

Effectiveness of Chromated Copper Arsenate against Deteriorating Agents of *Eucalyptus* Poles and Posts in Four Eco-Regions in Kenya

Miriam Gathogo^{1*}, Evanson Omuse², George Muthike¹

¹Kenya Forestry Research Institute, Nairobi, Kenya

²International Centre of Insect Physiology and Ecology, Nairobi, Kenya

Email: *gathogomiriam@gmail.com

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Abstract

Previous studies done elsewhere have shown that *Eucalyptus* poles treated with chromated copper arsenate (CCA) can last over 30 years. Kenya is exceptional because in some eco-regions, the *Eucalyptus* poles' life span has greatly reduced to 5 years. The current study was designed to evaluate wood deteriorating agents of CCA-treated *Eucalyptus* poles and variability in four eco-regions of Kenya, namely, dryland, coastal, highland and humid lake. A total of 360 *Eucalyptus* pole samples were used for this experiment. Three CCA treatments were used to treat transmission poles at 20 kg/cm³ fencing posts samples at 6 kg/cm³, and a control group. Results indicated that termites and wood-decay fungi attacks caused wood deterioration in the four eco-regions. The proportion of power transmission pole degradation by wood deteriorating agents varied across eco-regions, between treatments and control and between time after treatments. Dryland eco-regions had the highest termite-related degradation (41.82%) while wood-decay fungi attack was highest in the highland eco-regions (9.20%). Samples treated with 6 kg/cm³ recorded the lowest level of wood deterioration, manifested by minimal superficial termite and wood-decay fungi attack. Samples treated with 20 kg/cm³ were characterized by moderate termite and wood-decay fungi attacks observed around the heartwood region, unlike sapwood. This study concluded that the deterioration of *Eucalyptus* CCA-treated poles is a question of climatic variability and hence, to increase the poles' lifespan, CCA treatment should be tailored according to the characteristics of the ecoregion of use. Further investigations will inform the diversity of termites and decay-fungi across different eco-regions.

Keywords

Wood Deteriorating Agents, CCA, Transmission Poles, Wood-Decay Fungi

1. Introduction

Wood is a natural, sustainable and organic composite characterized by its hygroscopic behaviour, orthotropic composition, and variable natural durability (Verbist et al., 2019). Recently, the use of wood has extended social interest, which has led to a global growth in its demand (Zhu et al., 2016). Hitherto, this demand is often more than not covered by the production of wood of low natural durability (due to biological deterioration). According to the European Standard EN 350 (CEN, 2015), wood durability is the “resistance of wood to destruction by wood-destroying organisms”. Wood durability can vary widely depending on the species, the age of the tree from which the wood was derived, the geographical site on which the tree is growing, and the tree growing conditions (Mazela & Popescu, 2017).

In Kenya, *Eucalyptus* wood is processed for sawn timber, used in building and construction and other secondary processed products like furniture. The species is also used for utility poles, which are largely absorbed in the electricity and telecommunication transmission industry. Other uses include fencing, palisade components, decking supports, railway sleepers, soil stabilization, soil terracing, and terrestrial and aquatic foundation pilings. All these uses expose wood to degradation agents at different levels, which then influences the level of durability of wood.

The use of wood is subsequently limited due to its susceptibility to wood-degrading organisms (Edlund & Nilsson, 1998). Decomposition of wood in terrestrial and marine environments, in general, involves many biotic agents including fungi, bacteria, insects, nematodes, molluscs, and crustaceans (Gelbrich, 2009; Marais et al., 2022). According to Juan and Rosana (2023), the main biological agents capable of reducing the structural integrity of wood are wood-decay fungi, saproxylic beetles and termites. Biotic degradation agents such as subterranean insects and marine borers occur overshadowing the effect of fungal and bacterial decay but are restricted in geographical spreading and aquatic submissions, respectively (Clausen, 2010).

The natural durability of wood is, therefore, key to the estimation of the service life of wooden products. The wood properties involved in natural durability relate to the structure of lignin in the cell wall, the anatomy of the xylem, nutrient availability, the quantity and composition of heartwood extractives, and the occurrence of moisture-regulating components (Juan & Rosana, 2023). For instance, the wood moisture content influences the establishment of wood-deteriorating organisms (Juan & Rosana, 2023) while high lignocellulosic substance makes the wood cell more resistant to deteriorating agents (Andlar et al., 2018). During cell wall invasion, wood-decay fungi combine both enzymatic and non-enzymatic mechanisms built on low-molecular-weight compounds. Often, the grabs of saproxylic beetles digest wood cell components, causing deterioration of the wooden structure (Juan & Rosana, 2023).

