



The Influence of Artisanal and Small-Scale Gold Mining on Tree Species within the Bukombe-Mbogwe Forest Reserve, Mbogwe District, Tanzania

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Abstract: Bukombe-Mbogwe Forest Reserve (BMFR) has witnessed a consistent decline in its tree species, a phenomenon exacerbated by the presence of Artisanal and Small-scale Gold Mining (ASGM) activities in the district. This research sought to comprehensively investigate the variations in tree species within the forest reserve and the neighbouring villages attributable to ASGM operations. A total of 138 participants were selected through random sampling, consisting of 120 individuals who responded to a questionnaire survey and 18 participants who engaged in key informant interviews. The study employed a multi-method approach, incorporating participant observations, three focus group discussions (representing each village), and thorough literature reviews. Qualitative data underwent content analysis, while descriptive analysis was employed for quantitative data, with Microsoft Excel utilized for data presentation. The findings unequivocally indicate a decline in the abundance of forest tree species after the initiation of ASGM activities. The *Pterocarpus chrysotrix* (Mkurungu) species is on the brink of extinction, closely followed by the *Brachystegia microphylla* (Mgela) and *Afzella quenzensis* (Mkora) species. Alarming findings reveal that environmental training remains woefully inadequate, with 78% of respondents attesting to a lack of training, while only 22% reported receiving some form of training. Equally concerning is the inefficacy of mine closure plans, with a mere 1.7% possessing restoration strategies, 24.1% intending to undertake tree planting initiatives, and a staggering 74.2% having no concrete plans in place. In light of these dire outcomes, it is apparent that ASGM activities have cast a deleterious impact on the preservation of forest tree species within the BMFR. Urgent measures are imperative to bolster protection against human incursions into the BMFR, fostering an environment conducive to natural regeneration. Moreover, the establishment of a comprehensive environmental management plan tailored to the BMFR is an indispensable requisite to mitigate the adverse effects of ASGM and restore the balance of this vital ecosystem.

Keywords: Bukombe-Mbogwe forest reserve, artisanal and small-scale gold mining, tree species decline, restoration strategies, ecosystem restoration, biodiversity conservation

1. Background Information

Artisanal and Small-scale Gold Mining (ASGM) is a mining approach characterized by its reliance on limited capital investment, utilization of rudimentary technological tools, and the prevalence of substandard working conditions, resulting in modest gold production (Mutagwaba *et al.*, 2018). This practice is predominantly embraced by rural community residents, nomadic populations, and farmers, driven by the aspiration for rapid wealth accumulation. ASGM plays a pivotal role in bolstering foreign exchange earnings and generating employment opportunities (G'afurovich *et al.*, 2020; Asare *et al.*, 2022). However, despite these advantages, the practice is marred by compromised living conditions within mining sites and their adjacent regions (Umirzoqov, 2020).

Globally, ASGM engages approximately 40.5 million men and women, with over 150 million individuals depending on it for their livelihoods. This trend is attributed to the escalating value of gold and the escalating challenges associated with alternative means of sustaining livelihoods (Hentschel *et al.*, 2002). The demand for timber logs during mining operations has prompted the encroachment and exploitation of nearby forests, mirroring the situation in Peru (Diringer *et al.*, 2019). Consequently, deforestation rates within forest reserves have surged, leading to a decline in tree species abundance and compromising carbon sequestration, as observed in Amazonian forests (Espejo *et al.*, 2018).

While ASGM yields economic growth and improved living standards in Africa, it concurrently imposes negative



environmental repercussions due to miners' heightened focus on gold recovery rather than environmental preservation (Adesipo *et al.*, 2020). Around 54 million people depend on ASGM activities for their livelihoods, particularly in rural contexts, where it assumes a rush-type nature (Hilson, 2016). In regions such as Congo, Ghana, and Nigeria, despite being formally licensed, artisanal miners are implicated in the exploitation of forest tree species required for mining operations, intensifying ecological concerns (Adesipo *et al.*, 2020; Akomaning *et al.*, 2021; Girmay, 2018; Nkubai *et al.*, 2019; Takyi, 2021).

The legal recognition of artisanal and small-scale gold mining through mining licenses issued to individual entities has contributed positively to government revenue through taxation in Tanzania (Kinyondo and Huggins, 2020; Machacek, 2019; Mtasigazyza, 2021). In communities where ASGM is conducted, a notable transformation often occurs, with farmers transitioning to miners (Britwum, 2022). This demographic shift results in an upsurge in the human population within and around mining sites, prompting the extraction of nearby forest tree species to meet the demands of mining activities. Consequently, this contributes to the degradation of forest reserves, akin to the scenario in North Mara (Massay and Kassile, 2019). The process of gold extraction leads to the removal of forest tree species to access gold and utilize its resources. However, attempts at restoration through reforestation and afforestation as a response to mining-induced degradation have proven ineffective due to severe environmental damage (Roman-Danobeytia *et al.*, 2021).

The degradation of the Bukombe-Mbogwe Forest Reserve (BMFR) has been exacerbated by the presence of ASGM activities within the Mbogwe District. This phenomenon has caused a noticeable decline in the diversity of tree species within the forest reserve. The demand for timber logs for pit construction in mining areas around Mbogwe District, as well as in other districts within the Geita Region, has propelled deforestation rates. In the early 1980s, Resolute Mining Limited from Australia, focused primarily on gold recovery rather than environmental conservation, owned the mine sites. Trees were solely sourced from BMFR for pit construction and timber, predominantly at the Nyakafulu mine site, until the late 1990s (Michael, 2019). The subsequent introduction of *Eucalyptus paniculata* aimed to supplement the diminishing endogenous tree species from BMFR. After 2016, Tanzanians assumed ownership of gold mining sites, leading to escalated rates of environmental degradation, driven by the widespread desire to establish pits for gold extraction. This heightened degradation caused a significant decrease in the tree species population within the forest reserve (Sophia *et al.*, 2018).

The overarching objective of this study was to comprehensively examine the intricate interplay between

artisanal and small-scale gold mining activities and tree species within the Bukombe-Mbogwe Forest Reserve. Specifically, this study meant to assess the status of indigenous forest tree species subsequent to the initiation of ASGM, appraise the accessibility of environmental training during ASGM operations, and scrutinize post-mine closure strategies. By delving into these facets, the study endeavors to enhance our understanding of the multifaceted ecological ramifications of ASGM within the Bukombe-Mbogwe Forest Reserve, ultimately guiding sustainable resource management and conservation endeavors.

