Journal of Agriculture & Forestry Research | JAFR |
Volume no.3, Issue no. 1, Year 2024
www.sarpo.net

Research Article Open access

Aboveground Biomass, Carbon Stock, and Stand Characteristics of Three Selected Riverine Reserved Forests in Sinnar State, Sudan

Nasreldin A. Gurashi[1]; Elmugheira M.I. Mohammed [2,3,*]; Sohad A. Fadlelmola[4]; Elmalih M.I. Mohammed[5], and Faisal I. Musa [6,7]

[1]*Department of Forestry, Faculty of Natural Resources and Environmental Studies, University of Sinnar, Sinnar, Sudan*

[2]*Department of Forest Management Science, Faculty of Forest Sciences and Technology, University of Gezira, Wad Medani, Sudan*

[3]*Department of Documentation and Publication, Deanship of Scientific Research and Innovation, University of Gezira, Wad Medani, Sudan*

[4]*Department of Forestry and Environment, Faculty of Forest Sciences and Technology, University of Gezira, Wad Medani, Sudan*

[5]*Freelance, Gedaref, Gedaref State, Sudan*

[6]*Department of Forestry, Faculty of Agriculture and Natural Resources, University of Blue Nile, Ad-Damazin, Sudan*

[7]*Department of Forestry, School of Earth Sciences and Natural Resources Management, Mizoram University, Aizawl, Mizoram, India*

Corresponding author: Elmugheira M.I. Mohammed

E-mail: elmugheira1984@gmail.com

ABSTRACT

This study aims to assess the aboveground biomass, carbon stock, and stand characteristics of the selected riverine forest reserve in Sinnar State toward the sustainable management of forest resources in Sudan. A total of 108 circular sample plots (0.1ha) were systematically established, and ANOVA was run for data analysis. The Geref sites illustrated the highest heights for all three forest reserves and the largest diameter at breast height (DBH) and volume for Abu-Geili and Ronga, with significant differences between the forests and across the sites. The tree density of the Karab sites in Abu-Geili for the trees of 14, 24 and 28 years were ten, nine, and three times that of the Kamrab reserve, respectively. The Ronga forest illustrated the highest aboveground biomass and carbon stock in the Karab and Geref sites compared to Abu-Geili and Kamrab ones, with significant differences between sites and reserves. The carbon stock shows a good correlation with DBH attaining the R2, F, and P values of 0.67, 545.7, and 0.0001, respectively. The study recommends that the biomass and carbon stocks of A. nilotica plantations occur North and south of Sinnar Dam can effectively predicted using DBH with R2 of ≤ 0.6. Moreover, a conservation plan is urgently needed to protect the trees growing in the Karab sites and the forest edges.

Keywords: Biomass; Carbon Stock; Ecosystem; Riverine Forest; Sustainability; Wood Density

• **Received:** 23.01.2024 • **Received in revised form:** 28.02.2024 • **Accepted:** 28.02.2024

To cite this article: Gurashi, N.A.; Mohammed, E.M.I.; Fadlelmola, S.A.; Mohammed, E.M.I.; Musa, F.I. Aboveground Biomass, Carbon Stock, and Stand Characteristics of Three Selected Riverine Reserved Forests in Sinnar State, Sudan *J. Agric. For. Res.*, 2024, 3(1), 13-21.

1. INTRODUCTION

Trees play a vital role in mitigating environmental carbon degradation's diverse effects and reducing global warming. Forests maintain over 86% of the terrestrial carbon stock on the earth through photosynthesis and store excess carbon as biomass (FAO, 2010; Bora et al. 2013). An accurate estimate of forest carbon storage separately for different stands of various localities is of great significance to the research on the productivity of terrestrial ecosystems (FAO, 2010; Bora et al. 2013). Therefore, the achievement that supports a country in enhancing the sustainable management of forest resources and makes possible calculations of biomass and carbon stock obeying international practices is of great significance (Ali et al. 2015; Hassan et al. 2022; Harouna, et al. 2023). Such functions and information are significant for conservation and management purposes, particularly for Sudan's riverine forests.