Insect and fungi survival rates are also directly affected by climate change,

which also affects the population of the bio-agents. Increasing winter temperatures in certain locations have been associated with changes in the occurrence and effects of a range of biotic agents because rates of overwinter survival may confine epidemics and breakouts (McAvoy et al., 2017; Martín & López, 2023). Apart from termites and fungi, the other economically important insects causing wood degradation include beetles (Coleoptera) in the families Cerambycidae, and Curculionidae (Ulyshen, 2016), termites in the families Kalotermitidae and Rhinotermitidae (Reinprecht et al., 2016) and carpenter bees (Sreedevi et al., 2022). Beetles and carpenter bees can bore large galleries in wood (Sreedevi et al., 2022). However, they normally attack debilitated or freshly felled trees and more rarely occur on wood in service (Rodríguez-Barreal, 1998). Attack by different wood deteriorating agents is illustrated in **Figure 1**.

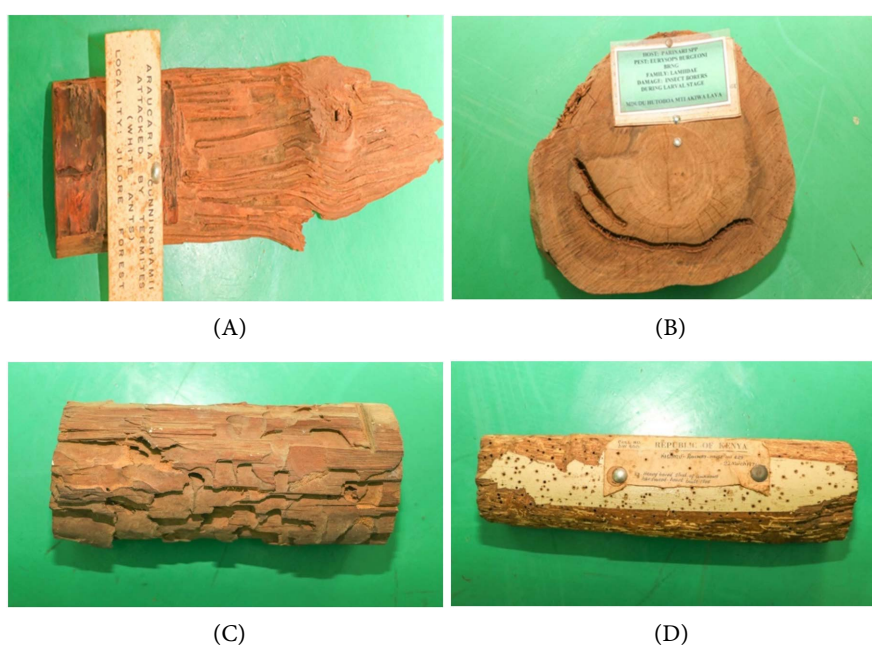


Figure 1. Impact of termites, beetles and wood borers on different species of wood. Courtesy of KEFRI Insect Reference collection.

Several bark beetles such as *Ips typographus* and *Dendroctonus ponderosae*, have been documented to have earlier emergences and prolonged flight season lengths in warming conditions (Bentz et al., 2019). The damage by the bark beetles on wood is demonstrated in **Figure 2**.

Treatment of wood with different preservatives is aimed at enhancing the durability of otherwise non-durable or less durable wood or parts of the wood. The most used preservatives in Kenya and to some extent in the East African region include water-based chromated copper arsenate (CCA) and oil-based creosote. CCA is usually formulated to contain 18.5% Copper (CuO), 47.5% Chromium (CrO₃), and 34.0% Arsenic (As₂O₅) compounds. These chemicals are pressure-impregnated into the wood targeted for outdoor purposes, to protect it from insects, borers and wood-deteriorating microbes including fungi. Copper

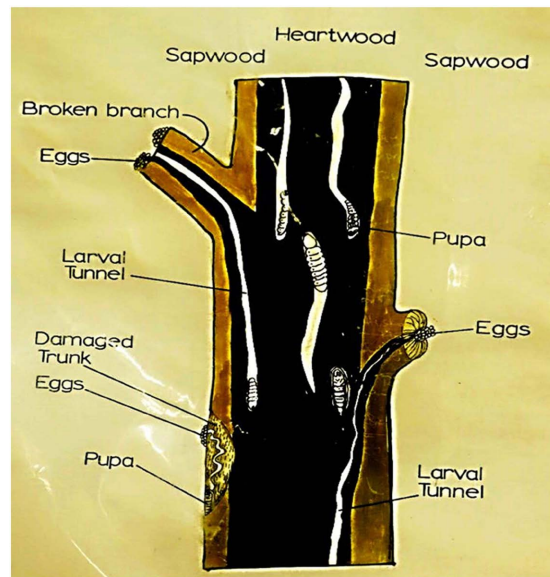


Figure 2. Illustration of damage to wood by bark beetles. Courtesy of KEFRI Insect Reference collection.

