers of energy-related carbon dioxide emissions in China's industrial sector. The findings suggest a long-run relationship between industrial carbon dioxide emissions and the influencing variables (CO₂ emissions per unit of energy consumption, industrial value added, labor productivity and fossil fuel consumption).

The study attributed industrial CO₂ emissions as the key determinant to the coal-dominated energy structure in the country. Liu et al. (2015) examined the effect of population, income and technology on energy consumption and industrial pollutant emissions in China. The research did not find evidence of Environmental

Kuznet Curve (EKC) hypothesis. In addition, the impact of population density, income and technology on energy consumption and pollutant emissions varies at different level of development. The study suggests formulating specific region-oriented emissions reduction strategies for sustainable development in China.

World-system theory (WST)

Wallerstein (1976) first brought the world-system theory into focus in a seminar paper in 1974. The key issue is that, the theory takes a macro-sociological approach in analysing the working of the world capitalist economy as total social system. He described the establishment of the European capitalist economy system as a basis for economic growth and environmental problems.

According to York et al. (2003b), the perspective argues that the regional, inter-regional and transnational division of labour separates world economy into periphery countries (poor countries), semi-periphery countries (emerging economies) and the core countries (developed economies). The developed economies are based on higher skills, the method of production is capital-intensive; the semi-periphery countries are also based towards high skills and tend toward more capital intensive method of production; while the periphery countries uses low skill and labour intensive production (York et al., 2003b). This theory follows the traditional Marxist political economy perspective (TMPEP) and its logic at a global level, and extended its reach to investigate environmental impacts (Burns et al., 1994; York et al., 2003a). The main focus is that all countries of the world are organized into a single world economy that is dominated socially, economically, politically, and military by developed nations (Wallerstein, 1974). According to Halsall (1997), Wallerstein's works provide a detail "understanding of the external and internal manifestations of the modernization process during this period and makes possible analytically sound comparisons between different parts of the world". The theory structure countries into three main locations: core or wealthy powerful countries, the United States of America (USA), Japan and most Western European countries, these countries control the trade relationship with other countries of the world-. They dominate economically and politically. Semi-periphery or emerging economies like Brazil, Russia, India, China, Mexico and Turkey occupy intermediate power when compared to the periphery; and the periphery like African countries and other less developing countries in the world, "have small typically industrialized economies and lack global political power" (York et al., 2003b). According to York et al. (2003b), economic development is the main driving force of environmental problems, and this is consistent with PEP (Political Economy Perspective).

The underlying point in this theory is that the core

countries dominate as the major producers and consumers, but the basic natural resources need for production such as minerals and other primary commodities are extracted from the periphery nations (Frey 1994, 1995; York et al., 2003b). The WST counters the evidence which shows the presence of EKC (Ecological Kuznets Curve) of reduced environmental impacts in core countries through ecological modernization as spurious and untenable. In addition, Roberts and Grimes (1997) criticized the evidence of EKC on the ground that for carbon dioxide (CO₂) emissions, EKC can be "explained by nations at different positions in the world-system being locked into different trajectories of fossil fuel use", and evidence and findings only exist for local impacts (York et al., 2003b). This vital point draws attention to whether economic development actually reduces environmental problems or shifts them elsewhere (Stern, 1993).

Thus, the assumption that EKC has relevance in developing economies raise a big question, because it is brought about as a result of the relationship between economic development and environmental impacts (Ehrlich and Holdren, 1970, 1971). The implication is, the WST approach regards the example of the Netherlands as combining a very high population density with good environmental outcomes is misleading because one must consider the worldwide relationship between population and the environment. Furthermore, York et al. (2003b) argues that the wealthy nations have the technology to distance themselves from the environmental impacts they have generated. Therefore, it is spurious and misleading to rely on the evidence of the impacts that a country generates within its borders, instead of taking a worldwide system analysis on the impacts. This means that damage to the environment anywhere is damaging to the environment everywhere.

