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Assessment of factors contributing on early rotting of Chromated Copper Arsenate treated utility power distribution wood poles in Tanzania

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ABSTRACT

The study aimed to assess the factors contributing to the premature decay of Chromated Copper Arsenate (CCA) treated utility power distribution wooden poles in Tanzania. Deteriorated poles samples from various regions in Tanzania were analyzed using handheld X-ray spectrometry to quantify the retention of CCA preservative chemicals. The ages of these poles were estimated based on annual growth rings. The findings indicated that premature failure of CCA treated wooden poles is attributed to an imbalance in the chemical composition of the preservative solution. The study found that CuO retention in most samples ranged between 10-18 kg/m^3, significant lower that the 24 kg/m^3 minimum required by standards. Insufficient As_2O_5 levels and premature timber harvesting were also contributing factors. The study concluded that early decay of CCA treated wooden poles is multifactorial, with the primary cause identified as an inadequate ratio of chemical elements in the CCA compound. This imbalance is characterized by reduced levels of Copper and Arsenate and an elevated content of Chromium (a bonding agent), likely adjusted to balance the minimum retention values. Additionally, premature timber harvesting and treatment with high moisture content aggravate the degradation process. The study also highlights the need for stricter treatment protocols and suggests policy intervention to enhance pole durability. Implementing these changes could reduce TANESCO's annual expenditure on replacements, improve infrastructure reliability, and enhance worker safety. Further research is needed to assess alternative preservatives and examine the impact of environmental conditions on decay rates.

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INTRODUCTION

TANESCO generates 1,800MW (Installed Capacity) from mixed sources including Hydro, Natural gas and Diesel driven generators. The company transmits power through the National grid under 400 kV (Under construction), 220kV (3,340km), 132kV (2,063km) and 66kV (668km) on steel transmission poles and tower structures and distributes through 33kV, 11kV and 0.4/0.23kV on concrete, steel and treated wood poles. The species mainly used for utility poles in Tanzania are *Eucalyptus Saligna* and *Eucalyptus Grandis*, and the preservative used is Chromated Copper Arsenate (CCA).

For some years, TANESCO has been facing many challenges in the quality of the wood poles it procures. The life span on service of the poles it procures does not go beyond seven years on average while the standards (BS 1990: Wood Poles for Overhead Power and Telecommunication lines, BS 4072: Wood Poles Preservation using Copper/Chromium/Arsenic Composition (CCA) and BS 5666: Methods and Analysis of Wood Preservatives and Treated Timber) specifies up to forty (40) years' service life of CCA & Creosote treated wood poles. These factors have led to a situation where the replacement of decayed poles annually nearly equals the number of poles procured for new connections or constructions. Moreover, the rapid decay of these poles poses significant safety hazards to workers and the general public and contributes to frequent power outages (Salman et al., 2023).

To address these challenges, TANESCO has implemented several measures. These methods include conducting specialized training sessions for staff on wood poles inspection techniques and acquiring advanced inspection equipment such as digital moisture content meters and handheld X-ray spectrometers (TANESCO Annual Report, 2020). Despite TANESCO's efforts, premature decay remains a major issue. Previous studies have examined decay factors, but none have focused on Tanzania's unique environmental conditions.

An assessment conducted by Townsend and his colleagues (2003) suggested a bigger problem than a mere factor such as the leaching of heavy metals used in preservation and the effect of underground waters for early rotting of wooden CCA treated poles.

Moreover, most studies (Da Costa et al., 2022; Kertal et al., 2013, Lebow (2015) on CCA-treated poles focus on temperate climates. However, Tanzania's tropical climate, characterized by high humidity and termite prevalence, presents unique decay challenges that require further investigation.

Therefore, the purpose of this paper is to assess the causes of early rotting of utility wood poles which in turn results into many losses including production times, financial and operational aspects.

An overview on power distribution infrastructure and wood poles durability

As of 31st December 2019, distribution lines (33 kV, 11 kV and 0.4/0.23 kV) comprise 36,605 km for 33 kV, 6,460 km for 11 kV and 1,825,354 km for Low Voltage (0.4/0.23 kV) respectively. On average, TANESCO spends more than TZS. 70 Billion per year for the procurement of wooden poles for new distribution projects as well as the replacement of rotten poles.

