FROM CANOPY TO SOIL: ASSESSING THE IMPACTS OF TREEFALL GAPS ON SOIL QUALITY IN OKOMU PLATEAU FOREST, NIGERIA

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Abstract

The impact of treefall gaps on soil quality in Okomu Plateau Forest was investigated. An inferential approach was adopted for the study, and twenty soil samples each from the treefall gaps and from beneath the canopies of adjoining trees were analyzed for their soil quality properties. Treefall gap area was calculated using the line intercept (offset transect) method, and the gap center was determined using a center identification approach. Descriptive statistics were employed to summarize the data, and Student t-test was used to determine the significance of the effects of treefall gaps on soil quality. Except for sand (79.95%), silt (14.25%), pH (4.65), effective cation exchange capacity (5.33 cmol kg^{-1}), soil organic matter (6.64 g kg^{-1}), soil organic carbon (3.83 g kg^{-1}), total nitrogen (0.34 g kg^{-1}), available phosphorus (0.97 mg kg^{-1}), calcium (3.93 cmol kg^{-1}), magnesium (0.94 cmol kg^{-1}), potassium (0.18 cmol kg^{-1}), sodium (0.26 cmol kg^{-1}), total heterotrophic bacteria (125.45×10^4 cfu g^{-1}) and total heterotrophic fungi (11.45×10^3 cfu g^{-1}), the concentrations of clay (8.15%), bulk density (1.42 g cm^{-3}), iron (173.15 mg kg^{-1}), manganese (2.29 mg kg^{-1}), zinc (7.34 mg kg^{-1}), and copper (1.21 mg kg^{-1}) were higher in treefall gap soils. Further analysis revealed that treefall gaps had significant negative impacts on silt, effective cation exchange capacity, available phosphorus, exchangeable cations, total heterotrophic bacteria, and total heterotrophic fungi, while they had significant positive effects on clay and iron. The study concluded that, despite improvements in clay, bulk density and micronutrient levels, treefall gaps overall negatively influenced soil nutrient availability and microbial activity in Okomu Plateau Forest.

Keywords: Canopy Gaps; Forest Ecosystems; Soil Quality Properties; Tropics; Okomu Plateau Forest

1. Introduction

Treefall gaps are disturbances serving as fundamental drivers of forest dynamics (Bonan, 2015). Gap theory, or gap dynamics theory (Watt, 1947 cited in Yamamoto, 1992), highlights the ecological role of canopy gaps created by treefall disturbances in forest biomes (Lin, 2020). Trees die standing, branches break off, or are blown to the ground forming a hole in the tree canopy (McCarthy, 2001) referred to as treefall gap, also known as forest canopy gap (Tian et al., 2024). The gaps created influence the micro-environmental conditions (light, moisture or temperature) of the forest. Treefall gaps characteristically impact forest ecosystem succession, biodiversity, and the coexistence of flora and fauna species (Rebertus & Veblen, 1993). Disturbances play a significant role in shaping ecosystem structure, function, and dynamics, and they can directly alter biodiversity through differential species elimination as well as indirectly by modifying biotic and abiotic environments (Lin, 2020).

Treefall gaps play significant roles in the ecology of tropical rainforest such as Okomu Forest Reserve, and aid in understanding the functioning of forest ecosystems (Naaf & Wulf, 2007). They are important ecological factors in determining soil quality which can subsequently change the variations of soil quality properties (He et al., 2015). Gaps have been shown to modify soil properties, which in turn influence overall soil quality (Podrázský & Řehoř, 2006). Poulson and Platt (1989) reported that the conditions within treefall gaps are mostly dissimilar from those under tree canopies. Ravnjak et al. (2022) reported that each newly formed gap results in changes to environmental factors affecting flora, fauna, and soil quality. Consequently, these processes result to the formation of hubs of soil nutrient or isle of fertility that surge soil efficiency and general pedological variety in the forest (Denslow & Spies, 1990).