The world-system theory laid emphasis on total impacts and not micro impacts, impacts generated both within and beyond the national borders, and this underlies a "theoretical understanding of threats to sustainability" (York et al., 2003b). It is further argued that environmental problems continually rise with economic growth, but will extend beyond the countries that generated these impacts, in contrast with EKC.

MATERIALS AND METHODS

Data sources and samples observed

Data sources, descriptions and analysis

The study constructs an unbalanced time series cross-section (TSCS) data set of 51 countries in Africa for the period 1960 to 2012. The study period (1960 to 2012) is based on the availability of the data according to the classification of World Bank into Low Income Countries in Africa (LICA), Lower Middle Income Countries

(LMICA), Upper Income Countries in Africa (UICA) and High Income Countries in Africa (HICA). The size of the sample changes according to the model specification. The excluded countries are mostly Islands whose data are not available from the World Bank between the period under investigation, and Southern Sudan who became independent 3 years ago.

The African continent consists of a list of sovereign countries, partially recognized and unrecognized states (Somaliland, and Sahrawi Arab Democratic Republic) and dependent territories, that is, non-sovereign territories (French Southern and Antarctic Lands, Saint Helena, Ascension and Tristan da Cunha, Canary Islands, Ceuta, Madeira, Mayotte, Melilla, Plazas de Soberanda, Reunion and Lampedusa and Lampione), all located on the African continental plate (National Geographic, 2011; De Waal, 2010; Freshfield, 1869; Rennell, 1830; von Strahlenberg, 1730; Theiler, 1982). However, by international convention, they are considered European (De Waal, 2010).

In addition, the Island of Socotra is on the continent of the African plate, but part of Yemen territory (Freshfield, 1869; National Geographic, 2011; Theiler, 1982). This study considered only the sovereign states on the continent due to data availability. Of the 54 sovereign states in Africa, the research investigates 51 countries which yield a good coverage of the independent countries on the continent. We collected online data from the World Bank Africa Development Indicators. We are now positioned to investigate our anthropogenic environmental impacts by mapping the driving forces into our modified STIRPAT frameworks.

Variables

Response variable: For our outcome variable, we used the World Bank data analysis in 2013 for per capita carbon dioxide emissions, and related emissions in Africa, comprising agricultural methane emissions, agricultural nitrous oxide emissions, carbon dioxide emissions from residential buildings and commercial public services, energy related methane, methane emissions, nitrous oxide emissions including industrial and energy processes, other greenhouse gas emissions, HFC, PFC, and SFG (thousand metric tons of CO₂ equivalent) and PM10, country level (micrograms per cubic metre).

Of these emissions, we examine only carbon dioxide emissions stemming from the burning of fossil fuels and manufacture of cement, which include CO₂ produced during consumption of solid, liquid and gas fuels, and gas flaring. We gathered this information from the World Bank Development Indicator (2013), which was originally provided by Carbon dioxide Information Analysis Centre, Environmental Sciences Division, Oak Ridge National Laboratory, Tennessee and USA.

Population size: The population size refers to the total population or total number of people in geographically sovereign states. Population size is the total number of human beings occupying a specified sovereign country in Africa.

GDP per capita (2005 constant prices US\$) (affluence): The GDP per capita is sourced from the World Bank Development Indicator (2013) national accounts data, and OECD National Accounts data files. The GDP per capita refers to the gross domestic product divided by midyear population. GDP is the sum of gross value added by all resident producers in the economy, plus any product taxes, and minus any subsidies not included in the value of the products. It is calculated without making deductions for the depreciation of fabricated assets or for the depletion and

degradation of natural resources. Data are in 2005 constant US dollars, permitting comparisons across African countries over time.

Technology: The information on technology is derived from the World Bank Development Indicator (2013) national accounts data and OECD National Accounts data files. This study does not enter into the controversy surrounding technology but represents technology with two structural indicators: manufacturing as a percentage of GDP and services as a percentage of GDP. This is consistent with many studies of ecology and modernisation. Manufacturing as a percentage of GDP is the manufacturing sector of value added which is expressed as a percentage of GDP.