In Tanzania, wood poles for distribution networks are predominantly made from *Eucalyptus* and *Pine*. *Pine*, categorized as a softwood, matures slowly and is favored for furniture and decorative structures due to its soft characteristics. Conversely, TANESCO commonly utilizes Eucalyptus species, such as *E. Saligna* and *E. Grandis*, are commonly used due to their straight growth, but their limited sapwood thickness affects preservative absorption. The durability of CCA-treated wooden poles is influenced by various factors, including tree growth and timber quality, harvesting methods affecting mechanical stability, pre-treatment processes and the choice of wood preservative (often CCA or Creosote). Other factors include transportation methods, installation techniques, and ongoing monitoring of pole performance on-site (Townsend et al., 2003).

Polyzois and Kell (2007) postulated that it is generally perceived that a high quality, correctly preservative treated wooden utility poles should have a service life of 40 years or more. Service life expectations of 40+ years hold for Southern USA and for regions of Australia where annual average temperatures are similar to Tanzania. However, issues with premature pole failure are common across the African continent, all of the utility's poles experience short life, even where pole quality and treatment standards are high. Key factors are elevated, decay rates due to climate, and termites' attacks on the core of the poles due to cracking. This can be a major issue with Eucalyptus species.

Generally, there are two major types of preservatives used in Tanzania for extension of wood poles service life. These are Creosote **(**Coal tar) which has been used since the year 1800's as heavy-duty wood preservatives. The other preservative method involves the application of Copper Chromium Arsenate (CCA), this is the typical chemical preservative which enhances the durability by preventing microbial decay. Poles are protected by Oxide formulation of CCA type C as recommended by the international standard whereby minimum recommended oxides proportional of the respective compounds in the treatment solutions (CCA) are CUO (18.5%), Cr_2O_3 (47.5%) and As_2O_5 (34%). CCA is a mixture of stable metallic oxides which, in contact with the wood cells, form insoluble precipitates in the wooden cell walls and when they become fixed in the wooden fibres, they do not migrate or evaporate. In addition, Morais et al., 2013, reported that there are three types of CCA compounds used in the treatment of wooden poles namely type A, B & C. These types differ from each other by their salt proportions in the preservative solution as follows; A: CUO (18%), Cr_2O_3 (65%) and As_2O_5 (17%), B: CUO (20%), Cr_2O_3 (35%) and As_2O_5 (45%)} and C: CUO (18.5%), Cr_2O_3 (47.5%) and As_2O_5 (34%). All poles under the study are treated by type C of CCA.

Mechanical failure of treated wooden poles due to temperature gradient

It is well established that the South West Highland Zone experiences consistently lower temperatures over extended periods. Throughout the research duration, an observed occurrence involves the transport of treated wooden poles to sites before achieving complete dryness. This phenomenon leads to significant cracking, thereby creating apertures from the sapwood to the heartwood of the wooden poles. Subsequently, these fissures facilitate termite infiltration, ultimately resulting in premature decay of the recently treated and installed wooden poles (Sharapov et al, 2020).

Existing literature predominantly explores factors associated with the decay of wooden poles, yet limited attention has been given to the influence of tropical climates on early decay phenomena. Tanzania's high humidity averaging 70-85% in coastal regions accelerates fungal decal. Additionally, termite activity is more aggressive than in temperate climates, leading to faster structural weakening.

This study focuses on the factors contributing to the premature decay of utility wooden poles in Tanzania.

MATERIALS AND METHODS

Materials

Sampling Approach

Rotten poles were collected from TANESCO regional sites in Tanzania. A purposive stratified sampling methods was used to ensure representation from regions with varying climate conditions and documented differences in pole decay prevalence, as reported in TANESCO maintenance records. The country was stratified by climate zone and decay zone and decay incidence, and at least 5 poles were purposively selected from each zone, resulting in a total of 49 samples. Within each region, sampling locations were chosen based on accessibility and the presence of visibly decayed poles, allowing for targeted comparison of decay characteristics across diverse environmental conditions.

Methods

Pre-treatment Process Assessment

A document review method was used to assess the conformity of TANESCO's wood pole pre-treatment practices with established specifications. Observation from the document review were triangulated with expert opinions and field reports to validate findings related to species mixing and drying-related defects.