The riverine Acacia nilotica forests growing on flooded basins along the Blue and White Nile and their tributaries are alternating distributed on both sides of the banks. These forests are under management plans since 1935 (FAO, 2010). They form a unique forest ecosystem covering a vast area and are of economic importance for Sudan's economy and its nature conservation. The Acacia nilotica produces a valuable timber used for railway sleepers, boat building, furniture, constructions, and fuel wood, as well as protecting the Nile system, watershed, and soil against wind and water erosion (Ibrahim et al. 2018; Yousif et al. 2015). Forest managers are sometimes challenged by the task of transforming national-level goals into forest-level prescription, yet more difficulties are expected to arise from the fact that global emphasis on forest management planning is being based not only on timber production but also on values such as biodiversity conservation, carbon sequestration, wildlife and amenities (Elsiddig, 2002). One of the core riverine forests is the Sinnar Riverine Forest Reserves.

Sinnar State Forests contribute ecologically and economically to the local community's livelihoods and the national economy (Ibrahim et al. 2018; Yasin and Mulyana, 2022). Acacia nilotica trees are systematically planted in the reserved sites along the Blue Nile River (plantation forests) for different utilization purposes (Alzubair and Hamdan, 2020; Mohammed et al. 2022). Trees grow faster in locations with fertile soil and plenty of moisture and more slowly in rocky soil and drier climates (Ibrahim et al. 2015; Mohammed, 2019). Though various studies explored the influences of anthropogenic and environmental disturbances on the riverine forest populations, little is known about their growing biomass and carbon stock. Hence, the present study aims to assess the aboveground biomass, carbon stock, and stand characteristics of three selected riverine forest reserves in Sinnar State. The outcomes of this study will form the baseline information for the sustainable management of Sudan forest resources and conservation of vulnerable sites in Sinnar State and similar ecosystems.

2. MATERIAL AND METHODS

2.1. Study area

The study covered Abu-Geili, Ronga, and Kamrab Riverine Forest Reserves. They respectively occupy 338.94 ha, 93.5 ha, and 206.64 ha and lie between 32˚ 34′ and 13˚ 34′, 33˚ 34′ and 12˚ 14′, and 34˚ 15′ and 13˚ 01′ (Fig. 1). Topographically, most riverine forests are classified into Karab, Maya, and Geref sites with different soil types and compositions (Fig. 2). Karab site is characterized by sandy soil, while Maya and Geref have dark cracky clay and silt soil, respectively (Elsiddig, 2002).

2.2. Data collection

Data collection took place in 2023 using systematic sampling procedure and covered 108 sample plots with an area of 0.1 ha. The distance between each two adjacent inventory lines was 200m and 100m between sample plots. In each sample plot, tree growth variables like diameter at breast height (DBH) and the total height were measured using caliper and Suunto clinometers, respectively (Mohammed, et al. 2023).

2.3. Data analysis

The tree basal area, volume, aboveground biomass, and carbon were computed using the bellow functions as reported by references (Gurashi et al. 2023; Ibrahim et al. 2018; IPCC, 2006; Mohammed et al. 2022):

Basal Area (BA) = π*(DBH2 ÷ 4) ………………………… (1)

Volume (V) = BA*h*F………………………………………….(2)

Aboveground Biomass (AGB) = 0.0673 * (ρ * DBH2*h) 0.976 ……………….………………. (3)

Carbon stock (CS) = ABG*0.47 ……………………………. (4)

Where DBH, h, F, and ρ are diameter at breast height, total tree height, form factor, and wood density, respectively. = basal area (m2), 3.142 = a constant and D = dbh (m)

Analysis of variance (ANOVA) in SPSS was used for comparing the stand characteristics, biomass, and carbon stock within the sites and between the various forests. Moreover, linear regression, Tukey's, Games-Howell, Mann-Whitney test, and Spearman Rank Order Coefficient were run for correlation and significant differences check (Mohammed, et al. 2023).