2.0 Theoretical and Conceptual Frameworks

2.1 Theoretical framework

The theoretical underpinning of this research draws upon two foundational concepts: Conservation Theory and Disturbance Theory. Conservation Theory, propounded by Gifford Pinchot, emphasizes the ethical stewardship of natural resources. Pinchot advocates for the prudent and sustainable utilization of Earth's resources to ensure both present and future generations benefit. Central to this theory is the notion that public land use should not be entirely restricted but rather focused on responsible resource management. Pinchot's stance discourages exploitative practices, emphasizing the preservation of resources for posterity. However, the theory faced critique from Muir, who asserted that human intervention could potentially compromise the nation's landscape. Muir advocated a stance of complete avoidance of human activities in conservation areas. In the context of this study, human survival necessitates limited access to conserved resources, as individuals extend into restricted zones, thereby tapping into forest tree resources. The growing demand for gold emerges as a significant threat to the Bukombe-Mbogwe Forest Reserve (BMFR) and its surrounding villages, thereby warranting examination.

Disturbance Theory revolves around the critical role of natural biodiversity in sustaining life on Earth, even as it contends with the impediments posed by human endeavors. Extensive discussions have explored the dynamics of forest ecosystems undergoing various disturbances (Turner *et al.*, 1993). These disturbances have manifested as temporal and spatial shifts in the composition of naturally occurring vegetation across diverse communities. The intervention of human activities disrupts these ecosystems, raising concerns about the vulnerability of certain species to extinction. Although the rejuvenation of natural biodiversity is expected, excessive disturbance may surpass its capacity for renewal, thereby triggering global apprehension.

In essence, these theoretical frameworks offer lenses through which to comprehend the intricate interplay between human activities, particularly artisanal and small-scale gold mining, and the tree species within the Bukombe-Mbogwe Forest Reserve. Conservation Theory underscores the imperative of balancing resource utilization with preservation, as societal

needs press against ecological integrity. Conversely, Disturbance Theory accentuates the fragility of biodiversity in the face of human-induced disruptions, signaling the necessity of informed conservation strategies. By embracing these ecological perspectives, this study endeavors to illuminate the nuanced implications of artisanal gold mining on tree species, thus contributing to a more holistic understanding of sustainable resource management and environmental safeguarding.

2.2 Conceptual Framework: Unveiling Dynamics of Influences

The conceptual framework elucidates the intricate interplay among various components, with background variables anchoring the left, independent variables occupying the middle, and the dependent variable poised on the right (Figure 1). Within this framework, hypotheses revolve around an array of individual characteristics, encompassing age, education, employment, economic status, and technological practices deployed in Artisanal and Small-Scale Gold Mining (ASGM), all of which potentially shape the conservation of tree species. Age, as an indicator of knowledge, maturity, and experience, assumes a pivotal role in influencing attitudes towards conservation. Economic status stands as a testament to potential wealth accumulation through mining activities. Education reflects an individual's capacity to engage with diverse sources of information and innovation. Employment signifies a gateway to diverse activities and resource access, consequently exerting variegated impacts on tree species conservation in the Bukombe-Mbogwe Forest Reserve (BMFR) and its environs. The outcomes of these influences encompass a spectrum, manifesting as either augmenting or diminishing impacts on tree species conservation, predicated on positive or negative outcome results. These independent variables collectively wield sway over the trajectory of tree species conservation, thereby serving as the focal point of investigation.

The study delves into the temporal dynamics of tree species presence within the study area subsequent to the onset of ASGM activities. By scrutinizing variations over time, the research unearths tree species that have faced endangerment or extinction since the advent of ASGM. The absence of endangered species attributed to ASGM activity implies a favorable impact on tree species conservation within the study area. Conversely, the presence of endangered or near-extinct tree species signals a deleterious influence stemming from ASGM.

The strategies harnessed during ASGM operations wield significant leverage on tree species conservation, inducing both augmentation and depletion. Key among these strategies is the provision of environmental training, measures enacted post-tree harvesting, and the allocation of tailings disposal areas. The implementation of these strategies reflects a proactive approach to tree species preservation. Conversely,

their absence underscores a dearth of concerted efforts toward conservation within the study area.

The post-mine closure plans emerge as a vital barometer of environmental conscientiousness vis-à-vis tree species conservation within the study area. The presence of plans, encompassing tree planting and restoration initiatives, signifies a positive imprint of ASGM on the preservation of tree species. Conversely, the absence of such plans serves as a red flag, suggesting a lackluster commitment to the conservation of tree species as an aftermath of ASGM activities.

In essence, this conceptual framework serves as a compass guiding the exploration of intricate dynamics between the multifaceted variables and their collective impact on tree species conservation within the context of ASGM in the Bukombe-Mbogwe Forest Reserve. Through its lenses, this study endeavors to uncover the nuanced interconnections that shape the intricate relationship between human activities, environmental sustainability, and tree species preservation.

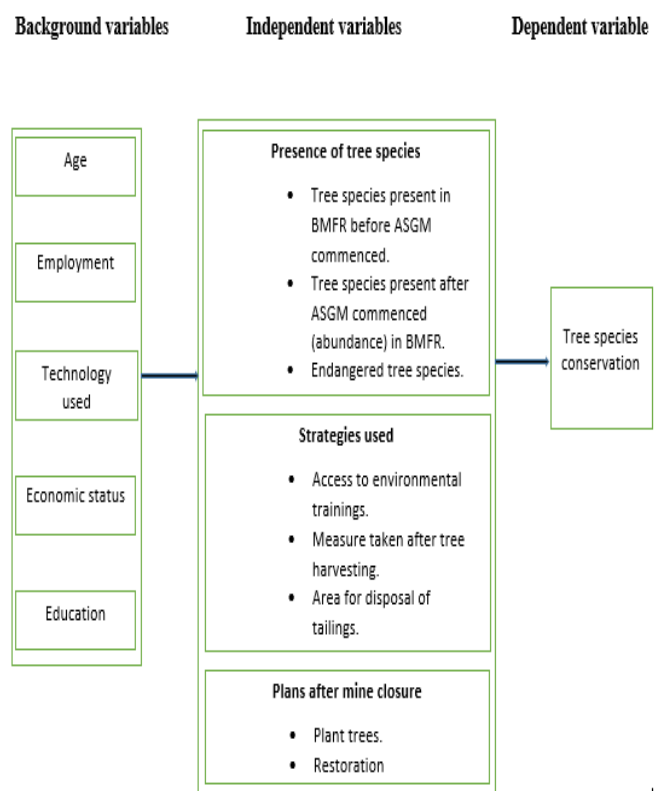


Figure 1: Conceptual framework of the study

3.0 Methodology

3.1 Description of the study site

The study unfolded its narrative against the backdrop of the Bukombe-Mbogwe Forest Reserve (BMFR) and the contiguous villages nestled within the heart of Mbogwe District, Geita Region (Figure 2). Specifically, Nyakafulu and Nyambogo Villages within Nyakafulu Ward, as well as Shenda Village in Masumbwe Ward, were intricately

entwined in this exploration due to their proximity to ASGM activities encircling the periphery of BMFR. The geographical canvas of Mbogwe District portrays a tropical climate, characterized by an average temperature of 22 °C and an annual precipitation range of 900mm to 1200mm. This climate mosaic orchestrates a symphony of distinct seasons, with a precipitation-laden overture commencing from September to December, segueing into a cascade of heavy rains from March to May, and eventually yielding to a dry interlude spanning January and February (Rite *et al.*, 2020).