CCA Retention: X-Ray Spectrometry Determination of CCA

Determination of CCA retention on the wood poles was done using Hand Held X-Ray spectrometer (X-Met 8000, Oxford Instruments, UK). The wooden density in the equipment was set at 600 kg/m^2. During testing with a Handheld X-ray Spectrometer, X-rays are emitted at a potential difference of 50 kV and interact with atoms primarily within the sapwood region of the wooden poles (Ruddick et al, 1993). The readings from the X-Ray were used to calculate the CCA retention and total CCA values using equations 1-4. During the assessment, 49 sample wooden poles were tested whereby Net CCA retention and other parametric values were taken at 5 different points around each sample from bottom to the top. It has to be noted that handheld X-Ray Spectrometer provide good estimates with reasonable accuracy and precision for field measurements but its accuracy might not be as high as laboratory-based methods. These expressions are used to calculate the percentage of oxides retained in the treated wood poles;

$$CuO = \frac{CuO}{CuO+Cr_2O_3+As_2O_5} * 100\% \qquad (1)$$

$$Cr_2O_3 = \frac{Cr_2O_3}{CuO+Cr_2O_3+As_2O_5} * 100\% \qquad (2)$$

$$As_2O_5 = \frac{As_2O_5}{CuO+Cr_2O_3+As_2O_5} * 100\% \qquad (3)$$

$$Retention\ at\ 600\ kg\ (NR600) = CuO + Cr_2O_3 + As_2O_5 * \frac{600}{100} \qquad (4)$$

In Tanzania, as in many other African countries, electric poles treated with copper, chromium, and arsenic (CCA) are often installed before the required fixation period has elapsed, leading to significant environmental and public health concerns. Data were grouped based on the age of poles at the time of harvesting and vis-a-vis years of service for ease presentation.

Pole Age Estimation

Pole age was estimated by counting annual growth rings from cross-sectional samples. This method was validated by cross-referencing installation records where available. For a subset of poles (n=10), estimated ages were compared with installation records provided by TANESCO to confirm accuracy. The average discrepancy between growth-ring estimation and recorded installation years was ±1.5 years.

Statistical Analysis

Statistical analysis was conducted using SPSS v26 to assess trends in CCA retention and decay rates. A one-way ANOVA was performed to compare retention levels across different pole age and pole age groups against CCA retention. Mean retention values are reported with 95% confidence intervals, and standard deviation is provided in all measurements.

Environmental Factors

Environmental data such as temperature and humidity for each sampling site were obtained from meteorological station nearest region.

RESULTS AND DISCUSSION

Pre-treatment Process

According to TANESCO specifications for wood poles in connection to the actual practice of pre-treatment processes, the assessment revealed that the processes are followed almost to the required level but the limitation is mixed species whereby drying characteristics varies hence causes cracking while seasoned at the same conditions.

Climatic Factors

Climatic conditions (temperature, humidity) for each sampling site for the past three years were extracted from meteorological station data from the nearest regional weather offices. Decay rates measured as the percentage loss in a cross sectional area were higher in regions with high relative humidity zones (>75% RH), averaging 18%±3.5% compared to 9% ± 2.2%, suggesting a strong interaction between environmental moisture and preservative leaching contributing to accelerated decay in more humid zones.

Net CCA retention

Available data has revealed that many wood poles contained Net CCA retention which is below the minimum specified in standard documents for wooden poles specifications (S11, rev. Oct 2017). The specification stipulates that the minimum allowable CCA net retention should be 24 kg/m^3 expected to result into the lifetime of the treated pole to be 40 years. However, most of the data indicated values between 10 to 18 kg/m^3 Figure 1.

From Figure 1, it is evident that the average Net CCA retention at 600 mass units of timber is predominantly lower than the targeted value, indicating inadequate retention of CCA in most of the 49 sampled wooden poles tested. Furthermore, it was observed that the Net CCA retention is not consistently uniform across all poles or points tested. Some poles exhibit levels below the minimum requirement, while a few surpass the targeted value, attributable to factors such as variations in sapwood thickness.

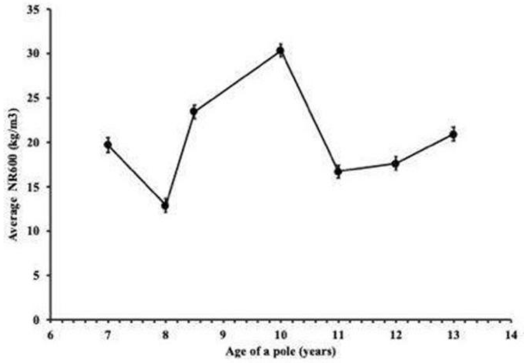

Figure 1: Net CCA retention vs. pole age at harvest (grouped data). Error bars show mean ± SD for 49 poles aged 7–13 years, with five measurements per pole.

