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Original Research

Micronutrient Status Across Smallholder Farmers' Fields in Benue State, Nigeria

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Abstract

We assessed extractable copper (Cu), zinc (Zn), iron (Fe), and boron (B), together with pH, cation-exchange capacity (CEC), and texture, in 48 topsoil samples (12 per local government area [LGA]) collected from smallholder fields in Gboko, Makurdi, Otukpo, and Ushongo, Benue State, Nigeria. Mean Cu concentrations ranged from 1.235 mg kg^{-1} in Gboko to 1.710 mg kg^{-1} in Ushongo, while mean Fe concentrations ranged from 0.387 mg kg^{-1} in Makurdi to 0.569 mg kg^{-1} in Gboko; omnibus tests did not indicate significant LGA differences in either element. Mean Zn was lowest in Makurdi (0.164 mg kg^{-1}) and highest in Ushongo (1.359 mg kg^{-1}), whereas mean B was lowest in Makurdi (0.413 mg kg^{-1}) and highest in Otukpo (0.994 mg kg^{-1}). Kruskal–Wallis tests indicated omnibus LGA differences in Zn, B, pH, and CEC, but not in Cu or Fe; pairwise differences were not tested. Twenty-eight samples (58.3%) were below the exploratory Zn cut-off of 0.5 mg kg^{-1}, which is not a validated critical limit. pH and CEC were measured to characterize soil conditions and test associations with micronutrients; none of the eight pre-specified correlations remained significant after adjustment. Because crop tissue, yield, and field-history data were unavailable, the results describe soil measurements and do not establish crop deficiency, yield response, or causal effects of texture or CEC.

1. Introduction

Micronutrients are required in small quantities, but they contribute to essential plant processes and can constrain growth, yield, and the nutritional composition of food crops when their supply is inadequate (Dimkpa & Bindraban, 2016). Soil concentrations alone do not establish crop uptake or human nutritional outcomes: these depend on nutrient form, crop species and cultivar, soil conditions, and management. Across sub-Saharan Africa, micronutrient deficiencies are widespread zinc (Zn), boron (B), iron (Fe), manganese (Mn) and copper (Cu) (Kihara *et al.*, 2020; Kuhe, 2025). This variability makes local measurement important, while cautioning against transferring regional deficiency estimates directly to individual farms.

Micronutrient availability is influenced by soil reaction, texture, organic matter, drainage, and nutrient interactions; relationships between soil properties and micronutrients vary by element and location (Ebong *et al.*, 2022). Soil pH can alter the solubility and sorption of several trace elements, while texture and organic matter affect retention, movement, and the size of extractable pools; therefore, a measured concentration is not equivalent to plant availability. Critical values also depend on the extraction method, crop, soil conditions, and calibration procedure (Siatwiinda *et al.*, 2024). These considerations motivated measuring pH and CEC alongside the micronutrients: pH provides a key chemical context, and CEC characterizes the soil's capacity to retain exchangeable cations. The present observational design can test associations, but cannot establish that either property caused a concentration pattern.

Benue State is an important food-producing region. Cassava, maize, yams are widely cultivated, including in Makurdi and Gboko, and maize, cassava, and yam are documented cropping systems in Ukum (Abah & Petja, 2016; Apelebiri *et al.*, 2024). These reports establish regional crop context; the crop species and management histories of the sampled fields were not recorded. Local soil studies also point to substantial spatial variation: Makurdi topsoils have been described as sandy loam and moderately acidic, while studies in Logo and Ukum local government areas (LGAs) of Benue State reported sandy soils and relatively low CEC (Ibrahim and Idoga, 2015;

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Agada *et al.*, 2024; Anhwange & Magashi, 2025). Accordingly, this study assessed extractable Cu, Zn, Fe, and B in smallholder topsoils from Gboko, Makurdi, Otukpo, and Ushongo, examined associations with pH and CEC, and described co-occurrence with texture. We hypothesised that micronutrient concentrations differ among LGAs; the observational analyses evaluate associations, not causal effects.