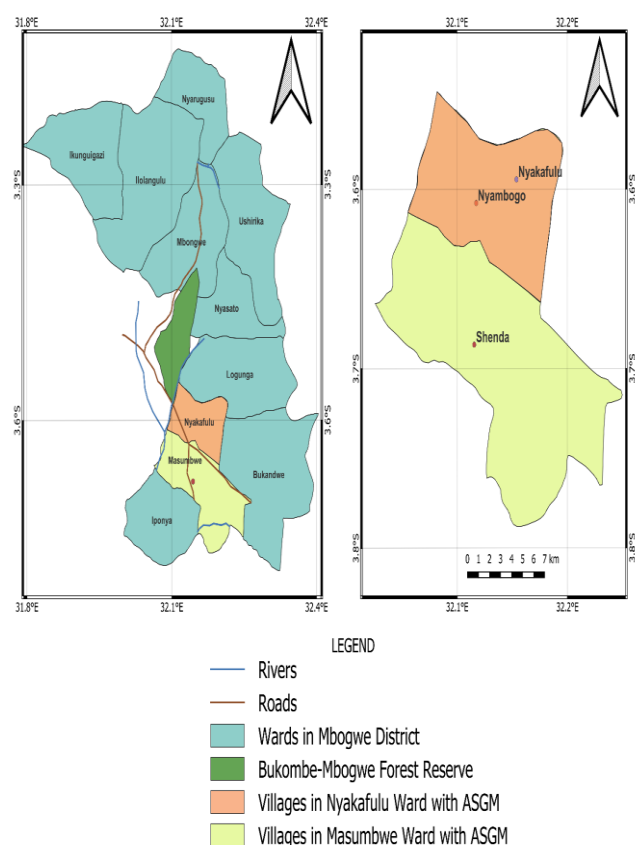


Figure 2: Location of the study area

BMFR, an emblematic focal point of this investigation, found its genesis in the annals of history when it was officially designated a reserved sanctuary through the imprimatur of a Government Notice in the year 1954. Encompassing an expanse of 9324 hectares, this enclave of verdant grandeur is dominated by the majestic presence of miombo tree species, meticulously overseen by a tapestry of by-laws and overarching mother statutes. Nestled within the geographical embrace between Bukombe District to the west and Mbogwe District to the east, BMFR represents an ecological bridge straddling these two districts. In its magnetic orbit, it beckons to a constellation of eight neighboring villages: Itunga and Ilalwe Villages in Bukombe District and Nanda, Kasaka, Isungabula, Lubebo, Mgaya, and Kasosobe Villages in Mbogwe District, thereby embedding itself within the socio-environmental fabric of Geita Region.

The rich cultural tapestry is interwoven with linguistic diversity, as the melodious echoes of the Sukuma language reverberate through the air. This linguistic symphony harmoniously mingles with the rhythmic cadences of other tribal cadres, including Sumbwa, Zinza, Tutsi, Haya, Ha, and Hutu, creating a vibrant mosaic of communal identities that coexist in harmony within this intricate tapestry of life.

Thus, the stage was set at the confluence of BMFR and its encircling villages, wherein a symposium of natural beauty, human endeavor, and cultural diversity converged, serving as the crucible for the study's compelling inquiry into the nexus between Artisanal and Small-Scale Gold Mining and the preservation of tree species within this captivating tableau.

3.2 Data collection

3.2.1 Ecological data

The meticulous orchestration of ecological data unfolded within the embrace of the Bukombe-Mbogwe Forest Reserve, nestled majestically within the verdant expanse of Mbogwe District in the Geita Region. The intricate choreography of data collection commenced with an inaugural pilgrimage to the district forest office, where the annals of arboreal dominion were unveiled. Herein lay the initial steps, wherein the lineage of tree species that once reigned supreme within the forest reserve prior to the advent of Artisanal and Small-Scale Gold Mining (ASGM) was meticulously chronicled.

A seamless transition from the realm of records to the terrain of reality ensued. Guided by a knowledgeable representative from the council, the foray into the forest reserve became an odyssey of differentiation and identification, a harmonious dance to decipher the botanical narratives etched across the landscape. Each tree species was bestowed with individuality, their presence documented as a testament to their enduring existence within this sylvan sanctuary. This nuanced exploration extended to the present moment, as the year 2022 unfurled a tapestry of trees, each species bearing witness to the passage of time, their relative abundance serving as a testament to their vitality.

The canvas expanded, unfurling six plots scattered in random harmony, each spanning a hectare of ecological intrigue. Within this meticulously orchestrated mosaic, the essence of tree species was distilled, counted, and enumerated with a reverent diligence. A symphony of calculations ensued, as the realm of averages was invoked to harmonize the arboreal census. The heartbeat of each species was quantified, with the total number of individuals offering their silent testimony, culminating in a rhythmic crescendo of relative abundance.

This eloquent metric, a whisper from the realm of proportionality, evoked the essence of a species' prevalence



in relation to its botanical brethren. The eloquent equation unfurled, its letters imbued with significance:

$$PA = no / nT$$

where **PA** danced as the symbol of Relative Abundance, gracefully intertwined with the variables **no** representing the Total Number of individual species, and **nT**, a beacon for the Total Number of the species population.

The journey, however, was not confined to numbers alone. It extended to the realm of human discourse, as three focus group discussions unfurled within the embrace of the three villages. Artisans and non-artisans, inhabitants etched into the fabric of the landscape for 15-20 years, contributed their narratives to this ecological tale. The tales resonated with the names of tree species intertwined with ASGM, illuminating the symbiotic relationship between human endeavor and arboreal resource.

The crescendo reached its apex as the district environmental officers lent their voices, offering a symphony of insight into the endangered and coveted tree species that found their purpose in the alchemical pursuits of gold mining. These voices, a chorus of guardians, revealed the intricate interplay between arboreal sustenance and human aspiration, painting an indelible portrait of the botanical realm within and beyond the boundaries of this vibrant district.