Furthermore, the analysis of Average CCA Net retention in relation to the age of Eucalyptus timber reveals no significant direct dependency when isolated from other factors. Within the lower age bracket of 7-9 years, certain poles demonstrate Net CCA retention below the established standard value. Conversely, among poles aged between 10-15 years, there is a distribution where some exhibit Net CCA retention lower than the standard target value, while others surpass the minimum threshold.

Retention values among poles of identical age did not exhibit any discernible systematic trend, suggesting the influence of multiple factors on early decay phenomena consistent with what is reported by Valle et al 2013. Additionally, in the majority of points or samples tested, the standard deviation is less than one unit, indicating a relatively uniform distribution of CCA.

Compounds composition ratios in the CCA

Certain deteriorated poles exhibited elevated net CCA retention values exceeding the minimum requirement. Subsequent data analysis revealed discrepancies in the proportions of elements within the CCA preservative chemical. Specifically, it was observed that the concentrations of CuO, CrO_3, and As_2O_5 in the solution, even before application onto the wood, did not adhere to the balanced proportions stipulated for Type C preservatives. The standard composition of compounds in the CCA solution is shown in Table 1a. Based on the available standards, Table 1b displays the analytical composition of the solid, paste, liquid concentrate or treating solution forms of CCA preservatives.

Table 1a: Standard nominal reading of treating formulation in the CCA solution as per BS 4072, AWPA P5 and TANESCO specifications (S11) (Source: TANESCO)

TYPE		CuO (%)	CrO3 (%)	As2O5 (%)
CCA-C	Minimum	17	44.5	30
	Nominal	18.5	47.5	34
	Maximum	21	50.5	38

Table 1b: Compounds composition ratios in the CCA treating formulation (Tanalith – C)

TYPE	CuO (%)	CrO_3 (%)	As_2O_5 (%)	Cu:Cr:As Ratio
CCA-C	18.5	47.5	34.0	1:1.7:1.5

In the findings, it was noted that two compounds, CuO and As_2O_5, exhibited proportional reductions, deviating from the standard ratios specified in Table 1. The values for CuO in the retained CCA within the wood poles predominantly fell within the range of 7 kg/m^3 to 17 kg/m^3. The factors contributing to early decay are further elucidated as follows.

Reduced CuO and As_2O_5 balance in the preservative chemical

Figures 2(a) and 2(b) indicate that the majority of wooden poles exhibit average levels of CuO and As_2O_5 active elements that are below the standard target values, suggesting inadequate retention in most cases. This deficiency may be attributed to factors such as elevated moisture content, unmatured wooden poles and insufficient concentrations of these elements in the preservative chemical. Equally, CrO_3 levels are notably elevated across the samples tested.

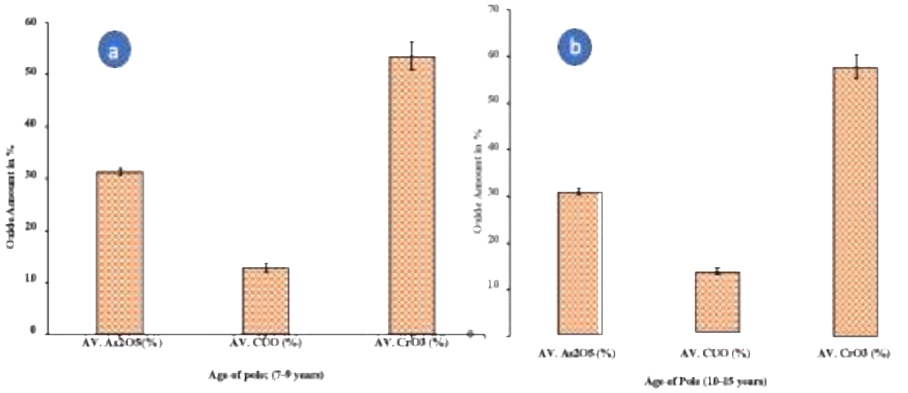

Figure 2: Retention levels of As_2O_5, CuO, and CrO_3 in poles harvested at ages (a) 7–9 and (b) 10–15. Error bars indicate mean ± SD for 19 poles (a) and 30 poles (b).

Copper acts as an antimicrobial agent, preventing fungal and bacterial degradation. Low CuO retention weakens this defense, allowing wood-decaying fungi to colonize the pole structure. Similarly, arsenic (As_2O_5) plays a crucial role in deterring termites, and its deficiency leads to increased termite penetration and internal damage.