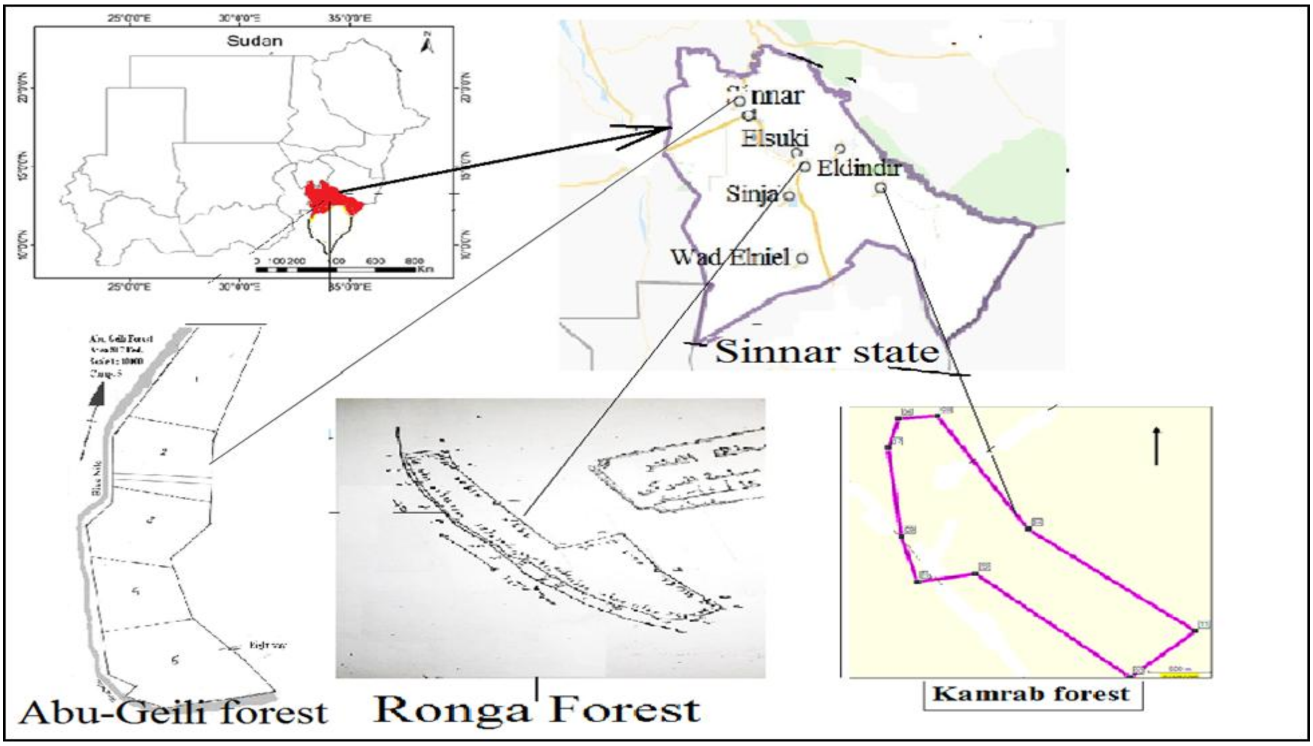

Figure 1: The study area map showing the Sudan and Sinnar State at the top and the Abu-Geili, Ronga, and Kamrab Forest Reserves at the bottom.