as a component in CCA protects wood against fungi and bacteria decay while arsenic is the insecticidal component, protecting wood from wood-deteriorating insects like termites and marine borers. Wood pressure treated with CCA wood preservative is commonly used for outdoor construction materials, transmission poles and fencing posts. Despite its potential against pests and microbes, the CCA efficacy may vary depending on the environmental conditions (temperature, precipitation) of the area from which the wood is sourced, the wood (tree species), and the wood type (heartwood or sapwood). Many wooden poles treated with wood preservatives have been observed to fail across eco-regions in Kenya and other regions possibly due to malpractices during pre-treatment and treatment procedures, in addition to a combination of abiotic and biotic factors responsible for decay (Muthike & Ali, 2021; Schultz et al., 2007). In high-humidity or rainy regions, a small percentage of CCA compounds may gradually be released by leaching and weathering (Williams et al., 2003). Release of these compounds can be minimized by applying finish to the surface of the treated wood, but little is known about how or to what degree finish properties affect the release of different preservatives (Hill, 2007).

The objective of this study was to provide information on the cause of lifespan reduction of CCA-treated *Eucalyptus* wood which has led to questioning the efficacy and quality of CCA preservatives, and variability in wood deteriorating agents in four eco-regions of the country.

2. Materials and Methods

2.1. Study Site

Eight sites were selected in the following distinct eco-regions (Figure 3). Wet highland regions were represented by Kenya Forest Service (KFS) Kericho Forest

Station and Kenya Forestry Research Institution (KEFRI) Londiani station; KEFRI Kibwezi-Kisayani station and KEFRI Garrissa station represented the hot and dry lowland eco-regions in Eastern Kenya; (Humid Lake regions were represented by KEFRI Migori and Maseno stations, while the humid coastal regions were represented by KEFRI Gede station and KFS Kwale station.

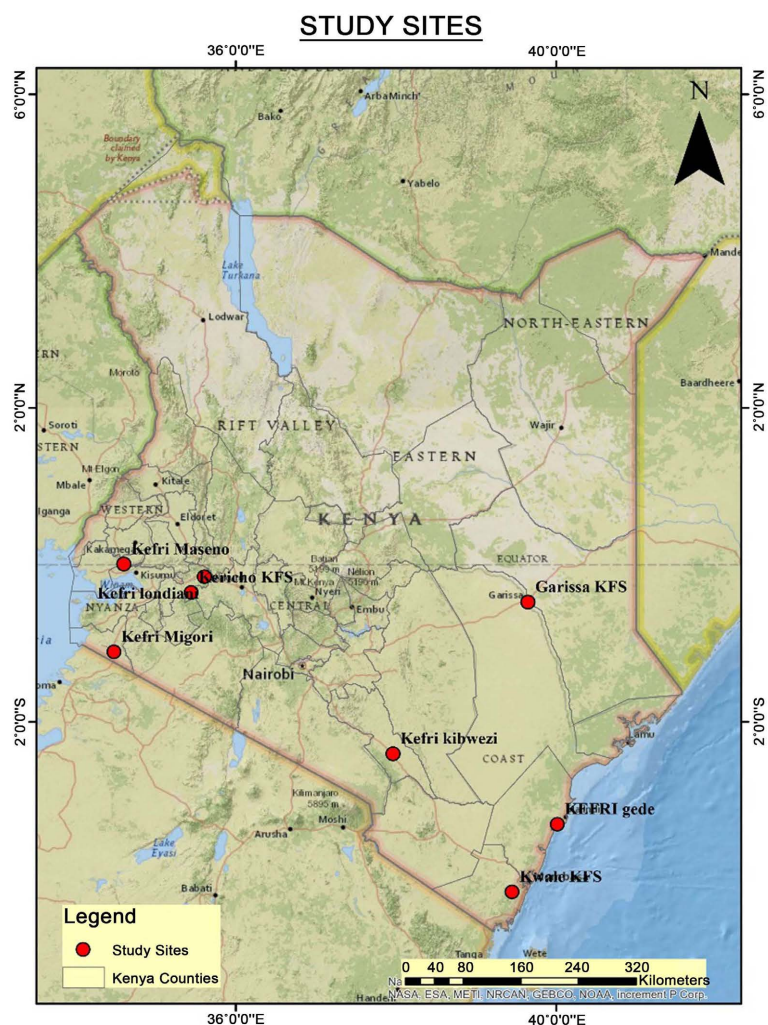


Figure 3. Kenya's map showing the study sites.