It is envisaged, that the disproportionate amounts of CCA elements found in the samples could also be attributable to poles treaters not applying sufficiently long CCA fixation periods after the treatment process. The findings indicate that a significant portion of eucalyptus wood poles are being harvested prematurely, typically at an average age of 8 years, whereas the standard requirement stipulates a minimum age of 12 years. The age of the eucalyptus tree significantly influences its durability, even when adequately treated, due to several factors. Being inherently hardwood, eucalyptus wood consists mainly of heartwood, with only a thin layer of sapwood (approximately 20 mm thick at most). This heartwood, which does not readily absorb preservative chemicals, limits the effectiveness of treatment. Typically, the age of the timber is estimated by counting annual rings along the cross-section of the wood. Estimating the age of *Eucalyptus saligna* and *Eucalyptus grandis* by counting annual rings along the cross-section of the wood is a commonly used and reliable method, based on the principles of dendrochronology, the scientific study of tree rings. Each annual ring generally represents one year of growth, with variations in the ring's width often reflecting environmental factors like water availability, temperature, and soil nutrients. In temperate climates, the distinct annual growth cycles lead to clear demarcation of rings, making age determination straightforward. However, in tropical regions where eucalyptus species like *saligna* and *grandis* often grow, the clarity of these rings can be less distinct due to less pronounced seasonal changes. Despite these challenges, counting annual rings remains an effective technique for estimating age, as long as the rings are clear and the method is adapted to local growth conditions. Additionally, this technique provides valuable ecological and historical insights, as the variations in ring width can be analyzed to infer past climatic conditions and environmental changes (Speer, 2010; Schweingruber, 1996).

The low CCA retention found in many poles suggest insufficient absorption during treatment, making them more prone to decay. This implies that the current treatment process is not achieving adequate protection, requiring improved fixation periods and chemical formulation adjustment.

Figures 3 and 4 illustrate that, in the majority of wooden poles, the average CCA Net retention does not exhibit proportionality with the duration of service for the treated wooden poles. This discrepancy suggests inconsistencies in the treatment process of wooden poles. The CCA retention value demonstrates no significant correlation with either the age of the wooden poles or the duration of service prior to deterioration.

Furthermore, the results indicate that CCA distribution is not uniformly consistent, with values showing slight variation among samples. This variance can be attributed to the fact that not all deteriorated wooden poles originated from the same batch. It has been observed that the duration of service spans a wide range, as does the age of the wooden poles. However, if the poles were consistently treated and met the recommended age criteria, it is expected that both the duration of service and the net retention of CCA would exhibit a similar pattern.

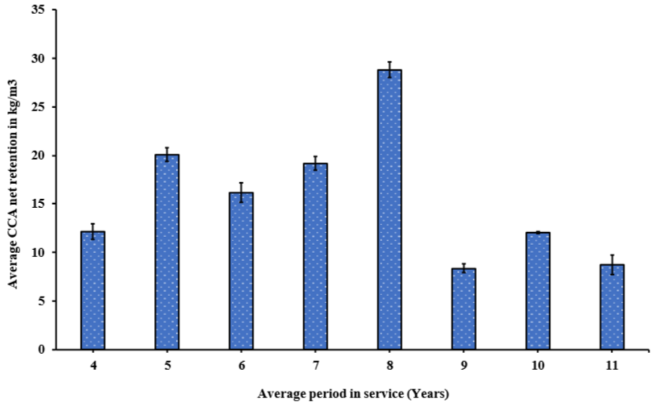

Figure 3: Percentage balance of CCA oxides vs. years in service for poles harvested at age 7–9. Error bars represent the mean ± SD for 19 poles.

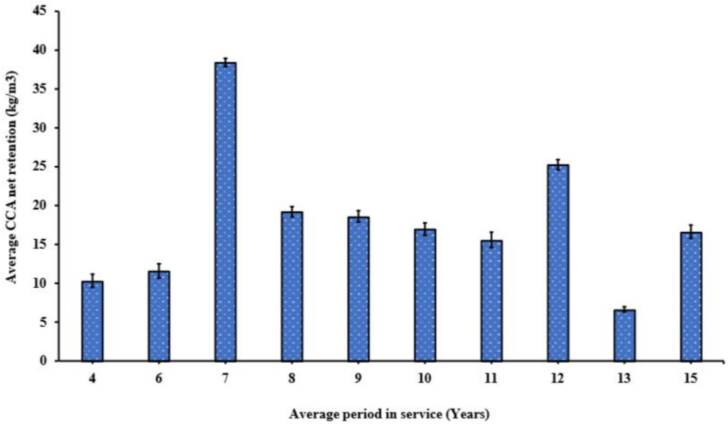

Figure 4: Percentage balance of CCA oxides vs. years in service for poles harvested at age 10–15. Error bars show mean ± SD for 30 poles.