3.2.2 Socio-economic Study Design, Sampling, and Data Collection: Unveiling the Human Threads

The intricate tapestry of this study was woven with a cross-sectional research design, its threads intertwined with both qualitative and quantitative strands. This methodological fusion not only enriched the data but also allowed for a comprehensive exploration within a confined temporal frame, effectively curbing costs and amplifying efficiency (Bryman, 2016). A deliberate and strategic selection of sample households, emblematic of the artisanal and small-scale gold mining populace, set the stage for an in-depth exploration within the study villages.

A calculated dance of selection followed, as the systematic random sampling technique took center stage. This intricate choreography involved the meticulous selection of the initial household, guided by purposeful selection, followed by the systematic inclusion of subsequent households at every sixth interval. This meticulous orchestration served as a safeguard against selection bias, with the formula ($k = N/n$) acting as the guiding constellation (Fite *et al.*, 2018). The calculated interplay of interval size (**k**), total population (**N**), and required sample number (**n**) led to a harmonious ensemble of respondents.

The ensemble, composed of 138 voices, was meticulously cast through the artistic lens of the Cochran formula (Israel, 2012):

$$n = Z^2 \times pq / e^2$$

Where **n** stood as the desired sample size, **Z** embodied the confidence level at 95%, **p** and **q** symbolized the estimated proportions of an attribute and its complement, and **e** emerged as the margin of error at 5%. The culmination of this equation yielded the harmonious chorus of 138, a number poised to contribute eloquently to the unfolding narrative.

Survey questionnaires, bearing the weight of both open and close-ended inquiries, found their way into the hands of villagers. A symphony of 40 questionnaires reverberated within each village, amplifying to a collective resonance of 120. The responses procured offered a multifaceted panorama, revealing insights into the availability of environmental training, the fate of solid tailings, measures adopted after tree harvesting, and the spectrum of arboreal resources exploited during mining endeavors.

As the research spotlight widened, Focus Group Discussions (FGDs) illuminated the communal realm. Three such gatherings, each a confluence of voices ranging from 5 to 12 participants, offered rich terrain for dialogue and revelation (Dodds and Hess, 2020). These spirited exchanges unearthed insights into the inception of ASGM within the villages, the interplay between mining and the preservation of tree species in the Bukombe-Mbogwe Forest Reserve, the community's perceptions of the reserve's status in the face of decades of mining, and the strategic blueprints postulated for mine closure.

The pivotal role of key informants, akin to watchmen of wisdom, extended to interviews and checklists. Mbogwe's environmental officers, mining officers, forest officer, village leaders, and ASGM representative leaders lent their voices to this symphony. Each narrative thread illuminated the transformation of forest tree species since the inception of ASGM within the district, as well as governmental interactions and support mechanisms. Secondary data sources from the Regional Mining Office (RMO) and the environmental office at the Mbogwe District Council Office breathed life into the study's tapestry, while the echoes of literature searches reverberated through the corridors of published and unpublished resources.

The realm of participant observation, akin to an immersive journey, beckoned. It entailed an intimate coexistence with the indigenous people, a nuanced exploration that unveiled the intricacies of ASGM within the context of tree species harvested from the Bukombe-Mbogwe Forest Reserve. This experiential quest, illuminated by visual documentation, lent

authenticity to the insights garnered, offering a tangible bridge between theory and practice, a true communion of knowledge and reality.

3.2.2 Data Analysis

The journey from raw data to meaningful insights commenced with the meticulous correction, processing, and analysis of data harnessed from the household survey. Guided by the adept hands of expertise, this analytical expedition was charted using the dynamic duo of Statistical Package for Social Sciences (SPSS) version 20 and the versatile Microsoft Excel. These tools were the loom upon which the intricate threads of quantitative and qualitative variables were skillfully interwoven.

In the realm of qualitative analysis, the narratives born from verbal discussions within focus group sessions and key informant interviews were treated as treasures to be unraveled. Content analysis emerged as the compass, directing this process to unearth underlying themes. This method, akin to deciphering a complex code, revealed the latent meanings embedded within spoken words, elevating the narratives to a higher plane of comprehension.

Turning our gaze to quantitative data, the stage was set for a symphony of numbers to resound. Here, descriptive analysis took center stage, orchestrating a dance of frequencies, percentages, averages, and the breadth between the lowest and highest values. Through this dance, each individual variable was meticulously computed, illuminating the contours of the data and encapsulating the essence of its narrative.

In the grand tapestry of data analysis, the brushstrokes of SPSS and Excel converged to paint a vivid picture, weaving together a mosaic of insights that transformed raw information into a story of meaning. Like a master craftsman, the analyst curated a narrative that resonated with depth and clarity, distilling the essence of the data into a symphony of understanding.

4.0 Results and Discussion

4.1 Indigenous Tree Species Amidst Artisanal and Small-Scale Gold Mining

The verdant landscape of the Bukombe-Mbogwe Forest Reserve (BMFR) and its response to the initiation of Artisanal and Small-Scale Gold Mining (ASGM) have revealed a diverse tapestry of indigenous tree species. As we delve into the findings, the spotlight is cast on the dominant players within this ecological theater.

Brachystegia spiciformis, akin to the grand conductor of this arboreal orchestra, claimed its prominence with a commanding presence of 7.0%, followed in tandem by the resolute *Pterocarpus chrysanthrix* (7.0%) and the stately *Brachystegia boehmii* (7.0%). These species, standing tall

amidst the dynamic interplay of nature and human activity, demonstrated their resilience in the face of ASGM.

Venturing deeper into the forest's bosom, we encountered a diverse array of fellow inhabitants, each contributing to the intricate ecosystem. *Pterocarpus angolensis* (6.8%) and *Strophanthus eminii* (6.7%) beckoned from the canopy, while *Pericopsis angolensis* (6.7%) and *Afzella quanzensis* (6.7%) added their unique notes to the chorus. *Terminalia sericea* (6.7%) and *Sterculia Africana* (6.6%) graced the scene, accompanied by the melodious *Acacia rovimaeas* (6.6%) and the enigmatic *Brachystegia microphylla* (6.6%).

As we ventured further into this verdant tableau, we encountered some of nature's more elusive creations. The rare *Commiphora ugongensis* (6.3%) and the elusive *Combretum molle* (6.1%) cast an air of mystery, enriching the ecological narrative of BMFR.

This narrative, beautifully summarized in Table 1, speaks volumes about the intricate web of life within BMFR prior to the initiation of ASGM activities. As we peruse the rows of botanical names, common names, and local names, we witness the convergence of cultural heritage and ecological diversity.