The four eco-regions have a variable average annual temperature, average annual rainfall and elevation in (Table 1) (<http://weatherpark.com/y/98118>).

Table 1. Study sites weather data during different assessment months.

Eco-region	Site	Month of assessment	Monthly average temperature (°C)	Monthly average rainfall (mm)	Altitude (masl)
Highland eco-regions	Kericho KFS Station	*May	17.0	125.7	2002
		**November	18.0	121.5	
	KEFRI Londiani	*May	16.0	125.7	2325
		**November	18.0	121.5	

Continued

Dryland eco-regions	KEFRI Kibwezi	*March	24.9	77.0	1020
		**November	23.5	117.5	
	KEFRI Garissa	*March	30.0	20.3	151
		**November	29.0	41.7	
Lake Basin eco-regions	KEFRI Migori	*May	20.0	89.1	1311
		**November	20.5	105.2	
	KEFRI Maseno	*May	22.0	142.2	1505
		**November	23.0	97.1	
Coastal eco-regions	KEFRI Gede	*March	29.0	15.0	20
		**November	27.0	23.8	
	Kwale KFS station	*March	28.0	21.7	412
		**November	27.0	24.1	

*First assessment, **Second assessment. The first assessment and second assessment were conducted five and twelve months after the installation of the graveyard experiments. Masl = metre above sea level.

2.2. Samples and Treatment Preparation

A total of 360 pieces of *Eucalyptus* pole samples were used for this experiment. The sample size was established using the following formula: 4 eco-regions \times 2 sites per eco-region \times 3 treatments (Control, 6 kg/cm³ CCA treatment; and 20 kg/cm³ CCA treatment) \times 15 wood samples (replications) per treatment = 360 pieces.

The samples used in the study were round fencing posts and splits from *Eucalyptus* power transmission poles. The CCA preservative was diluted into two different concentrations: 20 kg/cm³ (transmission poles treatment), and 6 kg/cm³ (fencing posts treatment). The third treatment (T3) was a control batch of splits of power transmission poles with untreated sapwood and heartwood portions.

The wood samples were air-dried and sawn at the KEFRI Karura workshop. Sawing of transmission pole samples was carried out using a narrow band saw (Wood mizer - LT 70) machine while fencing pole samples were sawn using the Circular Re-saw machine. The round posts were split into two halves exposing the heartwood portions. The transmission pole samples were split into eight pieces exposing the heartwood and CCA-engorged sapwood sections. The transmission poles for control treatment were split into eight pieces exposing untreated sapwood and heartwood. Samples measuring 600 mm long were prepared and used for the graveyard experiments.

2.3. Site Establishment

Measurements were taken using a field measuring tape to allow for a block, housing 3 equal plots, in every site. Staking was done to indicate the points of wood burying pits and the block diagonals. In every plot, 15 holes measuring 150

mm deep and 100 mm wide were pitted with a spacing of 2 m by 2 m between holes. A spacing of 3 m was allowed between the plots. Wood samples were inserted into the holes according to a randomized design developed in Genstatv.19 software and buried to 150 mm depth, exposing 450 mm above ground to allow for reading of labels. The poles were adjusted so that the labels faced the same direction for ease of identification during assessment.

2.4. Site Establishment

Visual observation method was used to assess the samples. The observation was made 5 months (or 7 months for some sites) and 12 months after treatment application and site establishment dates. The study was conducted from Month, Year through Month, Year. During each assessment period, all the wood samples were carefully pulled out of the pits and below-ground activity of wood deteriorating agents as manifested on the wood samples recorded in data sheets. After this observation, the samples were returned to the pits and the soil returned. Additionally, the GPS coordinates for each study site were recorded.

2.5. Site Establishment

Data entry was carried out in Microsoft Excel 2010 and analyzed using R Software Version 4.0.2 (R Core Team, 2022). Generalized linear model was used to assess any significant differences in the percentage of wood deterioration among treated wood samples and across Eco-regions. Mapping was done by using GPS location points of study sites from Handy GPS into Arc Map 1.0 of ArcGIS.

3. Results

3.1. Wood Deteriorating Agents

Termites and fungi were the main wood deteriorating agents in all eco-regions surveyed. Attack termites and fungi on the treated and control poles as observed in the field is illustrated in **Figure 4**.