Figures 3 and 4 illustrate that, in the majority of wooden poles, the average CCA Net retention does not exhibit proportionality with the duration of service for the treated wooden poles. This discrepancy suggests inconsistencies in the treatment process of wooden poles. The CCA retention value demonstrates no significant correlation with either the age of the wooden poles or the duration of service prior to deterioration. Furthermore, the results indicate that CCA distribution is not uniformly consistent, with values showing slight variation among samples. This variance can be attributed to the fact that not all deteriorated wooden poles originated from the same batch. It has been observed that the duration of service spans a wide range, as does the age of the wooden poles. However, if the poles were consistently treated and met the recommended age criteria, it is expected that both the duration of service and the net retention of CCA would exhibit a similar pattern.

Figure 3 reveals that poles aged 7-9 years exhibited CCA retention values relatively higher than the minimum standard values, in contrast to poles aged between 10 and 15 years. However, across sample poles of the same age, there was no discernible systematic trend in CCA retention values. This observation suggests that multiple factors influence early decay processes.

Figure 5 (a) and (b) illustrate that the average concentration of As2O5, an active oxide, in the majority of wooden poles across both age groups, closely approaches but remains slightly below the standard target values. This indicates effective retention within most wooden poles, albeit with a slight reduction over time. Conversely, the concentration of the preservative chemical CrO3 is significantly elevated above the threshold value.

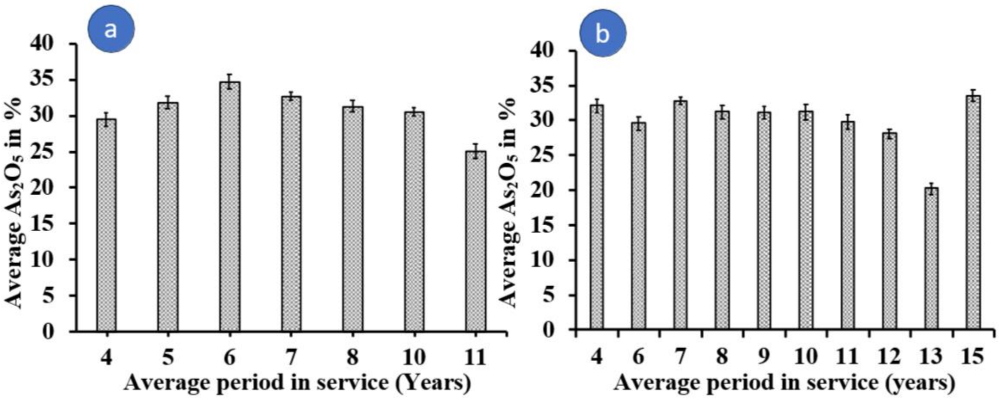

Figure 5: As_2O_5 percentage vs. years in service for poles harvested at ages (a) 7–9 (b) 10–15.

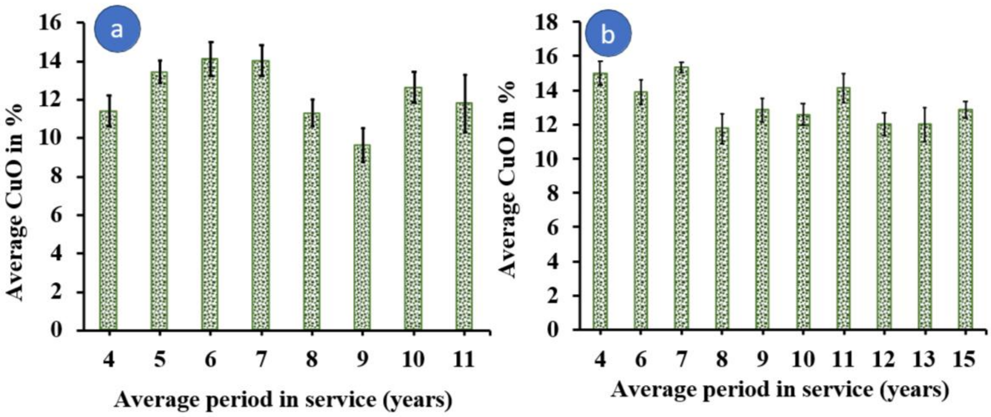

Figure 6: CuO percentage vs. years in service for poles harvested at ages (a) 7–9 (b) 10–15.