2. Methods

2.1 Study area, sampling design, and laboratory analyses

The study was conducted in Benue State, Nigeria. Forty-eight surface-soil samples (0–0.30 m) were collected from smallholder farmers' fields in four of the State's 23 LGAs randomly: Gboko, Makurdi, Otukpo, and Ushongo (12 samples per LGA). The study area is seasonally wet and dry, and soils have been described as developing from diverse parent materials (Fagbami & Akamigbo, 1986). Crop identities and management histories, were not systematically recorded; the description of the fields as long-established cereal-based systems were based on farmer's report. Therefore, the results are interpreted as descriptions of the sampled fields and not as representative estimates for all of Benue State.

Soil samples were air-dried in the shade, ground, and passed through a 2.0-mm nylon sieve. Soil pH was measured in a 1:2.5 (w/v) soil-to-water suspension (Thomas, 1996). Extractable Zn, Cu, and Fe were determined using the DTPA extraction procedure (Lindsay and Norvell, 1978), with concentrations measured by atomic absorption spectrophotometry (AAS), Baker and Suhr, (1982). Boron was extracted with hot water (Berger and Truog, 1939; Parker and Gardner, 1981; Bingham, 1982). Cation exchange capacity (CEC) was determined following Sumner and Miller (1996). Particle-size distribution was determined by the Bouyoucos hydrometer method (Bouyoucos, 1962; Gee and Bauder, 1986). All extractable element concentrations are expressed in mg kg^{-1}.

2.2 Exploratory zinc cut-off

The Nutrient index of Park et al (1951), was not used. An exploratory cut off, of 0.5 mg kg^{-1} Zn was used. Although published soil-test interpretation systems report similar values for DTPA-extractable Zn, critical limits depend on extraction procedure, soil characteristics, crop, and crop-response calibration (Lindsay & Norvell, 1978; Siatwiinda *et al.*, 2024). Consequently, Zn concentrations are reported without assigning deficiency or sufficiency status. The 0.5 mg kg^{-1} value is retained solely as an exploratory operational threshold for describing the observed distribution and should not be interpreted as a locally calibrated agronomic critical limit.

2.3 Statistical analysis

Descriptive statistics were calculated overall and by LGA. LGA was treated as a categorical grouping factor in observational comparisons; no treatment was imposed. Omnibus differences among the four groups were assessed using one-way ANOVA and the Kruskal–Wallis test. Shapiro–Wilk tests screened within-group normality, and Levene's test screened homogeneity of variance. Because several variables showed non-normality or unequal variances, Kruskal–Wallis results are emphasized; ANOVA is reported as a secondary comparison. No post-hoc pairwise tests were conducted, so the results support only omnibus statements about differences among LGAs. Spearman rank correlations were calculated for the eight pre-specified pairs of Cu, Zn, Fe, or B with pH or CEC. Benjamini–Hochberg adjustment was applied across these eight tests, with unadjusted p-values and adjusted q-values reported. Texture classes were summarized descriptively. The nominal significance level was $\alpha = 0.05$. All statistical Analyses, were conducted on 48 complete observations in Python 3.13.14.(Python Software Foundation, 2025).

3. Results

3.1. Data completeness and descriptive summary

The 48-observation dataset contained 12 samples from each of the four LGAs. Mean (± SD) concentrations were 1.494 ± 0.658 mg kg^{-1} for Cu, 0.890 ± 1.119 mg kg^{-1} for Zn, 0.472 ± 0.251 mg kg^{-1} for Fe, and 0.779 ± 0.399 mg kg^{-1} for B. Mean pH was 5.742 ± 0.476, and mean CEC was 9.479 ± 1.905 cmol kg^{-1} (Table 1). These are extractable-soil measurements; no deficiency or sufficiency class is assigned.

Table 1. Overall descriptive statistics for the measured soil properties. Concentrations are in mg kg^{-1}; CEC is in cmol kg^{-1}.