The services are the value added expressed as a percentage of GDP. The services' correspond to International Standard Industrial Classification (ISIC) divisions 50 to 99, and comprise value added in the wholesale and retail trade, including hotels, restaurants, transport, and government, financial, professional, and personal services such as education, health care, and real estate services. In addition, it also includes imputed bank service charges, import duties, and any statistical discrepancies noted by national compilers as well as discrepancies arising from rescaling. The value added is defined as the net output of a sector after summing up all outputs and subtracting intermediate inputs. The measurement calculates value added without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources.

According to the World Bank Development Indicator (2013), the industrial origin of value added is determined by ISIC (International Standard Industrial Classification). In addition, for Vehicle Assembly Building (VAB) countries, gross value added at factor cost is used as the denominator.

Final consumption expenditure (FCEG): We derived data on final consumption expenditure (FCEG) (annual % growth) from the World Bank Development Indicator (2013) data files, and the catalogue sources of World Development Indicators consist of World Bank national accounts data and OECD National Accounts data files. The FCEG is the average annual growth of final consumption expenditure based on constant local currency. Aggregates are based on constant 2005 US dollars. Final consumption expenditure (formerly total consumption) is the sum of household final consumption expenditure (formerly private consumption). It includes any statistical discrepancy in the use of resources relative to the supply of resources.

STIRPAT model

Beginning with the challenge of ImpACT identity, an attempt to investigate potential action and policy levers to alter environmental impacts was carried out by Waggoner and Ausubel (2002), through reformulating IPAT identity into ImpACT identity. The study decomposed T into consumption per unit GDP (C) and impact per unit consumption (T), implying that $I = PACT$. For example, an investigation of carbon dioxide emissions employing IPAT framework show that total emissions (I) are the product of population (P), affluence, that is per capita GDP (A), and carbon dioxide emission per unit GDP (T) whereas, the ImpACT framework states that total carbon dioxide emissions are equal to the product of P, A, energy consumption per unit of GDP (C), and carbon dioxide emissions per unit of consumption (T). The main objective of the ImpACT framework is to determine the variables that can be altered to minimize environmental impacts and the principal factors which influence each variable.

The STIRPAT model has its root in the refinement of IPAT and

ImpACT identities by Dietz and Rosa (1994a). The STIRPAT equation is:

$$I_i = aP_i^\alpha A_i^\beta T_i^\varphi e_i \quad (1)$$

Equation 1 can be linearized by taking logarithms on both sides of the equality.

$$\ln(I_i) = a + \alpha \ln(P_i) + \beta \ln(A_i) + \varphi \ln(T_i) + e_i \quad i = 1, \dots, n \quad (2)$$

Where: Constant “a” scales the model,

α , β and φ are the exponents of the population (P), affluence (A) and technology (T),

“e” is the error term

Subscript “i” shows all the explanatory variables and error term (e) vary across observational units. The exponents can be interpreted as elasticities in Equation 2. The STIRPAT model contains the IPAT

as a special case, namely: $a = \alpha = \beta = \varphi = e = 1$

and the ImpACT identity: $a = \alpha = \beta = \varphi = e = 1$.

This can also be derived from Equation 1 by setting $a = \alpha = \beta = \varphi = e = 1$. In the case of the STIRPAT framework, any of the elasticity coefficients can be greater than 1, or less than 1, or may be equal to 1. In a panel data analysis, the Equation 2 above becomes:

$$\ln(I_{it}) = a + \alpha \ln(P_{it}) + \beta \ln(A_{it}) + \varphi \ln(T_{it}) + e_{it} \quad (3)$$

Where: “t” is the time period or the year.