Figure 6 (a) and (b) depict that within the majority of wooden poles across both age categories, the average concentration of CuO, an active oxide, closely approximates but remains below the standard target values. This suggests adequate retention within most wooden poles, albeit with a slight decrease over time.

Similar to findings by Lebow (2015), our study confirms that CCA-treated poles in humid environments decay faster than expected due to preservative loss. Poles in high-humidity coastal areas exhibited faster decay rates, likely due to increased preservative leaching. Elevated moisture also promotes fungal colonization, further accelerating structural degradation. Unlike previous studies, this research demonstrates that premature harvesting and excessive moisture during treatment further exacerbate decay, indicating the need for a more holistic quality control approach.

Figures 7 (a) and (b) reveal that across the majority of wooden poles within both age cohorts, the average concentration of CrO_3, an active oxide, exceeds the standard target values. This indicates robust retention within most wooden poles. The deliberate elevation of CrO_3 concentrations above the threshold serves to strategically complement other oxides, which may be more economically costly.

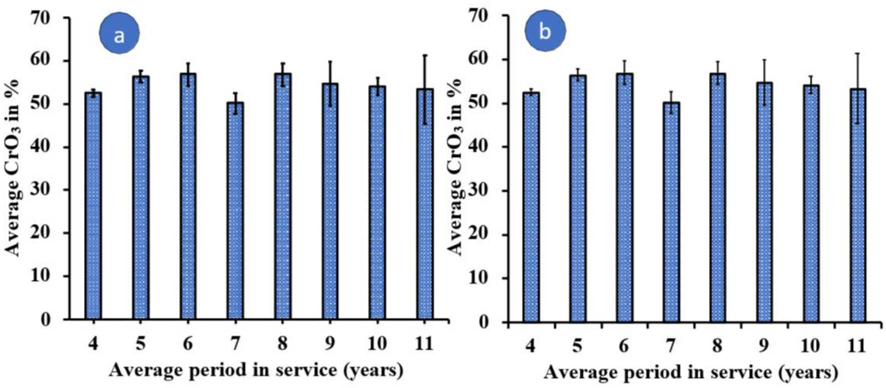

Figure 7: CrO_3 percentage vs. years in service for poles harvested at ages (a) 7–9 and (b) 10–15.

a) Rotten CCA Treated Wooden Pole due to Termite Attack

b) Longitudinal cracking of wooden poles already installed mainly due to temperature gradient

c) Failed CCA Treated Wooden Pole due to Premature Age of the Timber

d) Decayed CCA Treated wooden Pole at Kimara District due to Fungi Attack

Figure 8: Pictorial presentation of different reasons for early rotting of CCA treated wooden poles in Tanzania.

Figure 8 presents visual documentation illustrating contributing factors to the premature decay observed in CCA (chromated copper arsenate) treated wooden poles in Tanzania. These images were captured from samples comparable to those subjected to analyses of CCA chemical retention and estimated pole age.

This observation aligns with findings reported in studies by Choi et al. (2016) and Morais et al., (2013), detailed the impact of environmental conditions on the degradation of CCA-treated wood. Additionally, Johnston and her colleagues (2016) investigated the role of microbial activity in accelerating the decay of wooden structures. These studies provide valuable insights into the mechanisms underlying the early deterioration of CCA-treated wooden poles. Low retention CCA and imbalance proportional of oxides were some of the contributing factors for early decay. Specifically, Figure 8d illustrates the soft rot in the outer zone of a CCA-treated pole, which unequivocally indicates improper treatment. This could be due to preservative retention significantly below the required standard or insufficient fixation of the CCA elements. Inadequate fixation leads to the detoxification of the wood through the leaching of unfixed CCA elements during service in soil. It is noteworthy that such leaching may also have removed arsenic from the outer zone of the pole in Figure 8a. Arsenic leaches more rapidly than copper, which in turn leaches more rapidly than chromium, increasing the wood's susceptibility to termite attack, as observed.