Variable	n	Mean	SD	Median	Min.	Max.
Cu	48	1.494	0.658	1.545	0.081	3.630
Zn	48	0.890	1.119	0.289	0.001	3.920
Fe	48	0.472	0.251	0.422	0.032	1.050
B	48	0.779	0.399	0.819	0.078	1.867
pH	48	5.742	0.476	5.615	5.000	6.850
CEC	48	9.479	1.905	9.500	5.900	16.000

3.2 Variation among local government areas

Descriptive means differed among LGAs. Makurdi had the lowest mean Zn (0.164 mg kg^{-1}) and B (0.413 mg kg^{-1}); Ushongo had the highest mean Zn (1.359 mg kg^{-1}), and Otukpo had the highest mean B (0.994 mg kg^{-1}). Gboko had the highest mean Fe (0.569 mg kg^{-1}). Cu means ranged from 1.235 mg kg^{-1} in Gboko to 1.710 mg kg^{-1} in Ushongo. Makurdi had the highest mean CEC (10.733 cmol kg^{-1}), and Ushongo the lowest (7.583 cmol kg^{-1}). Mean pH was highest in Gboko (6.056) and lowest in Otukpo (5.317). Table 2 presents group means and standard deviations; Figures 1 and 2 show the sample distributions. These descriptive contrasts should not be read as significant pairwise differences because no post-hoc tests were

Table 2. Descriptive statistics by local government area; n = 12 per LGA.

LGA	Cu (mg kg^{-1})	Zn (mg kg^{-1})	Fe (mg kg^{-1})	B (mg kg^{-1})	pH	CEC (cmol kg^{-1})
Gboko	1.235 ± 1.009	0.789 ± 1.160	0.569 ± 0.333	0.770 ± 0.413	6.056 ± 0.412	9.417 ± 0.754
Makurdi	1.367 ± 0.451	0.164 ± 0.296	0.387 ± 0.215	0.413 ± 0.259	5.988 ± 0.584	10.733 ± 2.085
Otukpo	1.665 ± 0.530	1.250 ± 1.184	0.439 ± 0.213	0.994 ± 0.328	5.317 ± 0.185	10.183 ± 1.701
Ushongo	1.710 ± 0.416	1.359 ± 1.245	0.492 ± 0.217	0.941 ± 0.331	5.608 ± 0.173	7.583 ± 1.228