The Plateau Forest of Okomu, also known as the Okomu Forest Reserve, is among the 16 forest reserves located in the tropical rainforest ecological zone of Edo State, Nigeria (Isikhuemen & Ikponmwonba, 2020 cited in Orobator & Iyobosa, 2025). It is a biodiversity hotspot designated as one of the most densely forested areas in southern Nigeria (Enaruvbe, 2018b). Okomu Forest Reserve is a heterogeneous landscape consisting of rainforest, lacustrine, freshwater, and bordering /riparian biomes, and it is a component of the Guinea–Congolian biogeographical zone (Isikhuemen & Ikponmwonba, 2020), and it is characterized by ferrallitic soils. Prior ecological investigations (Agboola et al., 2017; Aigbe & Nchor, 2021; Enaruvbe, 2018a; Enaruvbe, 2018b; Isikhuemen & Ikponmwonba, 2020; Oroka & Ureigho, 2021) have been carried out in the Okomu Plateau Forest. However, one major feature of studies in Okomu Forest is the dearth of quantitative assessments of the influence of treefall gaps on soil quality.

Despite widespread interest in gap dynamics (Yamamoto, 2000) and the biogeographic and biodiversity importance of forests, empirical studies on treefall gaps in Nigerian forests are scarce. Similarly, studies examining the impacts of treefall gaps on soil quality in other regions have highlighted a lack of research on their effects on soil microbial populations, an important yet understudied aspect of soil microbial biogeography. Li et al. (2025) reported that gaps are critical for maintaining soil nutrient cycling and microbial communities. This gap has limited the scope of research and our understanding. Therefore, addressing it is necessary to advance knowledge in this area. This investigation is important for optimizing treefall gap management, improving our understanding of their effects on soil quality, and informing policy decisions regarding soil fertility following treefall gap disturbances. The research represents a foremost empirical study to examine the top-down effects of treefall gaps on soil quality in a mixed tropical forest in Nigeria.

The primary aim of this research was to comparatively assess the quality of soil between two distinct microhabitats: the areas beneath the tree canopies and under the treefall gaps in the Okomu Plateau Forest. Specifically, the study sought to determine the impact of canopy openings on the physicochemical and microbial properties of soil, thereby providing empirical data on the top-down effects of forest disturbances on soil fertility and nutrient cycling in a mixed tropical forest biome. The present study demonstrated that the gap dynamics theory is appropriate for evaluating the impact of treefall gaps on the quality of soil in Okomu Plateau Forest, Nigeria.

2. Materials and Methods

2.1. Description of Study Area

Okomu Plateau Forest is located in Ovia South West Local Government Area of Edo State, Nigeria (Figure 1), and occupies an area of 1,082 km^2 within the lowland forest zone (Agboola et al., 2017). Okomu Plateau Forest lies between latitudes 6˚11′0″N and 6˚40′0″N and longitudes 5˚7′0″E and 5˚36′0″E. The forest derives its name from the Okomu River, which comes from the Benin word *Akomu*, meaning 'unity'. The climate is hot and humid, characterized by a double-peaked rainfall pattern, with a mean annual rainfall of approximately 2,000 mm. Aigbe and Nchor (2021) reported that the soils are predominantly ferrallitic. Tree species in the forest include *Lovoa trichilioides*, *Terminalia spp.*, *Chlorophora spp.*, *Sterculia oblonga*, *Anopyxis klaineana*, *Pentaclethra macrophylla*, and *Staudtia stipitata*, among others. The forest is also home to a variety of animal species. Akinsorotan et al. (2011) reported that many of these species are endangered, including the white-throated monkey (*Cercopithecus albogularis*), the African forest elephant (*Loxodonta cyclotis*), the dwarf crocodile (*Osteolaemus tetraspis*), and the bush cow or bushbuck (*Tragelaphus scriptus*), among others.