On the other hand, the treatment of eucalyptus species for various uses, particularly in the timber industry, poses significant challenges due to their inherent properties. Eucalyptus wood is known for its high density and interlocked grain, which contribute to its strength but also complicate its treatability. The primary difficulty in treating eucalyptus wood lies in its low permeability, making it resistant to preservative treatments that are crucial for extending the wood's lifespan and enhancing its durability (Shupe et al., 2020). Among the various species, *Eucalyptus globulus* and *Eucalyptus grandis* exhibit notable differences in treatability. Eucalyptus globulus, commonly known as the Tasmanian blue gum, has been extensively studied and is generally found to be more resistant to preservative penetration due to its denser structure and higher extractive content (Tjeerdsma & Militz, 2018). In contrast, *Eucalyptus grandis*, or the rose gum, tends to be more amenable to treatment, as it has a relatively more open cell structure and lower extractive content, which facilitates better penetration of preservatives (Barrio et al., 2021). These treatability differences are crucial for industrial applications, as they influence the selection process for specific purposes, such as construction, furniture making, or paper production. Understanding the anatomical and chemical characteristics that affect treatability is essential for optimizing treatment processes and improving the utility of these species (Santos et al., 2019). Continued research into the specific factors influencing treatability can lead to improved treatment methods, enhancing the economic and functional viability of Eucalyptus wood.

Statistical Analysis

A one-way ANOVA revealed a statistically significant difference in CCA retention across sampled poles age groups, 7-9 and 10-15 ages with ($F = 12.87$, $p = 0.001$). Since $p<0.05$, the difference in Net CCA retention between the two age groups is statistically significant. This suggest that pole age has a significant effect on how well CCA is retained.

CONCLUSIONS AND RECOMMENDATIONS

The study concludes that the premature decay of CCA-treated wooden poles is attributed to several factors evaluated within this investigation. Key aspects encompass CCA retention levels, and the age of the timber, all of which influence its susceptibility to degradation from various environmental stressors. A significant contributing factor appears to be the imbalance in the chemical composition of the CCA compound, highlighting the critical importance of precise chemical formulations in preserving the structural integrity of treated wood products.

The imbalance in the oxide ratio within chromated copper arsenate (CCA) treatment leads to premature deterioration of wooden poles, thereby incurring significant costs for the distribution company. Such imbalance undermines the reliability of electricity supply, posing substantial risks to infrastructure resilience and operational continuity. It underscores the critical importance of maintaining precise oxide ratios in CCA treatment processes to ensure the structural integrity and longevity of wooden poles, thereby safeguarding the reliability of electricity distribution networks.

Moreover, the observed imbalance may be attributable to the incomplete fixation of CCA elements, resulting from insufficient fixation periods. During the proper fixation process, chromium acts as a mordant, covalently bonding to the lignin in the wood. Subsequently, copper and arsenic bond to the fixed chromium, as they cannot bond directly to the wood elements. The duration required for complete fixation of these elements typically spans around a month, varying with environmental conditions. However, if poles are planted before fixation is complete, a common occurrence in many countries, the covalent bonding of chromium to the wood may be incomplete. Consequently, not all copper and arsenic may bond to the chromium. In such cases, the unfixed copper and arsenic would rapidly leach out if the poles are placed in wet soil, disproportionately in relation to the originally present chromium. This leaching detoxifies the wood, potentially causing early decay, as observed.

The research findings indicate that utility companies should not solely rely on net retention value as the primary parameter for accepting poles deliveries or supplies. Instead, the individual oxide contents serve as crucial indicators, providing insight into whether the oxide ratios have been adequately met, thereby signifying the appropriate treatment of wooden poles. A comprehensive assessment of individual oxide concentrations is essential for ensuring the efficacy and longevity of treated wooden poles in utility applications.

Recommendations

It is recommended that in order to ensure the durability and structural integrity of CCA-treated wooden poles, it is essential to implement a series of standardized procedures across the production and treatment process.

To enhance objectivity and consistency, third-party inspections should be incorporated into the procurement process, utilizing calibrated handheld X-ray fluorescence (XRF) analyzers to perform on-site chemical verification of treated poles prior to deployment.

While concrete poles present a durable alternative, they have higher upfront costs and logistical challenges in rural areas due to weight and transport limitations. However, their life cycle cost may be lower over a 40–50-year service span due to minimal maintenance. It is recommended that future studies should incorporate direct measurement of termite activity and soil conditions to better understanding their role in decay.

Conflict of Interest

The authors hereby declare that there are no conflicts of interest related to the content of this article.

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