Termites were also found in all the eco-regions with exception of highland eco-regions. Fungal attacks causing wood deterioration were observed in Highland and Lake eco-regions (**Table 2**). The Lake region and highlands ecoregion (only Kericho, except Londiani) had a combination of both termite and fungal attack.

3.2. Efficacy of Wood Preservative against Damage by Wood Deteriorating Agents in the Four Eco-Regions of Kenya

The proportion of fencing poles damaged by wood deteriorating agents after treatment with 6 kg/cm³ CCA varied across eco-regions ($\chi^2 = 174.99$, $df = 7$, $p < 0.0001$), between control and treatment ($\chi^2 = 127.35$, $df = 1$, $p < 0.0001$) and between time after treatments ($\chi^2 = 40.45$, $df = 1$, $p < 0.0001$). The damages by wood deteriorating agents were highest in coastal region (Gede and Kwale), Kibwezi (dryland eco-regions) and Maseno (lakeside eco-regions) (**Figure 5**).

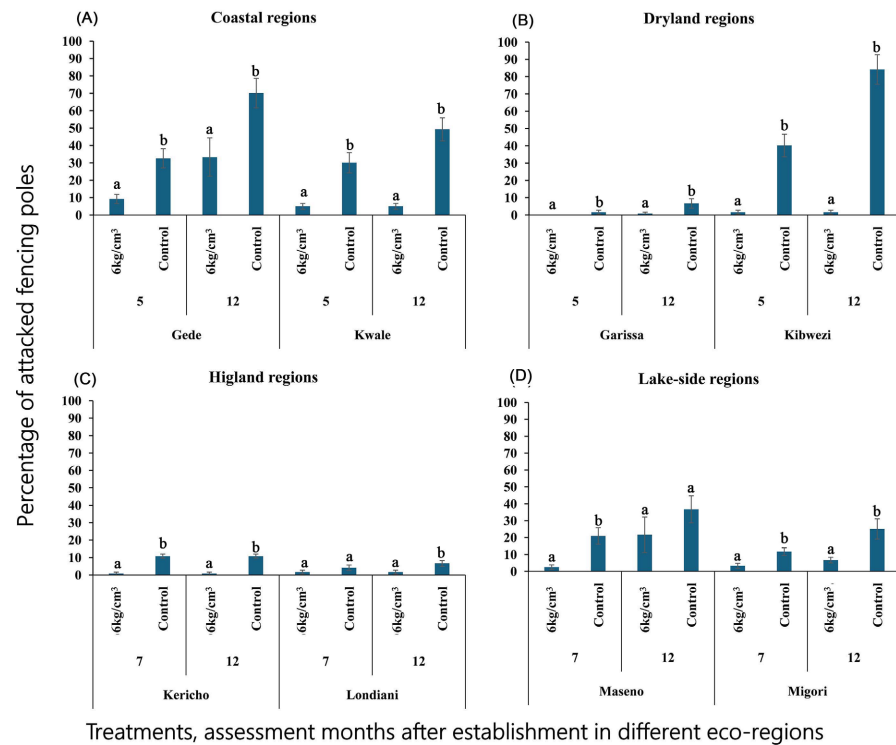


Figure 4. Illustration of observed damage caused by termites and fungi. 20 kg/cm³ water based chromated copper arsenate (CCA) treated sample assessment (A), termite activity on heartwood of a 20 kg/cm³ CCA treated sample (B), 20 kg/m³ CCA treated sample with a combination of fungal and termite activity (C), an attacked heartwood (HW) and an intact sapwood (SW) (D), an intact 6 kg/m³ CCA treated sample (E), a control group sample showing higher damage level.

Table 2. Proportion (%) of poles affected with wood deteriorating agents.

Ecoregion	Assessment site	Deteriorating agent	
		Termites	Fungi
Coast	Gede	100	–
	Kwale	100	–
Lake region	Migori	100	7
	Maseno	100	23
Dryland	Garissa	100	–
	Kibwezi	100	–
Highland	Kericho	17	87
	Londiani	–	100

En dash (–) indicates absence of wood deteriorating agent.



Treatments, assessment months after establishment in different eco-regions

Figure 5. Wood deterioration of fencing posts treated with 20 kg/m³ water based chromated copper arsenate across locations in four Kenya's eco-regions: coastal regions (A), dry land regions (B), highland regions (C) and lake-side regions (D).