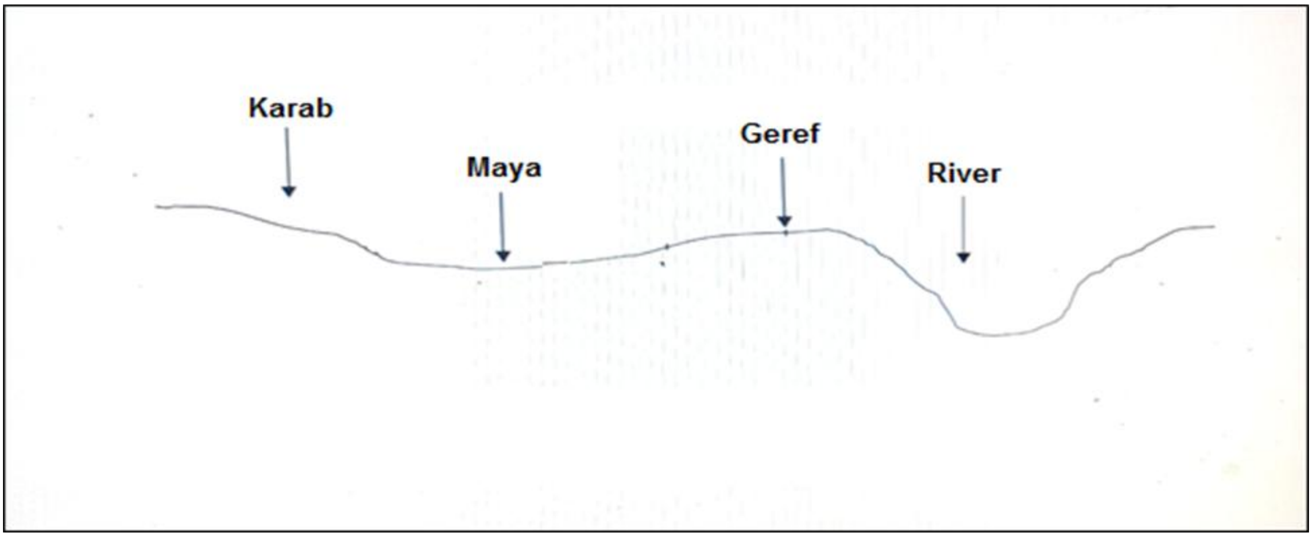

Figure 2: Graphic transect across a wander of the Blue Nile basin

3. RESULTS

3.1. Tree and stand characteristics

The Geref sites illustrated the highest heights for all three forest reserves and the largest diameter at breast height (DBH) and volume for Abu-Geili and Ronga, with significant differences between the forests and across the sites (Table 1). The mean stand density and height of the Kamrab forest were half that of Abu-Geili and Ronga, respectively (Table 2). Moreover, the Karab sites showed the highest basal area value across the three riverine reserves (Table 1).

Table 1: Tree age and mean diameter at breast height (DBH), height, basal area, and volume of *Acacia nilotica* assessed per site across the three-selected Riverine Forest Reserves

Forest	Site	Age (year)	DBH (cm)	Height (m)	Basal area (m^2/ha)	Volume (m^3/ha)
Abu-Geili	Geref	14	16.03	13.43	1.66	12.65
		24	22.37	16.65	3.20	27.70
		28	22.97	22.61	3.17	36.19
	Maya	14	20.93	14.03	2.77	21.80
		24	26.03	18.62	4.04	37.24
		28	19.68	12.20	2.38	16.40
	Karab	14	25.41	19.05	3.99	38.06
		24	20.68	15.54	2.97	22.06
		28	26.80	20.41	4.08	41.57
Ronga	Geref	14	31.98	20.51	5.79	59.87
		24	40.26	20.05	9.14	92.38
	Maya	14	24.14	18.01	3.46	33.34
		24	32.72	17.01	6.20	54.90
	Karab	14	30.30	20.90	5.30	55.59
		24	32.71	20.57	6.70	68.93
Kamrab	Maya	14	19.48	7.94	2.11	8.55
		24	33.59	9.84	6.28	31.75
		28	40.30	10.10	13.42	66.09
	Karab	14	18.39	8.56	1.88	7.88
		24	32.39	8.92	5.94	27.61
		28	40.05	10.25	13.29	66.64

Table 2: Mean stand density, diameter at breast height (DBH), height, and volume for Abu-Geili, Ronga, and Kamrab Riverine Reserved Forests

Forest	Sample Plots	Density (Tree/ha)	DBH (cm)	Total Tree Height (m)	Volume (m^3/ha)
Abu-Geili	28	165	21.1	16.04	28.19
Ronga	39	154	29.8	19.62	60.84
Kamrab	41	84	34.7	9.31	34.75

3.2. Aboveground biomass and carbon stock

The tree density of the Karab sites in Abu-Geili Riverine Forest Reserve for the trees of 14, 24, 28 years were ten, nine, and three times that of Kamrab Riverine Forest Reserve, respectively (Table 3). The Ronga forest illustrated the highest aboveground biomass and carbon stock in the Karab and Geref sites compared to Abu-Geili and Kamrab ones, with significant differences between sites and reserves

(Table 3). Similar pattern for carbon stock and basal area (Fig. 3).