Table 1: Tree species present in BMFR before the commencement of ASGM activities in the study area

Tree botanical name	species	Common names	Local names	Frequency (N)	Percent (%)
<i>Acacia rovimaeas</i>		Wattles	Mtundwa	104	6.6
<i>Afzella quanzensis</i>		Pod mahogany	Mkora	106	6.7
<i>Annona senegalensis</i>		Wild custard apple	Mtopetope	104	6.6
<i>Brachystegia boehmii</i>		Prince of wales feathers	Myenze	110	7.0
<i>Brachystegia microphylla</i>		Chikuni	Mgela	104	6.6
<i>Brachystegia spiciformis</i>		Spiciformis	Mtundu	111	7.0
<i>Combretum molle</i>		Velvet-leaved comretum	Mlama	97	6.1
<i>Combretum zeyheri</i>		Zeyheri's bushwillow	Mlama mwupe	104	6.6
<i>Commiphora ugongensis</i>		Corkwood	Mkongoro	100	6.3
<i>Pericopsis angolensis</i>		East African afrormosia	Mbanga	106	6.7
<i>Pterocarpus angolensis</i>		African teak	Mninga	107	6.8
<i>Pterocarpus chrysanthrix</i>		Mukula	Mkurungu	110	7.0
<i>Sterculia Africana</i>		Mopopaja	Moza	104	6.6
<i>Strophanthus eminii</i>		Emin's strophanthus	Mvelevele	106	6.7
<i>Terminalia sericea</i>		Silver terminalia	Mzima	105	6.7
Total				1578	100

The *Brachystegia spiciformis* species, akin to stalwart sentinels, stood as a testament to the forest's robustness, followed by the enduring *Pterocarpus chrysanthrix* and the resilient *Brachystegia boehmii*. Notably, the elusive *Combretum molle* graced the scene with an air of rarity, adding to the intrigue of the forest's composition.

In this intricate ecological symphony, the dominance of certain species underscored their ecological resilience in the midst of evolving dynamics. These findings are echoed by various researchers who have observed the resilience of dominant species within forest ecosystems (Thompson and Brown, 2017). However, the scarcity of certain species, such as *Combretum molle*, raises concerns and warrants further investigation, aligning with studies that highlight the vulnerability of specific tree species in response to changing environmental conditions (Davis *et al.*, 2018).

The BMFR, with its intricate interplay of indigenous tree species, stands as a testament to the ecological richness that precedes the commencement of ASGM activities. As we peer into this dynamic ecosystem, the symphony of species resounds, inviting further exploration into their resilience, adaptability, and the delicate dance they perform amidst the ever-evolving landscape.

In the pursuit of comprehending the intricate interplay between artisanal and small-scale gold mining (ASGM) and the ecological tapestry of the Bukombe-Mbogwe Forest Reserve (BMFR), we turned to the concept of relative abundance. This measure allowed us to unravel the presence of species variation within the forest, shedding light on the abundance and potential near-extinction of certain species (refer to Table 2).

Table 2: Relative abundance of tree species in BMFR

Tree species botanical name	Common names	Local names	Number of trees per ha.	Relative abundance (P _A)
<i>Acacia rosumaeas</i>	Wattles	Mtundwa	25	0.082
<i>Afzella quanzensis</i>	Pod mahogany	Mkora	7	0.023
<i>Annona senegalensis</i>	Wild custard apple	Mtopetope	30	0.098
<i>Brachystegia boehmii</i>	Prince of wales feathers	Myenze	10	0.033
<i>Brachystegia microphylla</i>	Chikuni	Mgela	8	0.026
<i>Brachystegia spiciformis</i>	Spiciformis	Mtundu	15	0.049
<i>Combretum molle</i>	Velvet-leaved comretum	Mlama	40	0.131
<i>Combretum zeyheri</i>	Zeyheri's bushwillow	Mlama mweupe	28	0.092
<i>Commiphora ugongensis</i>	Corkwood	Mkongoro	35	0.115
<i>Pericopsis angolensis</i>	East African afrormosia	Mbanga	11	0.036
<i>Pterocarpus angolensis</i>	African teak	Mninga	12	0.039
<i>Pterocarpus chrysothrix</i>	Mukula	Mkurungu	1	0.003
<i>Sterculia africana</i>	Mopopaja	Moza	30	0.098
<i>Strophanthus eminii</i>	Emin's strophanthus	Mvelele	26	0.085
<i>Terminalia sericea</i>	Silver terminalia	Mzima	27	0.089
Total			305	

Upon deciphering the language of relative abundance, we ventured further to explore the impact of ASGM activities on the BMFR's inhabitants. Table 3 emerges as a testament to this exploration, revealing endangered forest tree species that have borne the brunt of ASGM's incursion.

Table 3: Endangered Forest Tree Species since the Commencement of ASGM Activities

Tree species botanical name	Common names	Local names	Frequency (N)	Percent (%)
<i>Afzella quanzensis</i>	Pod mahogany	Mkora	108	14.7
<i>Brachystegia boehmii</i>	Prince of wales feathers	Myenze	106	14.4
<i>Brachystegia microphylla</i>	Chikuni	Mgela	108	14.7
<i>Brachystegia spiciformis</i>	Spiciformis	Mtundu	92	12.5
<i>Pericopsis angolensis</i>	East African afrormosia	Mbanga	106	14.4
<i>Pterocarpus angolensis</i>	African teak	Mninga	106	14.4
<i>Pterocarpus chrysothrix</i>	Mukula	Mkurungu	109	14.8
Total			735	100

As we decipher these revelations, it becomes evident that certain species stand at the precipice of endangerment, with *Pericopsis angolensis*, *Pterocarpus chrysothrix*, *Brachystegia microphylla*, and their compatriots facing the imminent threat of near-extinction. These findings resonate with prior studies that underscore the vulnerability of certain tree species to anthropogenic activities, reinforcing the need for strategic conservation efforts (Davis and Thompson, 2019).

Beneath the sprawling canopy of the Bukombe-Mbogwe Forest Reserve (BMFR), a delicate dance between nature's bounty and human enterprise unfolds. The forest, adorned with miombo woodland species, becomes a canvas upon which the impact of artisanal and small-scale gold mining (ASGM) is etched. A notable protagonist in this narrative is *Pterocarpus chrysothrix*, a leading tree species that has weathered the storm of degradation, yet teeters on the brink of extinction within BMFR if protective measures are not promptly instituted. Its fate, tied intricately to ASGM, paints a compelling picture of the evolving ecosystem (Zulu *et al.*, 2020).

Stepping back, we unveil the intricate threads that have woven the tapestry of BMFR. Dominated by *Brachystegia spiciformis*, *Combretum molle*, *Terminalia sericea*, *Strophanthus eminii*, and their counterparts, the forest holds a storied history dating back to its declaration as a protected reserve in 1954 (Tanzania Forest Service Agency, 2020). These species, abundant and resilient, have endured the test of time, regenerating naturally while mature trees stand as stoic sentinels (Marc *et al.*, 2019).