Note: Values represent mean ± Standard Deviation

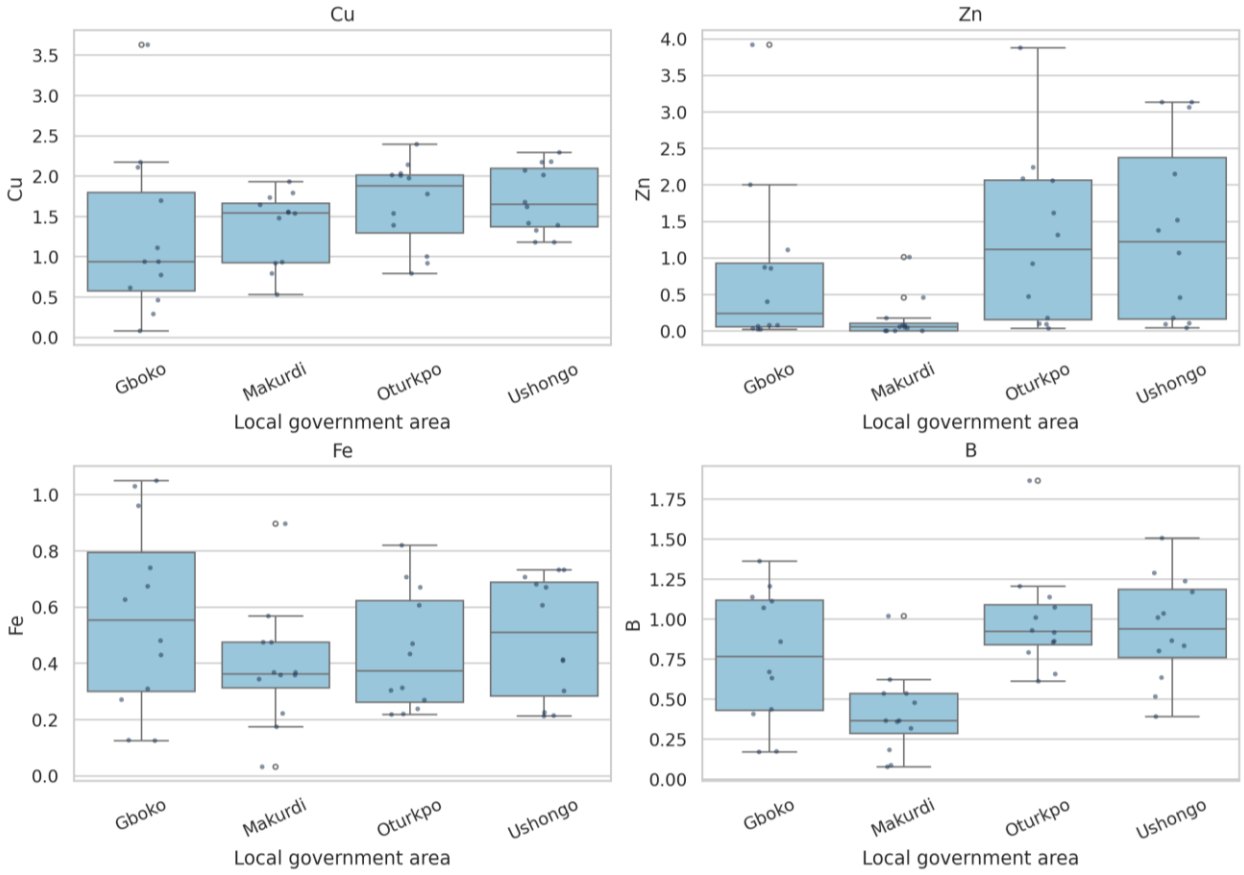


Figure 1. Distributions of extractable Cu, Zn, Fe, and B by LGA; concentrations are in mg kg^{-1}

performed. Soil pH means were highest in Gboko and Makurdi and lowest in Otukpo; CEC was highest in Makurdi and lowest in Ushongo (Table 2; Figure 2).

3.3 Omnibus comparisons among LGAs

Kruskal–Wallis tests indicated differences among LGAs for Zn ($H = 14.413$, $p = 0.002$), B ($H = 15.994$, $p = 0.001$), pH ($H = 21.220$, $p < 0.0001$), and CEC ($H = 20.388$, $p < 0.0001$), but not for Cu ($H = 5.849$, $p = 0.119$) or Fe ($H = 2.280$, $p = 0.516$). ANOVA produced the same significance pattern (Table 3). These are omnibus results only; the analyses do not identify which pairs of LGAs differ. Kruskal–Wallis results are emphasized because assumption screening indicated non-normality for Zn, Fe, and B, and unequal variances for Zn and pH.

3.4 Texture distribution and observations below the Zn cut-off

Four texture classes were reported: sandy clay loam (17 samples), sand (15), sandy loam (12), and loam (4). Twenty-eight of 48 samples (58.3%) had Zn concentrations below the exploratory cut-off of 0.5 mg kg^{-1}. By LGA, the corresponding counts were 7/12 in Gboko (58.3%), 11/12 in Makurdi (91.7%), 5/12 in Otukpo (41.7%), and 5/12 in Ushongo (41.7%) (Table 4; Figure 3). Because this cut-off is not validated as a critical limit, these proportions do not estimate the prevalence of crop Zn deficiency. The data are descriptive and do not establish that texture caused the observed pattern.