Table 3: Tree age and mean density, aboveground biomass (AGB), and carbon of *Acacia nilotica* computed per site across the three-selected Riverine Forest Reserve

Forest	Sites	Age (year)	Density (Tree/ha)	AGB (Tone/ha)	Carbon stock (Tone/ha)
Abu-Geili	Geref	14	190	40.00	18.80
		24	143	87.49	41.12
		28	120	145.70	68.47
	Maya	14	175	63.92	30.04
		24	173	109.11	51.28
		28	101	40.46	19.02
	Karab	14	200	118.78	55.79
		24	180	35.29	16.58
		28	90	58.42	27.45
Ronga	Geref	14	150	161.71	76.00
		24	120	175.31	82.39
	Maya	14	90	121.3	57.04
		24	120	101.99	47.93
	Karab	14	165	155.34	73.01
		24	140	172.01	80.87
Kamrab	Maya	14	110	17.45	8.20
		24	100	27.15	12.76
		28	90	107.04	50.30
	Karab	14	20	17.63	8.28
		24	30	14.59	6.85
		28	30	61.04	28.68

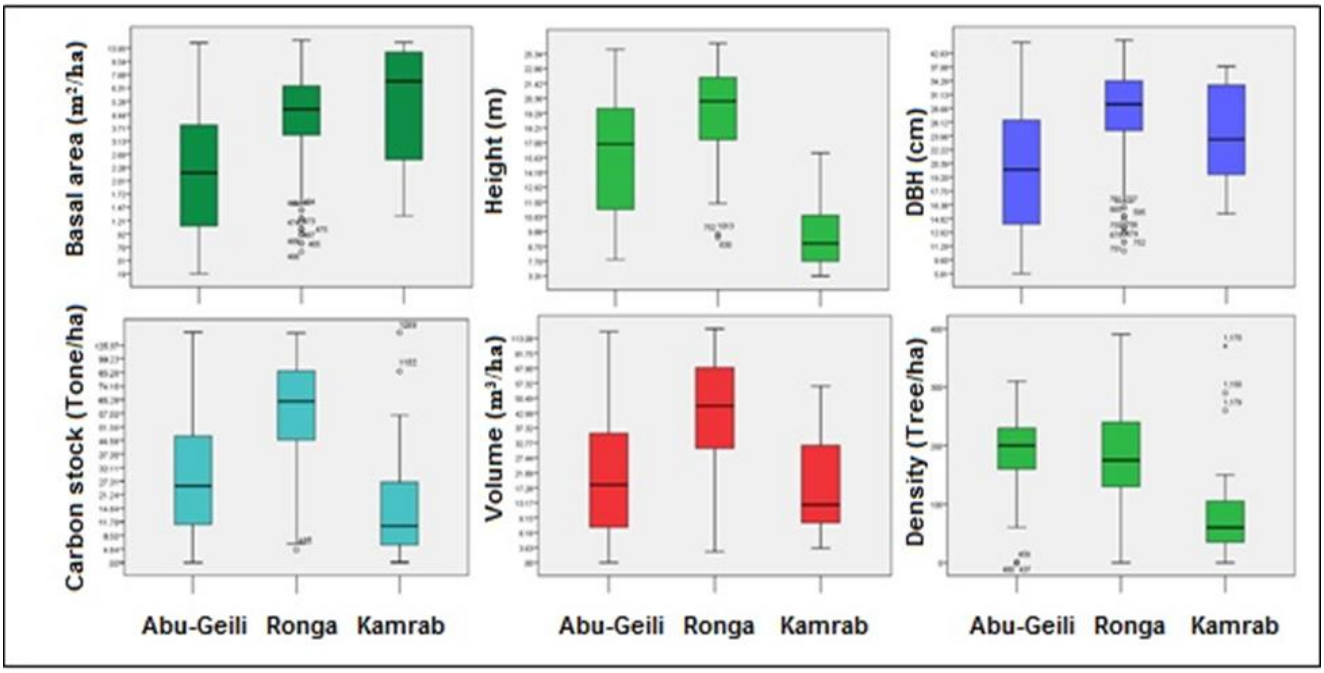

Figure 3: The vertical box plots of the mean diameter at breast height (DBH), height, Basal area, trees density, volume, and the carbon stocks across the various forest reserves of the study area.

3.3. Carbon stock and stand characteristics correlations

The carbon stock shows a good correlation with diameter at breast height (DBH) attaining the R2, F, and P values of 0.67, 545.7, and 0.0001, respectively (Table 4). All tested variables displayed significant differences with various Beta, F, P values, and fitness (Table 4). While the site variable (Geref, Maya, or Karab) illustrated a strong negative correlation with carbon stock, the other variables like volume, basal area, height, diameter at breast height (DBH), and age exhibited an opposite trend (Table 5).