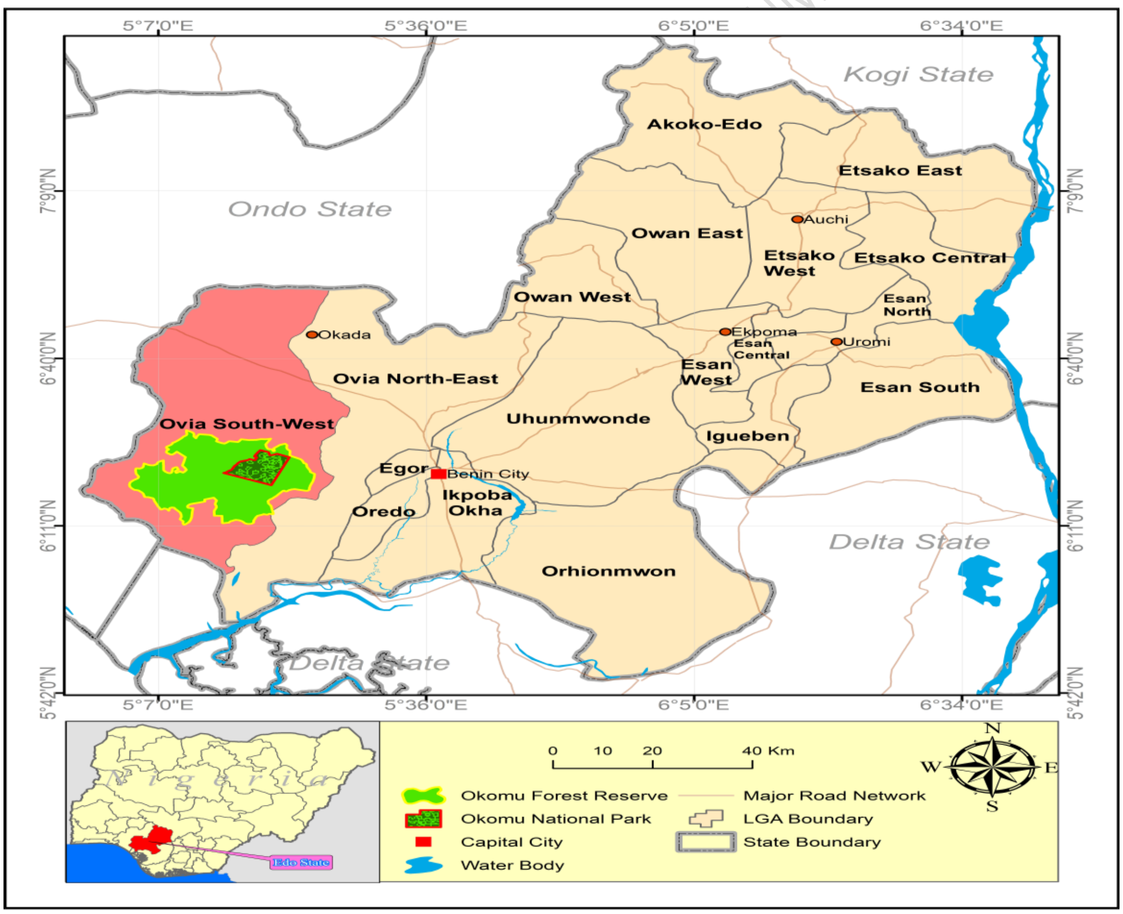

Figure 1. Location of Okomu Forest

Source: Odigie (2024)

2.2. Determination of Treefall Gap Area

First, a reconnaissance survey was conducted to assess the presence of treefall gaps in the forest. In the study, a treefall gap was defined as an opening in the canopy layer created by the demise of a part of a tree, an individual tree or an assemblage of trees in which no trees are greater than two-thirds the canopy height (Obiri & Lawes, 2004). Treefall gap area was calculated using the line intercept (offset transect) method described by Grainger and van Aarde (2013). In each treefall gap, the longest axis, and a number of equally spaced offset lines that bisected the lengthiest axis were identified and measured. The length of the offset lines were summed and multiplied by the distance between the offset lines using equation 1.

Treefall gap area (A) was calculated as: $A = I^* (C+D+E)$………………………….. Eq. 1

Where *I* represent the interval between offset lines and *C*, *D*, *E*, etc. are the lengths of the offset lines.

The center of each treefall gap was determined using the Center Identification Approach, where the geometric center was located by measuring equal distances from the gap edges with a measuring tape (Gagnon et al., 2004).