The STIRPAT model is employed as a starting point because it allows an additive regression model in which all the variables can be conducted in logarithmic form, facilitating estimation and hypothesis testing (York et al., 2003a), the limitations of both IPAT and ImpACT. In addition, the York et al. (2003a) study used the STIRPAT model refined by Dietz and Rosa (1994a), and combined T with the error term, rather than estimating it separately to conform to the IPAT framework, which York et al. (2003a) T to balance I, P and A. The modifications yield:

$$\ln(I_{it}) = a + \alpha \ln(P_{it}) + \beta \ln(A_{it}) + \theta \ln(M_{it}) + \psi \ln(S_{it}) + e_{it} \quad (4)$$

The approach of this study is slightly different from York et al. (2003a, 2003b) modifications, as this study considered T as an important variable that should be disaggregated into manufacturing sector and services sector and estimated, instead of making the blanket assumption that T could be treated as part of the error term as in York et al. (2003a, 2003b). Thus, we identify two important components of technology that need to be empirically tested to achieve part of the objective of the impact of human activities on emissions. The identified disaggregated technologies are: manufacturing sector as a major component of GDP and services sector as a component of GDP (Shi, 2003). This is consistent with the economic modernization perspective and neoclassical economic growth theory which maintained that structural factors play crucial role in mitigating environmental impacts. Both theories argued that “the shift occurring away from manufacturing economies and toward service economies is commonly identified as a potential solution to environmental problems, because service economies are presumed to be less dependent on natural resources than industrial economies” (York et al., 2003b).

More still, the percentage of manufacturing and the percentage of services captured the difference in T. It is expected that economies whose GDP outputs are heavily derived from manufacturing will be

energy-intensive which will produce higher emissions. By contrast, economies whose GDP is largely derived from services will be less energy-intensive and produce lower emissions (Shi, 2003). By incorporating the disaggregated T variable into the Equation (3), this research specifies our model as:

$$\ln(I_{it}) = a + \alpha \ln(P_{it}) + \beta \ln(A_{it}) + \theta \ln(M_{it}) + \psi \ln(S_{it}) + e_{it} \quad (5)$$

Where: M is the manufacturing sector as a major component of GDP (percentage of GDP), and

S is the service sector as a major component of GDP (percentage of GDP),

θ and ψ are the exponents of M and S; and all others are as defined above.

The priori expectation is that all the elasticity coefficients α , β , θ and ψ are expected to be positive.

Endogeneity bias

Many scholarly outputs in the global community of STIRPAT users have employed the STIRPAT model because it allows for unobserved and omitted variables which are constant over time but may be correlated with some of the explanatory variables, for example, the initial level of technological efficiency and the possibility of using several lags of the instruments to control endogeneity bias.

The STIRPAT permits GMM estimation of dynamic models. In addition, it also allows the use of fixed effects or random effects, generalised least square/feasible generalised least square (GLS/FGLS), panel corrected standard error (PCSE) estimation techniques, thereby paving way for the analysis of the impact on growth of the driving forces that change over time, as well as exacerbating measurement error (Sianesi and Reenen, 2002; Temple, 1999). Baltagi (2008), Hsiao (2003), and Wooldridge (2010), stated that in a general panel data analysis, we have:

$$y_{it} = \alpha_i^* + \beta_i x_{it} + e_{it} \quad i = 1, \dots, N \\ t = 1, \dots, T \quad (6)$$

Where x is a scalar exogenous variable ($k=1$), and e_{it} is the error term with mean zero and constant variance σ_u^2 . The parameters

α_i^* and β_i may be different from different cross-sectional units, although they stay constant over time. Following this assumption, a variety of sampling distributions may occur. According to Baltagi (2008) and Hsiao (2003), such sampling distributions can seriously mislead the least-squares regression of y_{it} on x_{it} when all NT are used to estimate the model:

$$y_{it} = \alpha^* + \beta x_{it} + e_{it} \quad i = 1, \dots, N, \\ t = 1, \dots, T, \quad (7)$$

With respect to equations 6 and 7, Hsiao (2003) considers the situation that the data are generated as in either of the two cases below:

Case 1: Heterogeneous intercept ($\alpha_i^* \neq \alpha_j^*$), homogeneous slope ($\beta_i = \beta_j$). The study maintains that in these cases, pooled regression ignoring heterogeneous intercepts should not be used, since the direction of the bias of the pooled slope estimates is different from that identified priori; 'it can go either way'.

Case 2: Heterogeneous intercepts and slopes ($\alpha_i^* \neq \alpha_j^*, \beta_i \neq \beta_j$). Hsiao (2003) and Wooldridge (2010) state that a straightforward pooling of all NT observations, assuming identical parameters for all cross-sectional units, would lead to nonsensical results because it would represent an average of coefficients that differ greatly across individuals.