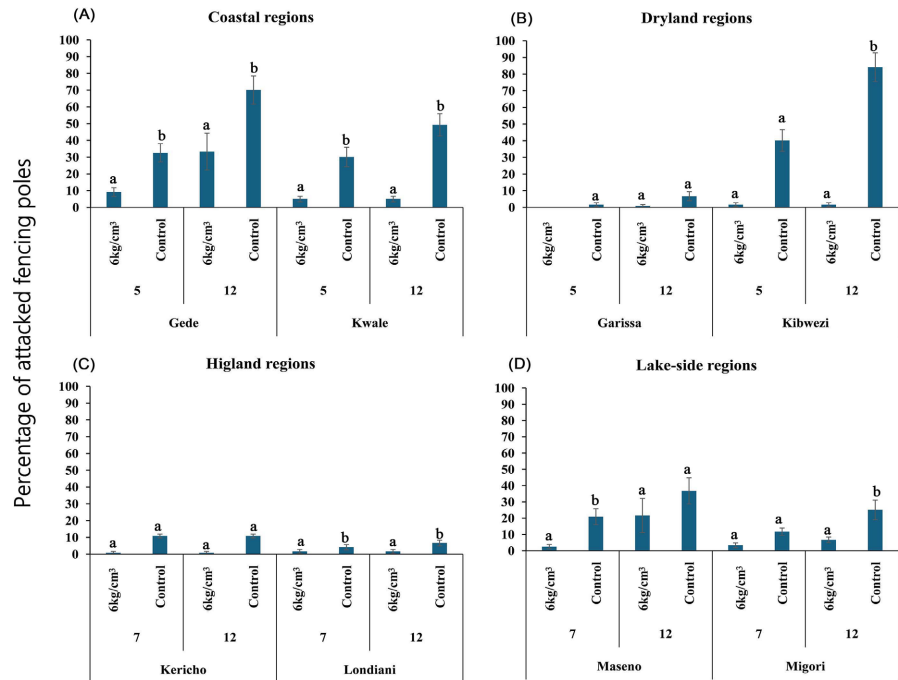
Likewise, the proportion of power transmission poles damaged by wood deteriorating agents after treatment with 20 kg/cm³ CCA varied across locations ($\chi^2 = 349.37$, $df = 7$, $p < 0.0001$), between treatment and control ($\chi^2 = 22.94$, $df = 1$, $p < 0.0001$) and between time after treatments ($\chi^2 = 56.44$, $df = 1$, $p < 0.0001$). The damage by deteriorating agents on transmission poles was highest in coastal eco-regions and lowest in highland eco-regions (Figure 6).

3.3. Trends in Damage by Different Wood Deterioration Agents

Deterioration was higher 12 months after treatment in samples treated with 20 kg/cm³ CCA. However, deterioration was only observed in the untreated portions of the wood, comprising of heartwood and some untreated parts of sapwood. Samples fully treated with 20 kg/cm³ and 6 kg/cm³ CCA remained intact. However, in Migori, Gede and Maseno the observation was different, where damage in samples treated with 6 kg/cm³ was observed (Figure 7).