2.3 Field Measurements and Soil Sampling

Adopting the procedures of Orobator and Oboh (2025) for sample area delineation, a 100 m by 100 m sampling area was established at the study site. Within the 1-hectare (100 m by 100 m) study plot, 20 distinct treefall gaps were randomly selected. From the geometric center of each gap, one soil sample was taken using a soil auger. For each gap, a corresponding control sample was collected from the nearest adjacent area under a tree canopy, resulting in 20 treefall gap samples and 20 canopy samples (n = 40). Soil samples were collected at a soil depth of 30cm, and Adewole et al. (2011) reported that soil depth up to 30 cm provide the bulk of soil nutrients and represent the most active zone for plant litter decomposition. Similarly, Odigie (2024) stated that soil mineralization occurs primarily within the upper 30 cm of the soil profile. Consequently, an inferential approach (Areola et al., 1982) which involved the side-by-side comparison of soils was adopted for this study. In this approach, soils from the under the tree canopies and from the center of the treefall gaps were compared to capture differences in soil quality indicators between both microhabitats.

2.4 Laboratory Analysis

The Bouyoucous Hydrometer method was adopted to analyze the soil texture. Soil bulk density (BD) was determined after the soil was oven dried at 105 °C for 24 hours (Black, 1965). The effective cation exchange capacity (ECEC) was determined by extraction with ammonium acetate (Chapman, 1965); the soil pH was determined with glass electrode pH meter in soil: water at ratio 1:1 (Mclean, 1982). To determine the soil organic carbon, the wet dichromate acid oxidation method was used (Nelson & Sommers, 1982). The soil organic matter content of the soil was calculated by multiplying the organic carbon percentage by 1.724 following the assumptions that soil organic matter is composed of 58% carbon. The total nitrogen content in soils was determined using the Kjeldahl digestion, distillation and titration method by oxidizing the organic matter in concentrated sulfuric acid solution (0.1N H_2SO_4) as described by Black (1965). The available P was extracted with Bray p-1 solution using molybdenum blue as indicator by the method modified by Nelson and Sommers (1982). Exchangeable bases (Na, K, Mg, and Ca) were determined after extracting the soil samples by ammonium acetate (1N NH_4OAc) at pH 7.0. The extractable micronutrients (Fe, Mn, Cu, and Zn) were obtained by leaching the soil with 0.1 N HCl and the concentration of the element determined by the Atomic absorption spectrophotometric (AAS) (Lindsay & Norwell, 1978). The Heterotrophic Bacteria Count and Heterotrophic Fungi Count within the soil samples were estimated by spreading aliquots (0.1 ml) of the decimal series dilutions of the sample onto duplicate nutrient agar plates (pH 7.2).

2.5 Statistical Analysis

The research employed both descriptive and inferential statistical techniques. Descriptive statistics (mean and standard deviation) were used to comprehend the nature and distribution of the soil quality data. Student's t-test analysis was conducted to assess differences in soil quality indicators between soils under the tree canopy and soils from treefall gaps in the sampled areas. Differences were considered statistically significant at $p < 0.05$. The impact of treefall gaps on soil quality was assessed by comparing each soil quality indicator between treefall gap areas and under the canopy areas.

3. Results and Discussion

A summary of the soil physical, chemical and biological properties for the areas under the tree canopies and the treefall gaps, as well the results of the Student's t-test analysis, is presented in Table 1.

3.1. Soil Physical Properties

Sand concentration was slightly higher in under the tree canopy (79.95 %) than in treefall gap (79.85 %), and the difference was insignificant ($p > 0.05$). Equally, silt was higher in under the tree canopy (14.25 %) compared to tree gap (12.00 %), and the difference was significant ($p < 0.05$). This is indicative of the effect of initial less litter and organic cover in treefall gaps areas (Tong et al., 2024). However, clay was higher in treefall gap (8.15 %) than in the under the tree canopy (5.80 %), and the difference was significant ($p < 0.05$). This may be due to clay particles redistribution instigated by the formation of small pit-and-mound features in treefall gaps areas, resulting to clay-rich soil microsites (Dun et al., 2024).
Bulk density (BD) is an important property influencing soil development (Mora & Lázaro, 2014). The results showed that the BD in the treefall gap (1.42 g cm^{-3}) was higher than that under the tree canopy (1.38 g cm^{-3}).