Baltagi (2008), Hsiao (2003), and Wooldridge (2010) also consider the classic analysis of covariance procedures. In this case, the studies took into account the assumption that the parameters characterizing all temporal cross-sectional sample observations are identical, and examined a number of specifications which permits differences in behaviour across individuals as well as over time. For example, "a single-equation model with observations of y depending on a vector of characteristic X " stated as follows:

(i) When slope coefficients are constant, and the intercept varies over individuals, we have:

$$y_{it} = \alpha_i^* + \sum_{k=1}^K \beta_k x_{kit} + e_{it}, \quad i = 1, \dots, N, \\ t = 1, \dots, T, \quad (8)$$

(ii) When slope coefficients are constant, and the intercept varies over individuals and time, we have:

$$y_{it} = \alpha_{it}^* + \sum_{k=1}^K \beta_k x_{kit} + e_{it}, \quad i = 1, \dots, N, \\ t = 1, \dots, T, \quad (9)$$

(iii) When all coefficients vary over individuals, we have:

$$y_{it} = \alpha_i^* + \sum_{k=1}^K \beta_{ki} x_{kit} + e_{it}, \quad i = 1, \dots, N, \\ t = 1, \dots, T, \quad (10)$$

(iv) When all coefficients vary over time and individuals, we have:

$$y_{it} = \alpha_{it}^* + \sum_k \beta_{kit} x_{kit} + e_{it}, \quad i = 1, \dots, N, \\ t = 1, \dots, T, \quad (11)$$

In each of the above cases, the model is classified further, based on whether the coefficients are assumed to be random or fixed as in Baltagi (2008) and Hsiao (2003). Nerlove (2005); and Hsiao (2003) point out that models with constant slopes and variable intercepts such as Equations 8 and 9 are "most widely used when

analysing panel data because they provide simple yet reasonably general alternatives to the assumption that, the parameters take values common to all agents at all times".

Furthermore, the analysis of covariance basically tests two aspects of the estimated regression coefficients: the homogeneity of regression slope coefficients and the homogeneity of regression intercept coefficients. The procedures for testing these two cases are:

1. Test whether or not slopes and intercepts simultaneously are homogeneous among different individuals at different times.
2. Test whether or not the regression slopes collectively are the same.
3. Test whether or not the regression intercept are the same.

Inclusion of additional variables in STIRPAT model

Unlike the IPAT and ImpACT frameworks, the STIRPAT permits the researcher to introduce other predictors by entering them into the basic equation. However, York et al. (2003a) argue that caution is required to ensure that additional variables are conceptually consistent with the multiplicative specification of the model.

Furthermore, the inclusion of the other polynomial, or quadratic, or non-linear terms is theoretically appropriate, but it can make the straightforward interpretation of the elasticity coefficients cumbersome and complicated (York et al., 2003a). For example, all empirical evidence on the environmental Kuznets curve introduced the squared term of affluence (per capita GDP) that permits non-monotonic interaction between a predictor and impact. This is because the modernization economy perspective, political economy, and state of democracy theories argue in favour of other polynomial terms which impact on emissions, predict a non-monotonic linkage between impacts and economic development, and employ a quadratic version of appropriate per capita GDP or per capita GNP (Grossman and Krueger, 1995; Shi, 2003; York et al., 2003a). Thus, the instantaneous elasticity coefficient for any given value of a predictor can be estimated using the first partial derivative, with respect to the appropriate driver variable of the regression model.

Recent studies (York et al., 2003a) have included dummies as additional variables to examine environmental impacts as long as they are conceptually appropriate for the multiplicative specification of the STIRPAT model. However, there may be problems regarding social and political variables that contribute to the determination of impacts, for example, bad governance (corruption), political regime, culture, and so on. Nevertheless, the Transparency International (TI) has succeeded in providing numerical values (corruption perception index (CPI)) that can be used as a measure of bad governance (TI, 1995). Variables such as culture, type of political regime or democracy or socialist system of government are typically represented by nominal or ordinal measurements, and "are not conceptualized for multiplicative modes" (York et al., 2003a). When there is a nominal or ordinal factor with few categories, dummy coding is a simple matter: a series of dummy coded (0 and 1) variables can be employed. The study used the numerical values of corruption perception index provided by the TI as an indicator of the practice of corruption across African countries.