Table 4. Summarized Regression values of the diameter at breast height (DBH), height, basal area, volume, and the hypothesis support for the carbon-stand characteristics regression

Hypothesis	Regression variable	Beta coefficient	R^2	F	P value	Hypothesis Supported
Is the tested variable significantly affects the carbon stock?	DBH (cm)	2.999	0.67	545.7	0.0001	Yes
	Height (m)	1.691	0.64	556.3	0.0001	Yes
	Basal area (m^2/ha)	1.043	0.60	483.2	0.0023	Yes
	Volume (m^3/ha)	0.760	0.55	522.4	0.0034	Yes

Table 5. Correlation Coefficients of the carbon stocks-stand characteristics regressions

Variables	Volume (m^3/ha)	Basal area (m^2/ha)	Height (m)	DBH (cm)	Sites	Forest	Age
Carbon (ton/ha)	0.770**	0.720**	0.650**	0.751**	-0.120	0.322**	0.330**
Volume (m^3/ha)	1	0.960**	0.609**	0.923**	-0.146**	0.354	0.361**
BA m^2/ha		1	0.456**	0.970**	-0.111**	0.365**	0.369
Height (m)			1	0.525**	-0.187**	0.255**	0.261**
DBH (cm)				1	-0.097**	0.423**	0.434**
Sites					1	0.152**	0.241**
Forest						1	0.910**
Age							1

DBH is the diameter at breast height of the adult tree measured at 1.3m aboveground level and ** indicate significant correlations at p <0.01 (Spearman's rank order correlation coefficients).

4. DISCUSSION

The tree growth variables and stand characteristics displayed significant differences between Abu-Geili, Ronga, and Kamrab Riverine Forest Reserves and within the reserve between Geref, Maya, and Karab sites. This variation is strongly supported by the site characteristics, disturbances, and the stage of stand development (Heshmati et al. 2018; Kutnar et al. 2019; Ligate et al. 2019; Yasin and Mulyana 2022). The high stand density in Geref site is an indicator for fertile soil, successful regeneration, young trees, and less disturbances. However, the lower tree height and density in the Karab sites is an evidence of stand degradation due to the frequent anthropogenic disturbances and the harsh site conditions such as soil moisture and other environmental factors. These findings are consistent with reference (Hassan, 2019; Hassan et al. 2022; Mohammed et al. 2022; Harouna et al. 2023). Moreover, the absence of large trees explain the presence of low basal area and volume, particularly for Geref and Maya in Abu-Geili and Ronga Riverine Forest Reserves. This result call for clear silvicultural operations, particularly regular thinning and pruning activities.

The aboveground biomass and carbon stock are directly associated with site quality and tree age with considerable variation between the Karab and Geref sites across the study area. Additionally, the continuous fluctuations in the dynamics of environmental factors and the intensive exploitation by the local communities can dramatically influence the forest core sites as well as the areas adjacent to the local settlement. Studies carried out by references (Benítez-Badillo et al. 2018; Chaudhary et al. 2016; Dimobe et al. 2019; Gebeyehu et al. 2019; Mohammed et al. 2021) documented that climate change, edaphic factors, and anthropogenic pressure disturbed the forest resources, increased the global worming phenomena, accelerated the natural habitat vulnerability, and amplified the biodiversity loss. However, for sustainable management of riverine forest resources, both stand composition characteristics and population resiliency limits, are essential pillars and corner stones. Therefore, the findings of this study are contributing positively and efficiently to the sustainability of Sudan forest resources and the similar environments at the regional and global levels.

Furthermore, the results suggest that carbon stock is largely controlled by growth variables such as diameter at breast height (DBH), height, basal area, and volume rather than other ecological conditions. The DBH predicted more than 60% of the aboveground carbon stock, which is a good outcome for both conservation policy formulation and management actionable plan. Likewise, carbon emission reduction, juvenile recruitment, and the stocking density enhancement are also achievable. These conclusions are in line with (Dai et al. 2014; Dimobe et al. 2019; Gurashi et al. 2023; Yasin and Mulyana 2022), who reported similar results. Moreover, the significant effects of mean DBH and height on carbon stock values and aboveground biomass show that changes in the ecosystem functions are mainly driven by these factors.