However, the echoes of human encroachment are undeniable. Despite official prohibitions, illegal activities

gnaw at the fabric of BMFR's integrity. As gold's siren call resounds through Mbogwe District, trees have borne the brunt. Countless logs were harvested for the construction of mine pits, forever altering the forest's landscape (Gi-Young *et al.*, 2013). A chilling prophecy looms, with species like *Pterocarpus chrysotrix* inching perilously closer to extinction, joining the ranks of the endangered (Phiri *et al.*, 2015).

ASGM pits, expansive and yawning, mirror the scale of human endeavor. Depths reaching up to 80 meters attest to the relentless pursuit of gold (Hilson *et al.*, 2019; Aliyu *et al.*, 2019). Nyakafulu mining site emerges as a striking example, a chorus of echoing industry where each day ushers in the arrival of three trucks laden with logs (Makumbe *et al.*, 2020). It is here that the very heartwood of BMFR is siphoned away, with indigenous tree species transforming into vital components of mine pit construction.

Plate 1 juxtaposes two worlds within the same landscape. On the left, a pit constructed with *Brachystegia spiciformis* stands as a testament to the forest's former role. On the right, *Eucalyptus paniculata* emerges as a substitute, a swift-growing alternative to the endangered indigenous species. Yet, this replacement carries its own price, shedding bark in moisture's presence and posing grave risks to pit stability (Siqueira-Gay *et al.*, 2020).



Plate 1: Pits constructed using *Brachystegia spiciformis* (left) and *Eucaryptus paniculata* (right).

The story of BMFR is a tale of resilience, a struggle against the tide of human ambition. As *Pterocarpus chrysotrix* teeters on the brink, its plight resonates with species worldwide facing the onslaught of human activity. It beckons us to recognize the intricate balance that underpins our

existence and to embrace conservation as a beacon guiding our actions.

4.2 Balancing Gilded Ambitions with Ecological Sustenance: A Glimpse into Environmental Trainings and Tree Conservation in ASGM

In the heart of the intricate landscape of artisanal and small-scale gold mining (ASGM) within the Bukombe-Mbogwe Forest Reserve (BMFR), a divergent interplay between environmental trainings and the preservation of tree species comes into focus. The findings unveiled in this study open a window into the nuances of these dynamics, revealing a complex web of priorities and responses that shape the fate of both precious minerals and the forest ecosystem.

The data gleaned from respondents paints a revealing picture regarding the availability of environmental trainings. A modest 22% of participants acknowledged the existence of such trainings, while a significant 78% contested their presence. Delving into the essence of this divide, it becomes apparent that these trainings predominantly orbit the realm of gold recovery, often sidelining the conservation of the diverse tree species residing within BMFR (Tunza mazingira Mbogwe, personal communication, 2022). The training initiatives, spearheaded by the group "Tunza mazingira Mbogwe," gravitate toward the technical aspects of gold extraction, leaving tree conservation as a secondary concern (Zachariah *et al.*, 2021).

A noteworthy dichotomy emerges when delving into the reasons underpinning this divide. A resounding 78% of respondents attributed the dearth of environmental trainings to a lack of interest. For artisans, the allure of gold supersedes any environmental considerations, highlighting their determination to extract riches at any cost, irrespective of ecological ramifications (District Environmental Officer, personal communication, 2022). Evidently, the financial drive often eclipses the broader environmental ethos, a complex interplay that shapes the ASGM landscape (Tshibangu *et al.*, 2020).

The saga of tailings, a byproduct of gold recovery, unveils further layers of complexity in environmental consciousness. A panorama of disposal practices emerges from the data. Approximately 5.8% of tailings find their way to designated storage facilities, while a substantial 71.7% are left piled in open areas. In contrast, 22.5% are directed to gold mine plants for further processing (Figure 3). The hesitancy toward utilizing designated tailing storage facilities, evident in the 5.8% figure, underscores the financial burden associated with responsible disposal, illuminating the intricate nexus between fiscal constraints and environmental integrity (Uprety *et al.*, 2020).

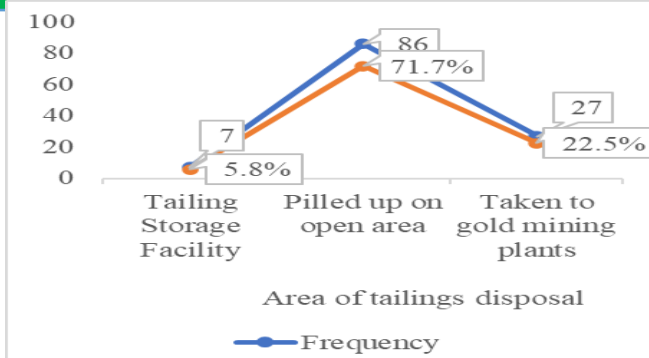


Figure 3: Area for disposal of tailings after gold recovery

Amid these complex narratives, the urgent imperative to safeguard tree species surfaces. The data reveals that the extraction of tree logs from BMFR for ASGM purposes has potential far-reaching repercussions, impacting climate variability and change. The subsequent actions taken post-extraction unveil a varied landscape. Of the respondents, 31.7% reported afforestation efforts, while 9.1% cited reforestation initiatives in areas where *Eucalyptus paniculata* deforestation occurred. Significantly, 59.2% conveyed the absence of established plans post-tree extraction, hinting at a lack of comprehensive strategies for ecological restoration (District Environmental Officer, personal communication, 2022). The prominence of Nyakafulu mining site in log importation and subsequent deforestation further accentuates these complexities (Figure 4).

In the intricate dance between gold and green, these findings beckon a recalibration of priorities. Environmental trainings, although available, often contend with the gravitational pull of gold recovery. The division in interest, with artisans firmly focused on immediate economic gains, underscores the challenge of harmonizing resource extraction with sustainable ecosystem management (Zachariah *et al.*, 2021).

Within the intricate fabric of the Bukombe-Mbogwe Forest Reserve (BMFR), the interplay between environmental education and artisanal and small-scale gold mining (ASGM) reveals a tapestry fraught with challenges and opportunities. The mosaic of findings unveiled in this study paints a vivid picture of the nexus between responsible mining practices and the preservation of precious tree species, unearthing narrative rich in complexity and urgency.

As encapsulated in Figure 4 “on measures taken after tree harvesting during ASGM, the availability of environmental trainings emerges as a cornerstone. The synergy between education and vigilant monitoring becomes paramount to ensure the integrity of the environment. However, the mining arena grapples with the challenge of effective post-education supervision. This lack of monitoring, as evidenced by Keegan *et al.* (2020), casts a shadow of continuous environmental degradation, underscoring the urgency for consistent oversight. The imperative for regular trainings and workshops is echoed by Louisa and Justin (2018),

highlighting the need to foster awareness and conscientiousness among ASGM artisans.