Decomposition of variables in STIRPAT model

York et al. (2003a) foreground the need to refine T , the technology, in our STIRPAT model. Technology comprises many factors that determine environmental impacts. York et al. (2003a) examines three main ways by which T can be utilized in the STIRPAT model.

Technology is interpreted as the antilog of the residual term in the STIRPAT model because the error term consists of all variables other than affluence and population. Technology can be decomposed or disaggregated by introducing new variables in the STIRPAT model, theorized to determine impact per unit of production. Previous studies (Shi, 2003; York et al., 2003a; Jorgenson, 2004; Jorgenson and Clark, 2013) support the idea that additional variables are vital for developing theory and for examining causal structures since, many social-ecological perspectives put forward social factors influencing impact. The ImPACT identity framework is also consistent with additional variables for consideration.

Apart from technology that is disaggregated, other variables can also be decomposed. The works of Shi (2003), Shi (2001), Cramer (1996, 1998), Dietz and Rosa (1994a), and York et al. (2003a) contended that the way a particular variable is decomposed and classified depends on conceptualization. The population as a driving force has also been disaggregated into number of households and average household size in investigating air quality impacts (Cramer, 1996, 1998; Croix and Gosseries, 2012; Cronshaw and Requate, 1997). Liddle and Lung (2010) also disaggregated population into age structure (20 to 34, 34 to 49, 50 to 64), and the estimated results show divergent anthropogenic impacts across age groups. York et al. (2003a) employed the percentage of the population in economically productive age categories as a driving force of carbon dioxide emission impacts. The York et al. (2003a) study considered the disaggregated population as a decomposition of the technology term since age structure was converted from the residual term into the explanatory variable, or the disaggregated population into population size and economically productive population. The benefit of the STIRPAT model is that it can be employed to investigate the components of the predictors (population, per capita GDP, technology, bad governance, openness of the economy) in other models than their original total forms.

FINDINGS

Impacts of net trade and population size on CO₂ emissions

The estimated results indicate that the average effect of net trade over CO₂ emissions, when the net trade changes across time and between countries increases by 1%, CO₂ emissions increases by about 1.02 and 2.24% for Lower Income Countries in Africa (LICA) and Lower Middle Income Countries in Africa (LMICA), respectively, when all other predictors are constant. This further suggests that CO₂ emission impacts rises more rapidly than the predictor. The average effect of population size over carbon dioxide emissions, when the population size changes across time and between countries increases by 1%, CO₂ emissions increases by about 0.74% for LICA, and reduces CO₂ emissions by about 0.51% for Upper Income Countries in Africa (UICA) respectively, holding all other predictors constant. A1 percentage point increase in manufacturing sector value added as a percentage of GDP, when the manufacturing sector changes across time and between countries, increases CO₂ emissions by about 0.21 and 0.45% for LICA and UICA respectively, when all the other predictors are

constant. A1 percentage point increase in services sector value added as a percentage of GDP, when the service sector changes across time and between countries, increase CO₂ emissions by about 0.44 and 0.38% for LICA and UICA respectively, when all other predictors are constant.

The findings suggest that the population size, manufacturing sector, services sector and net trade for LICA are statistically significant at 1, 10, 1 and 1% significance levels, respectively; LMICA suggests that the net trade is statistically significant at 1% significance level; and UICA shows that the population size, manufacturing sector and services sector are statistically significant at 1, 1 and 10% significance levels, respectively (Table 1).

Environmental Kuznets Curve (EKC) means that the interaction between economic development and environmental impacts may produce an inverted U-Shaped curve (York et al., 2003b). This implies that during the first stage of economic development, environmental impacts increases level-off and further, economic development takes place while environmental impacts reduces. This linkage between economic development and environmental impacts is known as the environmental Kuznets curve (EKC), named after economist Simon Kuznets.