5. CONCLUSION AND RECOMMENDATIONS

The study revealed that the aboveground biomass and carbon stock are different from site to another, and effectively are influenced by tree growth variables and stand characteristics. The diameter at breast height (DBH) predicts more than 60% of the carbon stock with strong positive relationship and regression fitness. However, site type exhibited an inverse pattern with significant differences across the three-selected riverine reserves. The study recommends that the biomass and carbon stocks of Acacia nilotica plantations occurred North and south of Sinnar Dam can effectively predicted using tree and stand variables with R2 of ≤ 0.6. Moreover, conservation plan is urgently needed, particularly for tree species growing in the Karab sites and the forest edges. More researches are needed regarding the Acacia nilotica tending operations and their growth inhibitors.

ACKNOWLEDGMENTS

The authors are thankful to the staff of Forest National Corporation (FNC) in Sinnar State, with special thank to Abu-Geili, Ronga, and Kamrab Riverine Forest Reserves staffs.

REFERENCES

Ali, O.B.; Ibrahim, E.M.; Abdelmagid, T.D. Detection of Tree Species Dynamic Changes on Savannah Ecology through Diameter at Breast Height, Case Study Heglieg Area, Sudan. Journal of Natural Resources & Environmental Studies, 2015, 3(1), 24–30.

Alzubair, M.A.H.; Hamdan, S.A.M. Deterioration of Blue Nile Forests and its Ecological Effects in the Gezira State– Sudan. MOJ Ecology & Environmental Sciences, 2020, 5(1), 34–40. https://doi.org/10.15406/mojes.2020.05.00174.

Benítez-Badillo, G.; Lascurain-Rangel, M.; Álvarez-Palacios, J.L; Gómez-Díaz, J.A.; Avendaño-Reyes, S.; Dávalos-Sotelo, R.; López-Acosta, J.C. Influence of Land-use Changes (1993 and 2013) in the Distribution of Wild Edible Fruits from Veracruz (Mexico). Tropical Conservation Science, 2018,11, 1–11. https://doi.org/10.1177/1940082918758662

Bora, N.; Nath, A.J.; Das, A.K. Aboveground Biomass and Carbon Stocks of Tree Species in Tropical Forests of Cachar District, Assam, Northeast India. International Journal of Ecology and Environmental Sciences, 2013, 39(2), 97-106.

Chaudhary, A.; Burivalova, Z.; Koh, L.P.; Hellweg, S. Impact of Forest Management on Species Richness: Global Meta-Analysis And Economic Trade-Offs. Scientific Reports, 2016, 6(23954), 1–10. https://doi.org/10.1038/srep23954

Dai, Z.; Birdsey, R.A.; Johnson, K.D.; Dupuy, J.M.; Hernandez-Stefanoni, J.L.; Richardson, K. Modeling Carbon Stocks in A Secondary Tropical Dry Forest in the Yucatan Peninsula, Mexico. Water, Air, and Soil Pollution, 2014, 225(4), 1–15. https://doi.org/10.1007/s11270-014-1925-x

\Dimobe, K.; Kuyah, S.; Dabré, Z.; Ouédraogo, A.; Thiombiano, A. Diversity-Carbon Stock Relationship Across Vegetation Types in W National park in Burkina Faso. Forest Ecology and Management, 2019, 438(November 2018), 243–254. https://doi.org/10.1016/j.foreco.2019.02.027

Elsiddig, E.N.A. The Management of Acacia nilotica L. Plantations along the Blue Nile Flood Basins in Sudan for Sustainable Production: A Review. U. of K. Journal of Agricultural Science, 2002. 10(1),119 – 130.

FAO. Global Forest Resources Assessment 2010 – Main Report. FAO Forest Paper No. 163, Rome, Italy. 2010.

FAO. Final Report, Sudan National Forest Inventory. 2021.Web: www.fao.org/sudan.

Gebeyehu, G.; Soromessa, T.; Bekele, T.; Teketay, D. Species Composition, Stand Structure, and Regeneration Status of Tree Species in Dry Afromontane Forests of Awi Zone, Northwestern Ethiopia. Ecosystem Health and Sustainability, 2019, 5(1), 199–215. https://doi.org/10.1080/20964129.2019.1664938

Gurashi, N.A.; Mohammed, E.M.I.; Mohammed, E.M.I. Modeling Carbon Stock-Dendrometric Parameters Relationship and Tree Species Diversity in Abu-Gadaf Natural Forest Reserve, Sudan. Journal of Agriculture & Forestry Research, 2023, 2(6), 1–10.