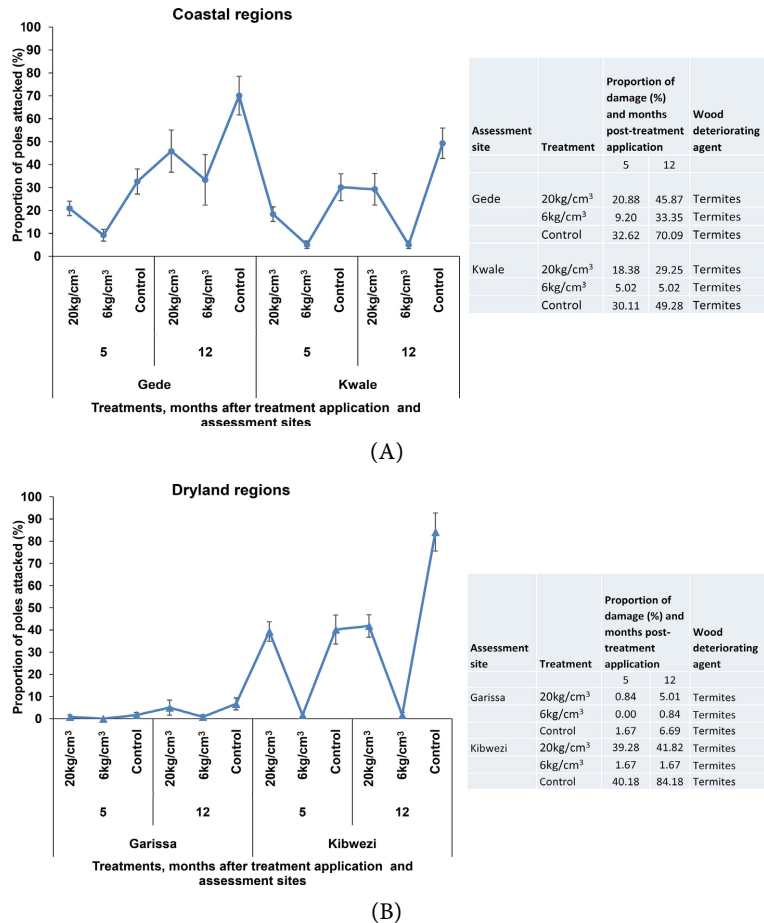
4. Discussion

Wood is susceptible to biotic and abiotic deteriorating agents. A high proportion of degradation was observed in dryland eco-regions. This degradation was isolated to the untreated parts of the treated wood and was highly attributed to termites and in some cases, fungi decay. These findings corroborate with other earlier studies where fungi decay and termites have been considered as major



Treatments, assessment months after establishment in different eco-regions

Figure 6. Wood deterioration of power transmission poles treated with 20 kg/cm³ water-based chromated copper arsenate in the four eco-regions of Kenya.



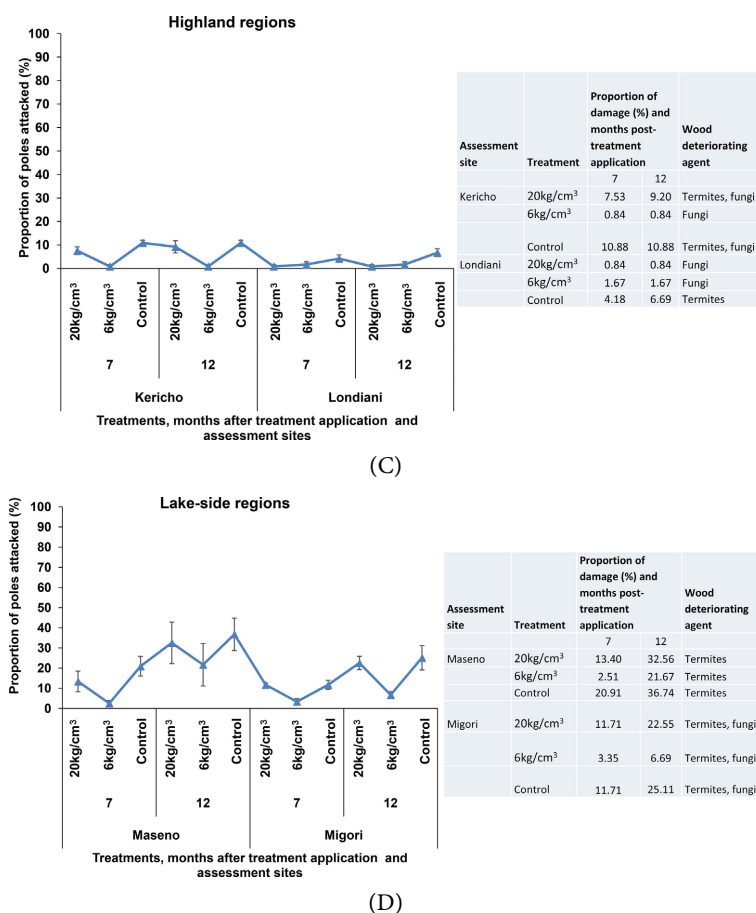


Figure 7. Trends in proportion of poles attacked under different treatments across the four eco-regions of Kenya.

bioagents involved in the decomposition of wooden poles (Martín & López, 2023; Liu et al., 2018).

Reportedly, climate conditions have a major influence on the biological disintegration of wood (Brischke & Thelandersson, 2014). Despite the influence of climate conditions, the nature of soil and microorganisms present in the matter pose a higher threat compared to climate conditions (Hietala et al., 2014). Temperature and precipitation are important climatic variables that can significantly influence the wood deteriorating agent community development, especially fungi and the decomposition of dead wood (Edman et al., 2021; Wijas et al., 2024). This study highlighted that termite diversity and fungal populations, and their abundance are influenced by temperature, elevation and rainfall. The percentage of attack and observed wood deteriorating agents (termites and fungi) showed variations across the eco-regions. This can be attributed to climatic variations of these eco-regions in terms of temperature and rainfall. For example, eco-regions such as highlands with high rainfall and low temperatures recorded significantly high damage instigated mainly by fungi while wood poles in coastal, lakeside and dryland regions characterized by low rainfall and high temperature were prone to termite attacks. This result corroborates the findings of Palin et al. (2011) who