DISCUSSION

In this study the magnitude impacts of net trade on carbon dioxide emissions, with other predictors (population size, final consumption expenditure, manufacturing sector and services sector value added as a component of GDP) were investigate, playing a moderating role. The main motivation is to test the validity of the world trade system perspective that it is spurious and misleading to rely on the evidence of the impacts a country generates within its borders, instead of taking a world-wide system analysis on the impacts. This means that, damage to the environment anywhere is damaging to the environment everywhere. The world-system theory laid emphasis on total impacts and not micro impacts. Our findings are closely related to the world system perspective and other literature that examined the causal impact of CO₂ emissions on net trade, established a clear association.

The empirical evidence suggests that net trade performs better in low income countries in Africa (LICA) and middle income countries in Africa (LIMCA), as both consistently positive indicating that net trade is a driver trigger and determinant of carbon dioxide emission loads. The relationship between net trade and carbon dioxide emissions with other predictors playing intervening roles in low income countries in Africa (LICA), middle income countries in Africa (LIMCA) and upper income countries in Africa (UICA) were investigate. The high income

Table 1. The impact of net trade and population size on CO₂ emissions.

Variable	LICA	LMICA	UICA
Intercept	-3.58*** (0.745)	0.876 (1.629)	-9.75*** (1.008)
ln(PS)	0.745*** (0.047)	-0.202 (0.155)	-.510*** (0.100)
ln(M)	0.216** (0.064)	-0.082 (0.124)	0.457*** (0.104)
ln(S)	0.447 *** (0.086)	-0.001 (0.238)	0.381 ** (0.121)
ln(FCEG)	-0.048 (0.027)	-0.058 (0.060)	-0.013 (0.011)
ln(NTA)	1.023*** (0.149)	2.240*** (0.388)	0.095 (0.080)
Sample	332	163	178

***P < 0.001; **P < 0.01; *P < 0.05. *The coefficients are asterisk according to their levels of significance (coefficient not asterisk are not significant), and the standard errors are in parenthesis. *Our dependent variable and all the explanatory variables are in logarithmic forms. *The GLS/FGLS indicates Generalized Least Squares/ Feasible Generalized Least Squares. * GDP is the Gross Domestic Product. * ln means natural logarithms. Baseline Model- Regress per capita CO₂ emissions- ln(I) on population Size- ln(PS), final consumption expenditure growth- ln(FCEG), manufacturing sector value added as a percent of GD- ln(M), services sector value added as percent of GDP- ln(S) and net trade ln(NTA). Dependent Variable: ln(I), GLS/FGLS.

countries in Africa (HICA) were excluded because Equatorial Guinea is the only country classified as HICA in the continent, and not suitable for a panel data analysis.

The coefficients for ln (NTA) have values greater than 1.0 because it shows it is statistically stronger and positive for LMICA than LICA and UICA. In other words, net trade (ln (NTA)) has stronger positive impacts on carbon dioxide emission loads in lower middle income countries than low income countries and upper income countries. It is a major driver-trigger of environmental impact for lower middle income countries than in low income countries and upper income countries.

The results of the international-emissions nexus analysis suggest that, there is evidence in our data to indicate that CO₂ emissions has statistically significant impact on net trade, population size, manufacturing sector and services sector. This implies that CO₂ emissions cause positive impacts in net trade intensity, when all other predictors are controlled. The final consumption expenditure is the only variable that has no statistically significant impact, and it cannot be used to explain CO₂ emission load. These findings confirm, support and reinforced the validity of the world system theory that international trade is indeed an important factor that has been neglected by some previous studies in the determinants of the concentration of carbon dioxide emissions in Africa at different income groupings.

Finally, it is suggested that the exchange of goods and services between African countries and the rest of the world should be conducted based on the international trade conventions to avoid a situation where African countries are used as a dumping ground for dirty goods. This is very crucial because the impact of net trade on CO₂ emissions is consistently positive in all the African countries at different income levels.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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