Hassan, T.T. The use of Non-timber Forest Products as Potential Adaptation measures in the Sudan’s Forestry Sector. University of Bahri.. Unpublished PhD Thesis. 2019.

Hassan, T.T.; Mohammed, E.M.I.; Magid, T.D.A. Exploring the Current Status of Forest Stock in the Areas Bordering Dinder Biosphere Reserve, Sudan. Journal of Forestry and Natural Resources, 2022, 1(1), 11–24.

Heshmati, M.; Gheitury, M.; Hosseini, M. Effects of Runoff Harvesting through Semi-Circular Bund on Some Soil Characteristics. Global Journal of Environmental Science and Management, 2018, 4(2), 207–216. https://doi.org/10.22034/gjesm.2018.04.02.008

Ibrahim, Elmugheira, Paity, B.; Hassan, T.; Idris, E.; Yousif, T. Effect of Tree Species, Tree Variables and Topography on CO2 Concentration in Badous Riverine Forest Reserve – Blue Nile, Sudan, 2018, 5(1), 1–12.

Ibrahim, Elmugheira, Osman, E.; Idris, E.; Yousif, T. Linear and Non-Linear Regression Equations For Estimating The Crown Diameter of Three Sudanese Edible Trees. Journal of Forest Products & Industries, 2015, 4(2), 44–52.

IPCC, Guidelines for National Greenhouse Gas Inventories (Institute for Global Environmental Strategies), Japan, 2006.

Kutnar, L.; Nagel, T.A.; Kermavnar, J. Effects of Disturbance on Understory Vegetation Across Slovenian Forest Ecosystems. Forests, 2019, 10(11), 1–16. https://doi.org/10.3390/F10111048

Ligate, E.J.; Wu, C.; Chen, C. Investigation of Tropical Coastal Forest Regeneration After Farming and Livestock Grazing Exclusion. Journal of Forestry Research, 2019, 30(5), 1873–1884. https://doi.org/10.1007/s11676-018-0792-5

Mohammed, E.M.I. Impact of landuse Practices on the Natural Forest in Dinder Biosphere Reserve and it’s Surrounding Areas - Sudan. Unpublished PhD Thesis. University of Bahri., 2019.

Mohammed, E.M.I.; Hamid, E.A.M.; Ndakidemi, P.A.; Treydte, A.C. The Stocking Density and Regeneration Status of Balanites aegyptiaca in Dinder Biosphere Reserve, Sudan. Trees, Forests and People, 2022, 8(February), 1–8. https://doi.org/10.1016/j.tfp.2022.100259

Mohammed, E.M.I.; Hammed, A.M.E.; Minnick, T.J.; Ndakidemi, P.A.; Treydte, A.C. Livestock Browsing Threatens the Survival of Balanites aegyptiaca Seedlings and Saplings in Dinder Biosphere Reserve, Sudan. Journal of Sustainable Forestry, 2021, 00(00), 1–18. https://doi.org/10.1080/10549811.2021.1935279

Mohammed, E.M.I.; Harouna, D.V; Osman, E.H.; Mohammed, E.M.I.; Fadlelmola, S.A.A.. Causes and Consequences of Mother Tree Population Decline in Fazara Natural Forest Reserve , Sudan. Journal of Biodiversity and Environmental Sciences, 2023, 23(1), 189–209.

Mohammed, E.M.I.; Mohammed, E.M.I.; Gerbeel, B.A.A. Intensive Harvesting Menaces Trees Producing Fodder, Edible Fruit, And Gum in Abu Gadaf Natural Reserved Forest, Sudan. Journal of Ecology and Conservation, 2023, 1(1), 32–34. https://doi.org/10.61577/jec.2023.100002

Yasin, E. H.E.; Mulyana, B. Spatial Distribution of Tree Species Composition and Carbon Stock in Tozi Tropical Dry Forest, Sinnar State, Sudan. Biodiversitas, 2022, 23(5), 2359–2368. https://doi.org/10.13057/biodiv/d230513

Yousif, T.A.; Mohamed, A.R.A.; Ibrahim, E.M.; Ahmed, F.E. Causes of Bank Erosion of Wadi Kaja Basin - West Darfur State, Sudan. Journal of Natural Resources & Environmental Studies., 2015, 3(3), 1–8.