identified Ascomycetes and Basidiomycetes as fungal classes predominantly causing decomposition on CCA-treated wood. Several other factors have been shown to influence wood degradation. For instance, [Chen and Olsen \(2016\)](#) have shown that some soil fungi are capable of modifying wood preservatives like CCA, hence, enabling secondary decomposition of wood by various organisms. Additionally, the complex mutualistic or parasitic influences with symbionts or natural enemies can regulate the populations of many insects and fungal flora in the soil ([Kandasamy et al., 2016](#)). Soil contact promotes fungal colonization due to the easy accessibility and greater moisture content of wood ([Schultz & Nicholas, 2002](#)), while heavy rainfalls or flooding, accompanied by elevated temperatures have been known to increase termite activity ([Oberst et al., 2019](#)).

Some termite activities were hidden, and some samples that were seemingly undamaged from external surface had massive termite attacks on the inside presenting completely worn-out wood on the above ground. This was an indication of dry-wood termites following their attack on already fungi-infested wood samples. Similar observations have been reported from other studies where attacks by termites were often discovered too late, leaving the outer wood surface intact while causing substantial destruction to the interior wood material ([Goodell, 2001](#); [Woodpress.com](#)).

Heartwood is found in the larger and established transmission poles and not easily in fencing posts. Reduced treatability in heartwood has been identified to cause reduced penetration and retention of preservatives. According to [Wang and De Groot \(1996\)](#), this can reduce the durability of heartwood compared to the treated sapwood. Coinciding results were obtained from this study, where termite attack was seen to manifest on heartwood compared to sapwood. The key wood properties involved in wood durability include the amount and composition of heartwood extractives, i.e., secondary low-molecular-weight organic compounds produced during heartwood development, though other factors such as the wood anatomy, density, lignin and moisture content are also intricate ([Martín & López, 2023](#)). The heartwood is considered more durable than the sapwood due to the higher concentration of toxic extractive compounds, such as alkaloids, phenols, and terpenes. In general, extractive content increases from the pith towards the outer heartwood and reaches a maximum at the transition zone between heartwood and sapwood; thus, as the tree ages, the extractive content increases ([Hillis, 2012](#)) and the decay susceptibility decreases ([Taylor et al., 2002](#)). This agrees with the results from this study where the fencing posts seemed more protected from wood deteriorating agents as manifested by minimal damage. Longitudinally, extractive concentration decreases with tree height. In many species, the outer heartwood at the base of the tree is the most resistant to decay ([Cornelissen et al., 2012](#)). This did not agree with the results from this study since in Kibwezi and Maseno sites, termites were imposing their attack on the untreated heartwood and in some cases on the transition region between heartwood and sapwood. [Wang and De Groot \(1996\)](#) highlighted that for species with naturally durable heartwood such as Cedars, treatment of

heartwood may not be critical. This is not the case for wood species with a less durable heartwood and treatment of heartwood is paramount for bridge construction.

The current study underlined that for effective wood treatment, the preservative must be able to penetrate the heartwood and the transition region, to ensure wood adequate wood durability. The premature failure of CCA-treated poles observed across climatic regions may be associated with poor quality of treatment, where the heartwood and the transition zone are not chemically impregnated (Lebow et al., 2003) and the heartwood may fail to provide effective durability due to the wood cells being immature (lacking full transformation into heartwood cells with enough extractives).

5. Conclusion

Termites and fungi were the main wood deteriorating agents of the utility wood poles. Termites were found in all the eco-regions with exception of highland eco-regions while fungal attacks were observed only in Highland and Lake eco-regions. This indicated that attacks by termites and wood rot fungi vary based on climatic conditions of the regions. The study highlights that the concentration of CCA is not a major factor influencing wood durability. The study, however, shows that the natural durability of *Eucalyptus* wood is questionable. To increase utility wood durability, treatment should target to include the heartwood part of the wood material, which was previously known to have natural durability, but seems to be prone to destruction. Further, treatment could be adjusted by the eco-region in which the poles or posts will be used. Wood species with lesser durable heartwood should be treated to the core to enhance wood durability. Higher pressure on such species is recommended during wood treatment for all uses. We recommend further studies to evaluate the mechanisms used by wood-deteriorating organisms, their ecology and mode of dispersion, as well as soil types and wood traits affecting durability of wood in service.

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Conflicts of Interest

The authors declare no conflicting interests regarding the publication of this manuscript.

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