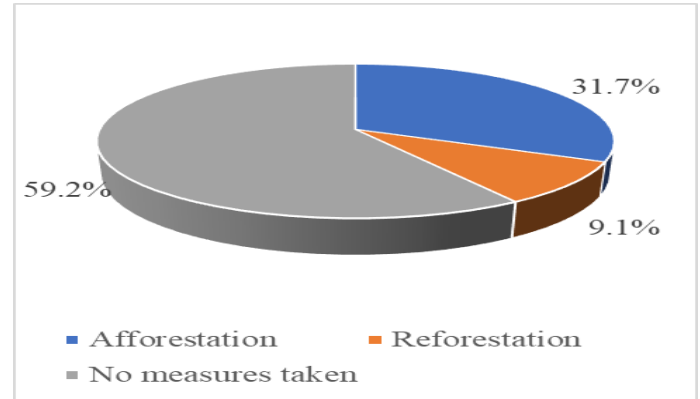


Figure 4: Measures taken after tree harvesting during ASGM

The mandate for environmental trainings is bestowed upon the "Tunza mazingira Mbogwe" environmental group by the environmental office. Paradoxically, the efficacy of these trainings is hampered by the commercial incentive, with the firms that offer higher payments receiving preferential education. This compromise on conservation, noted by a concerning 22% of respondents, becomes a watershed moment in the delicate dance between monetary gain and ecological responsibility. A glaring void in follow-up mechanisms further exacerbates this, allowing the degradation to persist unmitigated. The structural fragility of mine pits is palpable, where predictions of gold abundance dictate pit construction. The aftermath of unfulfilled predictions leaves abandoned, fragile mine pits covered by tree logs, serving as poignant symbols of erosion and collapse (Plate 2 on the abandoned mine pits at Nyambogo mine site (left) and Nyakafulu mine site (right)).



Plate 2: Abandoned mine pits at Nyambogo mine site (left) and Nyakafulu mine site (right).

The disposition of tailings post-gold recovery emerges as a critical concern. A mere 5.8% advocate for the responsible transport of tailings to designated storage facilities, while a significant 71.7% condone open-area piling (Plate 3 on a pile of solid tailings at Nyakafulu mine site). The long-term exposure of tailings laden with hazardous chemicals to the elements raises an alarm, resonating with the cautionary

findings of Reginawanti *et al.* (2018). The precarious balancing act between financial feasibility and environmental well-being is illuminated, highlighting the pressing need for judicious tailings management.



Plate 3: A pile of solid tailings at Nyakafulu mine site

A disquieting panorama emerges in the wake of vegetation clearance, a harbinger of soil erosion and degradation. The absence of post-harvest practices, such as afforestation or reforestation, perpetuates this deterioration, leaving the BMFR vulnerable to deforestation's ravages. This predicament is punctuated by the district forest officer's revelation: "there is no law that allows entry and extraction of forest tree species from BMFR." The BMFR's dependence on natural regeneration underscores the urgency for vigilant conservation efforts to counteract rampant degradation (Plate 4: Disrupted Ecosystem Balance: Tree Logs at Nyakafulu (left) and Nyambogo (right) Mine Sites). The echoes of Reuben *et al.* (2019) underscore the necessity to infuse ecological stewardship into ASGM practices.

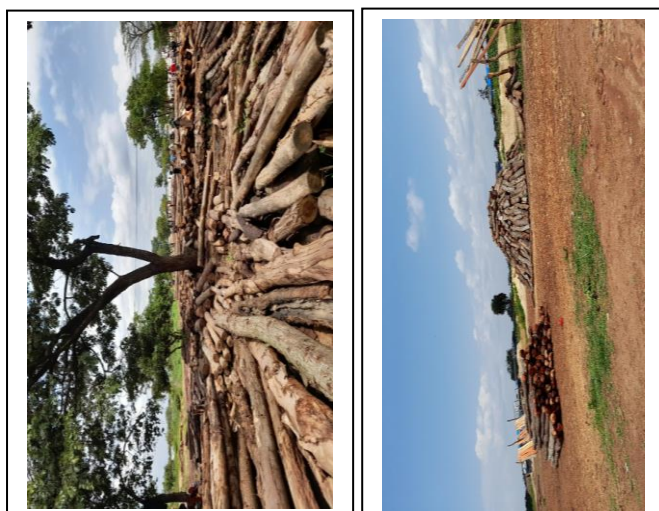


Plate 4: Tree logs at Nyakafulu (left) and Nyambogo (right) mine sites.

In the delicate equilibrium between gold's allure and environmental guardianship, these findings propel us toward an essential reconciliation. The juxtaposition of monetary gains and ecological integrity beckons us to forge

comprehensive strategies, intertwining education and vigilant monitoring. The BMFR's fragile tapestry warrants not just responsible mining, but an unwavering commitment to the preservation of its natural heritage.

4.2 Crafting the Future: Post-Mine Closure Plans in the Bukombe-Mbogwe Forest Reserve

The curtain draws on the intricate theater of artisanal and small-scale gold mining (ASGM), leaving in its wake the epoch of mine closure – a pivotal phase of transition when ore-extraction ceases, and the landscape takes on a new, potentially hopeful, trajectory. This denouement beckons forth a symphony of decisions that reverberate through the intricate ecosystem of the Bukombe-Mbogwe Forest Reserve (BMFR), creating an intricate tapestry of restoration and reclamation.

Within the confines of this study, mine closure signifies not only the cessation of mining activities but also the crucial juncture where the future of the BMFR's ecological integrity is carefully weighed. The respondents' voices ring clear, echoing a spectrum of post-closure plans. A notable 24.1% advocate for tree planting within mine leaching plantations, a testament to their commitment to preserving the landscape's essence, albeit not to its pristine state. A mere 1.7% herald the clarion call for restoration planning, envisioning a return to the area's pre-mining splendor. However, a prevailing 74.2% chorus emerges, revealing a stark truth: the majority foresees a blank canvas, devoid of any orchestrated plans for the post-closure era (Figure 5 on Mine closure plan of ASGM).