Table 1. Soil quality properties of areas under the tree canopy and in treefall gaps in Okomu Plateau Forest

Soil Nutrients	Under the tree canopy	Treefall gap	*p*-value
	Mean ± SD	Mean ±SD	
% Sand	79.95±0.89	79.85±0.89	0.94
% Silt	14.25±0.83	12.00±0.68	0.04*
% Clay	5.80±0.5	8.15±0.47	0.00**
BD (g cm^{-3})	1.38±0.02	1.42±0.02	0.19
pH	4.65±0.12	4.45±0.07	0.15
ECEC ($cmolkg^{-1}$)	5.33±0.3	4.04±0.37	0.01*
SOM (g kg^{-1})	6.64±0.86	4.52±0.77	0.07
SOC (g kg^{-1})	3.83±0.51	2.62±0.44	0.08
TN (g kg^{-1})	0.34±0.05	0.24±0.04	0.09
Avl P (mg/kg)	0.97±0.08	0.68±0.09	0.02*
Ca (cmol kg^{-1}),)	3.93±0.22	3.01±0.27	0.01**
Mg (cmol kg^{-1}),)	0.94±0.05	0.72±0.07	0.01**
K (cmol kg^{-1}),)	0.18±0.01	0.14±0.01	0.01**
Na (cmol kg^{-1}),)	0.26±0.04	0.17±0.02	0.03*
Fe (mg/kg)	165.60±2.64	173.15±2.01	0.03*
Mn (mg/kg)	2.13±0.12	2.29±0.1	0.31
Zn (mg/kg)	6.82±0.36	7.34±0.23	0.23
Cu (mg/kg)	1.06±0.05	1.21±0.07	0.09
THBC ($^{\times}10^4$ cfu g^{-1})	125.45±7.35	105.55±0.034	0.02*
THFC ($^{\times}10^3$cfu g^{-1})	11.45±0.68	8.65±0.53	0.00*

* indicates significance at $p < 0.05$; ** indicates significance at $p < 0.01$

The higher BD values in treefall gaps indicate increased soil compaction, possibly due to seedling recruitment (Muscolo et al., 2010). However, the observed BD values (below 1.75 and 1.85 g cm^{-3}) are under the critical limits for root restriction (Brady & Weil, 2002), suggesting that the soil BD in the treefall gap is unlikely to impede forest regeneration. Nonetheless, the higher BD in treefall gaps may still slow nutrient cycling (Goh et al., 2024).

3.2. Soil Chemical Properties

Soil pH value was higher under the tree canopy (4.65) than in the treefall gap (4.45), indicating that gap soils were more acidic; nonetheless, this difference was not statistically significant. The low pH the soils of the treefall gap may restrict nutrient availability and microbial activity (Meshesha, 2023). This finding aligned with the study of Levia and Frost (2003), who found lower soil pH in the gaps. The openness of the canopy can lead to a decrease in soil pH (Amolikondori et al., 2020), as soils under gaps are more exposed to rainfall, which can accelerate the leaching of cations (Levia & Frost, 2003), potentially explaining the observed lower pH in the treefall gaps. In contrast, Tang et al. (2019) reported a higher mean pH in gaps (4.45) than under the canopy (4.26) in a subtropical *Rhododendron* secondary forest in southwest China. Similarly, in broad-leaved *Pinus koraiensis* forests, Zhang and Zhao (2007) reported no significant differences in soil pH between gap and non-gap forest areas, which are in agreement with the current study.

Effective cation exchange capacity (ECEC) was higher under the tree canopy (5.33 cmol kg^{-1}) than in the treefall gap (4.04 cmol kg^{-1}), and the difference was statistically significant ($p < 0.05$) indicating the negative effect of treefall gap on ECEC. The low ECEC values may lead to poorer retention of nutrients in the soils (Shaibu et al., 2023). This result of the study is consistent with Orobator and Ukpoju (2026), who reported higher ECEC under the tree canopy (14.31 cmol kg^{-1}) than in gaps (12.50 cmol kg^{-1}) in a *Hevea brasiliensis* plantation. Tong et al., (2024) reported that gaps decrease SOC while enhancing some soil nutrients. This observation aligned with the lower ECEC observed in treefall gaps than in under the tree canopy in the present study. Consistent with these patterns, SOM and SOC were lower in the treefall gap. Since, SOM and SOC are significant drivers of ECEC owing to their ability to retain cations (Solly et al., 2020); reductions in their concentrations may have contributed to the lower ECEC observed in the treefall gap.

Soil organic matter (SOM) was higher under the tree canopy (6.64 g kg^{-1}) than in the treefall gap (4.52 g kg^{-1}), suggesting that treefall gaps may be associated with reduced organic matter accumulation in this mixed forest biome. The difference was not statistically significant ($p > 0.05$). However, the low SOM values in the treefall gap may negatively influence soil nutrient availability as well as carbon storage (Tsozué et al., 2021). This may be due to reduced litter decomposition and increased soil leaching in the gap (She et al., 2018). In agreement with our findings, Scharenbroch and Bockheim (2008) reported that soil organic matter was higher under the canopy than in treefall gaps. Potvin and Gotelli (2008) also reported that prior research has suggested that SOM content tends to decrease in gaps. Light intensity in canopy gaps may influence litter decomposition on the forest floor (Arunachalam & Arunachalam, 2020), potentially leading to slower litter accumulation. The field surveys showed that the accretion and decomposition of litter were partial in the treefall gap areas of the Okomu Plateau Forest.

Soil organic carbon (SOC) was higher under the tree canopy (3.83 g kg^{-1}) than in the treefall gap (2.62 g kg^{-1}), indicating lower SOC in the treefall gap soils which may limit nutrient availability. The difference was not statistically significant ($p > 0.05$). This aligned with the study of Tang et al., (2019), who reported that the mean value of organic carbon in the gap soil was lower (10.77 g/kg) than that under the canopy (14.10 g/kg) in a *Rhododendron* secondary forest. They suggested that litter decomposition in gaps enhances leaching, thereby reducing the accumulation of organic carbon in the topsoil. Comparable to our findings, Scharenbroch and Bockheim (2008) found that organic carbon content was higher under the canopy than in treefall gaps. However, Dun et al. (2024) reported that in *Robinia pseudoacacia* L. forests, soil organic carbon content was significantly higher in gap centers than in non-gap areas ($p < 0.05$).

Total nitrogen (TN) concentration was higher under the tree canopy (0.34 g kg^{-1}) than in the treefall gap (0.24 g kg^{-1}), suggesting lower TN levels in treefall gap soils. The difference was not statistically significant ($p > 0.05$). However, the observed low TN may affect plant production, species composition, microbial diversity, nutrient cycling, and organic matter transformation (Högberg et al., 2017; Sardar et al., 2023).The low TN values may be indicative of the acidic soil environment of the treefall gap, as well as the influence of microbial activity in gaps, which stimulates the release of TN in the soil (He et al., 2015). Nutrient losses in gaps may result from enhanced substrate availability and mineralization rates, combined with reduced nutrient uptake by plant roots (Zhang & Zak, 1995). Similarly, the findings of this research are consistent with those of He et al. (2015), who reported higher TN contents in non-gap areas than in gaps. However, the findings of the present study contradict those of Dun et al., (2024), who reported that TN contents were significantly higher in non-gap areas of *Pinus densiflora* Sieb. forests.

Soils under the tree canopy had higher available phosphorus (Avail. P) value (0.97 mg kg^{-1}) than those in the treefall gap (0.68 mg kg^{-1}), indicating lower Avail. P levels in treefall gap soils. The differences were statistically significant ($p < 0.05$). The lower levels of Avail. P may limit the growth of plant and retard forest regeneration (Hou et al., 2020). The observed lower levels of Avail. P may be due to the lower soil pH observed in the treefall gap. Tang et al. (2019) reported that lower soil pH limits the availability of nutrients such as phosphorus. Also, the reduction of litter in treefall gaps may result to the declination in Avail. P contents in gaps, in agreement with the findings in a subtropical humid forest (Arunachalam & Arunachalam, 2020). Gaps may also reduce Avail. P content through leaching losses (She et al., 2018).