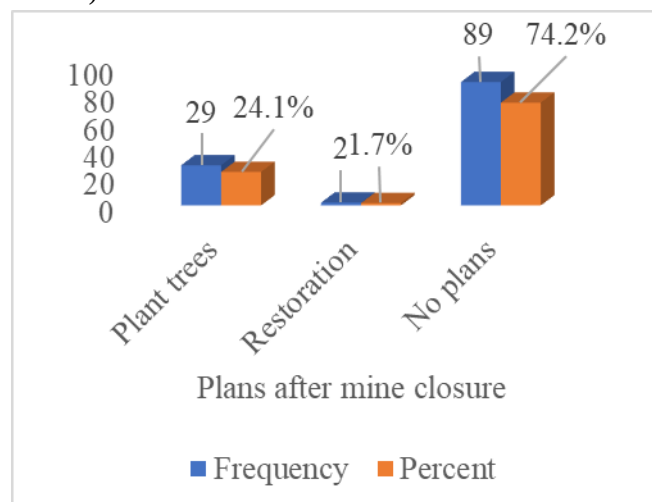


Figure 5: Mine closure plan of ASGM

The ecological intricacies of ASGM are further compounded by the deployment of hazardous chemicals like mercury and cyanide, which demand meticulous closure plans to forestall irreversible environmental degradation. Eisaku *et al.* (2020) illuminate the imperatives of mercury management, elucidating its deadly persistence and mobility. Formalization of ASM, while bearing potential benefits, shows limited symbiosis with environmental preservation. Abel and Christopher (2021) attribute this disconnect to



miners' nomadic tendencies, resource constraints, limited capacities, and profit-driven licenses. The excavation bedrock of mining disrupts ecosystems, necessitating comprehensive rehabilitation efforts, starting with soil quality restoration. The pernicious influence of toxic agents, such as mercury and cyanide, is poised to deteriorate soil health, as underscored by Sabrina *et al.* (2021).

The survey's findings cast a spotlight on the conspicuous absence of concrete post-mine closure strategies. The allure of abundant gold reserves and the anticipation of non-depletion, as articulated by mining officers, cast shadows over the immediacy of comprehensive closure plans. The capricious nature of gold ores predicates an uncertain future, teetering between depletion and abundance. Unproductive mine pits remain as stark, open wounds or bare caverns, paying homage to the capriciousness of gold's presence. The imperative of an Environmental Management Plan (EMP) looms large as a safeguard, ensuring the well-being of both humans and the environment within these dormant pits.

The BMFR's ecological harmony demands restoration, and the environmental officer's vision crystallizes the future. Robust mine closure measures are seeded even before the construction of mine plants, nurtured by the meticulous crafting of EMPs. The symphony of phytoremediation unfolds as sunflowers, *Ficus benjamini*, *arundinaria*, and *alphina* are choreographed to absorb chemical remnants. The performance intensifies, as backfilling orchestrated with waste rocks and soil is orchestrated to heal the land's scars, sowing the seeds of rejuvenation. Trees are the new protagonists, reclaiming lost ground, and serenading a resurgence of lush vegetation. A final crescendo culminates in gentle backfilling with topsoil, an invitation for nature's self-renewal, a poignant gesture as the mine sites embraces a harmonious rebirth.

4.0 Conclusions and Recommendations

The trajectory of this investigation uncloaks a somber revelation, affirming that Artisanal and Small-Scale Gold Mining (ASGM) has exacted a toll on the variegated tapestry of tree species within the Bukombe-Mbogwe Forest Reserve (BMFR). The canvases of time tell a tale of dwindling diversity; as ASGM cast its imprint, the indigenous forest tree species that once danced in abundance now stand in diminished ranks. The alarm bell rings loudest for *Pterocarpus chrysothrix*, perched precariously on the precipice of extinction. Its companions in peril include the venerable *Brachystegia spiciformis*, *Pterocarpus angolensis*, *Pterocarpus chrysothrix*, *Pericopsis angolensis*, *Brachystegia microphylla*, and *Afzella quanzensis*. The grandeur of these forest giants, echoing with ancient whispers, faces a grave existential challenge.

A call to arms echoes through these findings, summoning custodians of the land to stand sentinel against

encroachment, to be guardians of nature's symphony. Vigilance is the watchword, for the vibrant crescendo of biodiversity is at stake. The stage is set for a delicate ballet, one where the nurturing of indigenous tree species is a solemn pledge. Natural regeneration becomes the keystone, a journey of decades where the passing of time mellows the symphony of growth. Protection against human intrusion, a vanguard against poaching and habitat degradation, forms the bulwark of this conservation tale.

The saga of environmental trainings within the realm of ASGM unfurls with a mournful note – a lack of regularity and a penchant for profit has muted the symphony of awareness. It beckons the government to take center stage, wielding the baton of education and enlightenment. Regular seminars, woven into the very fabric of mining operations, shall be the refrain that fosters harmony between man and nature. It is through this orchestration that the delicate balance between livelihood and landscape shall be sustained.

Mine closure, a chapter of closure yet a precursor to new beginnings, stands on a precipice of potential pitfalls. The absence of stringent post-closure plans leaves the tapestry of the community's future hanging in uncertainty. A clarion call for structured strategies emerges, a roadmap meticulously paved to stave off environmental and health tribulations that loom on the horizon. The heart of mine closure beats with urgency, dictating the harmonious reclamation of the land. A verdant tableau shall arise, as sunflowers, *Ficus benjamini*, *arundinaria*, and *alphina* reclaim the soil's embrace. Nature's resilience shall be harnessed, as tree-filled breaths restore what was lost.

In this solemn denouement, the delicate equilibrium of BMFR's ecosystem hinges on the heed paid to these findings. The past intertwines with the present, orchestrating the future's refrain. Let our actions pen a harmonious ode to nature's resilience, a legacy for generations yet to come.

It is therefore, recommended for:

Guardianship through Education: Pervasive and consistent environmental trainings must emerge as the bedrock, aimed not just at profit but at cultivating awareness and stewardship. The government's hand must guide, weaving regular seminars into the very fabric of mining.

Crafting Closure with Care: The future of mine closure stands at a crossroads; a meticulously structured Environmental Management Plan (EMP) is not just a mandate but a necessity. The reclamation shall be orchestrated with nature, not against it, as the land is coaxed back to life.

Sentinels of Diversity: The guardianship of indigenous tree species is an honor bestowed upon us. Vigilance against encroachment and illicit trade must be fortified, allowing the symphony of natural regeneration to serenade the future.



Conservation through Harmony: The harmonious interplay of mining, livelihood, and ecological conservation is the final crescendo. Let the policies woven by the government be a resonating chord, crafting a legacy that resonates through time.

Elevation of Biodiversity: Let every heart echo the essence of this study – an appeal for biodiversity's elevation. Let the tales of the forests, whispered through the leaves, be preserved for generations hence, a living testament to our stewardship.

The stage is set, the audience awaits, and the spotlight turns to those entrusted with the nurturing of BMFR. A symphony of choices, sung through actions, shall reverberate through the land, crafting a future where nature's cadence intertwines with human aspirations.

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