Regarding exchangeable cations, soils under the tree canopy had higher concentrations of Ca (3.93 cmol kg^{-1}), Mg (0.94 cmol kg^{-1}), K (0.18 cmol kg^{-1}), and Na (0.26 cmol kg^{-1}), than those in treefall gaps: Ca (3.01 cmol kg^{-1}), Mg (0.72 cmol kg^{-1}), K (0.14 cmol kg^{-1}), and Na (0.17 cmol kg^{-1}), suggesting that treefall gaps are associated with lower levels of exchangeable cations in Okomu Plateau Forest. These differences were statistically significant ($p < 0.05$). Lower levels of exchangeable cations in the soils of tree gaps may reduce nutrient retention and supply, likely as a result of increased leaching. Gap formation exposes soil to higher rainfall, enhancing runoff (Jourgholami et al., 2018) and nutrient losses through leaching. In contrast to the findings of this study, Sisira et al., (2008) reported that Ca and K contents increased in gap centers in Sri Lankan tropical rain forest.

In contrast to exchangeable cations, the concentrations of Fe (173.15 mg kg^{-1}), Mn (2.29 mg kg^{-1}), Zn (7.34 mg kg^{-1}), and Cu (1.21 mg kg^{-1}) were higher in the treefall gap than under the tree canopy (Fe: 165.60 mg kg^{-1}; Mn: 2.13 mg kg^{-1}; Zn: 6.82 mg kg^{-1}; Cu: 1.06 mg kg^{-1}), indicating that treefall gaps may enhance the availability of micronutrients. The differences for Fe were statistically significant ($p < 0.05$), whereas, Mn, Zn, and Cu were not significantly different. However, the upward trend observed for the micronutrients in the treefall gap may be due to the influence of higher temperatures. Scharenbroch and Bockheim (2008) reported that treefall gaps frequently experience higher soil temperatures, consequently enhancing mineralization and leading to increased micronutrients. The concentrations of micronutrients observed in the treefall gaps were safe in terms of contamination, as their values were below the FAO/WHO permissible limits for soils: Fe (50,000 mg kg^{-1}), Mn (2,000 mg kg^{-1}), Zn (300 mg kg^{-1}), and Cu (100 mg kg^{-1}). However, their low status suggests that they may limit soil health and biological activities (Shukla et al., 2021). Conversely, He et al., (2015) observed that gaps in Alpine forests slow the release of trace elements such as Cu and Zn in Azalea (*Rhododendron lapponicum* (L.) Wahlenb.).

3.3. Soil Biological Properties

Higher microbial counts were observed under the tree canopy for THBC (125.45 $\times 10^4$ cfu g^{-1}) and THFC (11.45 $\times 10^3$ cfu g^{-1}) compared to the treefall gap (THBC: 105.55 $\times 10^4$ cfu g^{-1}; THFC: 8.65 $\times 10^3$ cfu g^{-1})). These differences were statistically significant and suggest reduced nutrient cycling efficiency, slower organic matter breakdown, and impaired soil functioning in the treefall gaps. The lower THBC and THFC levels may be due to the effect of lower pH in the treefall gap.

Soil pH affects the form and availability of microorganism activities and biological growth (Tang et al., 2019). The findings suggest that changes in soil chemistry are actively suppressing the microbial community. The lower counts of THBC and THFC in the treefall gaps may also be attributed to differences in vegetation composition within the forest (Ravindran & Yang, 2015). Okomu Plateau Forest is a highly heterogeneous ecosystem characterized by diverse flora. In agreement with our results, previous studies indicated that changes in soil microbial populations are important factors driving the high levels of biogeochemical cycling in gaps (Jourgholami et al., 2021; Yang et al., 2017).

4. Conclusion

The study assessed the impact of treefall gaps on soil quality in the Okomu Plateau Forest. The incidence of treefall gaps resulted in a significant decrease in silt, effective cation exchange capacity (ECEC), available phosphorus, exchangeable bases (Ca, Mg, K, Na), and microbial populations (THBC and THFC). Conversely, treefall gaps were associated with a significant increase in clay content and iron (Fe) levels. While decreases were observed in soil organic matter, nitrogen, and pH, and increases were noted in bulk density and other micronutrients (Zn, Cu, Mn), these specific changes were not statistically significant. The research concludes that treefall gaps generally have a negative impact on soil nutrient availability and microbial activity, suggesting that canopy loss disrupts nutrient cycling and soil fertility in the Okomu Plateau Forest. This underscores the significant role of treefall gaps in altering forest soil chemistry and biological health.

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