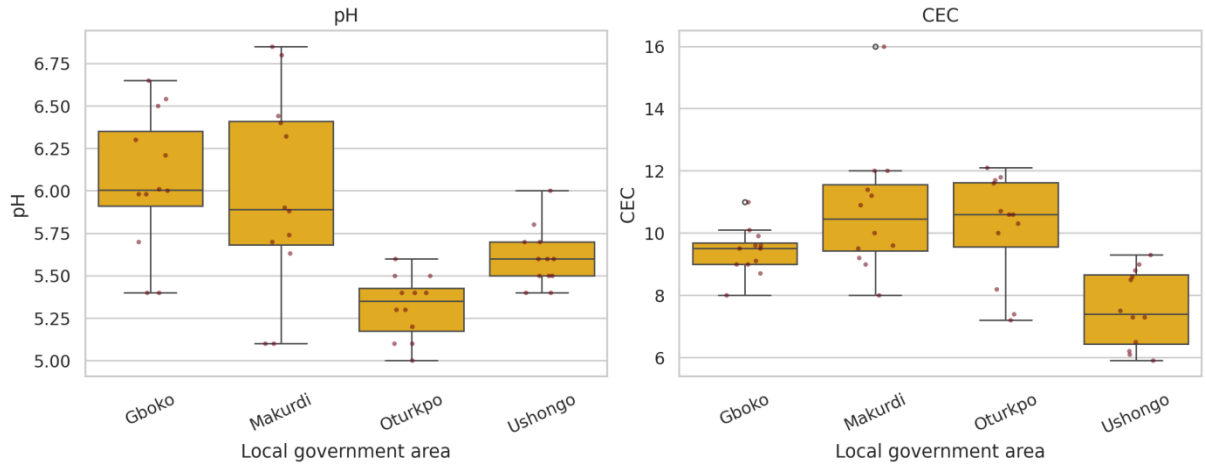


Figure 2. Distributions of soil pH and CEC by LGA; CEC is in cmol kg^{-1}

Table 3. Omnibus tests of LGA differences for the soil properties.

Variable	ANOVA F	ANOVA p	Kruskal–Wallis H	Kruskal–Wallis p	Levene p	Smallest within-LGA Shapiro–Wilk p
Cu	1.525	0.221	5.849	0.119	0.188	0.111
Zn	3.234	0.031	14.413	0.002	0.015	0.0001
Fe	1.159	0.336	2.280	0.516	0.095	0.029
B	7.274	0.0005	15.994	0.001	0.178	0.033
pH	9.947	<0.0001	21.220	<0.0001	0.002	0.262
CEC	9.731	<0.0001	20.388	<0.0001	0.119	0.062

Table 4. Counts below the exploratory Zn cut-off (<0.5 mg kg^{-1}) by local government area; the cut-off is not a validated critical limit.

LGA	Samples (n)	Zn < 0.5 mg kg^{-1} (n)	Zn < 0.5 mg kg^{-1} (%)
Gboko	12	7	58.3
Makurdi	12	11	91.7
Otukpo	12	5	41.7
Ushongo	12	5	41.7
Total	48	28	58.3

3.5 Correlations with pH and CEC

None of the eight pre-specified Spearman correlations between Cu, Zn, Fe, or B and pH or CEC remained statistically significant after Benjamini–Hochberg adjustment (all $q \geq 0.200$). The strongest unadjusted associations were negative correlations of B with pH ($\rho = -0.257$, $p = 0.078$) and Zn with pH ($\rho = -0.243$, $p = 0.096$); neither met the prespecified $\alpha = 0.05$ criterion. These results do not provide evidence of an association in this sample, but they do not establish that the soil properties have no effect.

4. Discussion

4.1. Interpretation in the Benue and sub-Saharan African context

This study found variation among the sampled fields in extractable Zn and B, pH, and CEC, while the omnibus tests did not detect differences in Cu or Fe among the four sampled LGAs. The evidence supports describing variation within this sample, not a uniform Benue-wide micronutrient status or pairwise ranking of specific LGAs. Local studies similarly describe variable texture and nutrient conditions: Makurdi topsoils have been reported as sandy loam with moderate acidity and low-to-moderate nutrient status, and Logo/Ukum soils have been described as sandy with relatively low CEC (Usman et al 2018; Agada *et al.*, 2024; Anhwange & Magashi, 2025). Kuhe (2025), assessing nutrient status of some Benue soils, reported low zinc and adequate copper in all locations studied. In northern Nigerian savanna, omission trials found substantial field-to-field variation in maize yield responses, including variation in response to secondary and micronutrients (Shehu *et al.*, 2018). Together, these studies support local diagnosis rather than transferring one regional recommendation to every farm.

The available critical values do not support classification of Fe, Cu, B, or Zn as sufficient or deficient because they were not calibrated to the extraction procedures used for every element. Measured concentrations are therefore reported without categorical nutrient-status claims. Without crop-tissue or yield data, this study cannot establish plant uptake, nutritional quality, or agronomic response.

4.2 Soil properties, crop context, and limits of interpretation

The study measured pH and CEC to provide chemical context and to test pre-specified associations with extractable micronutrients. Although texture, pH, and exchange capacity

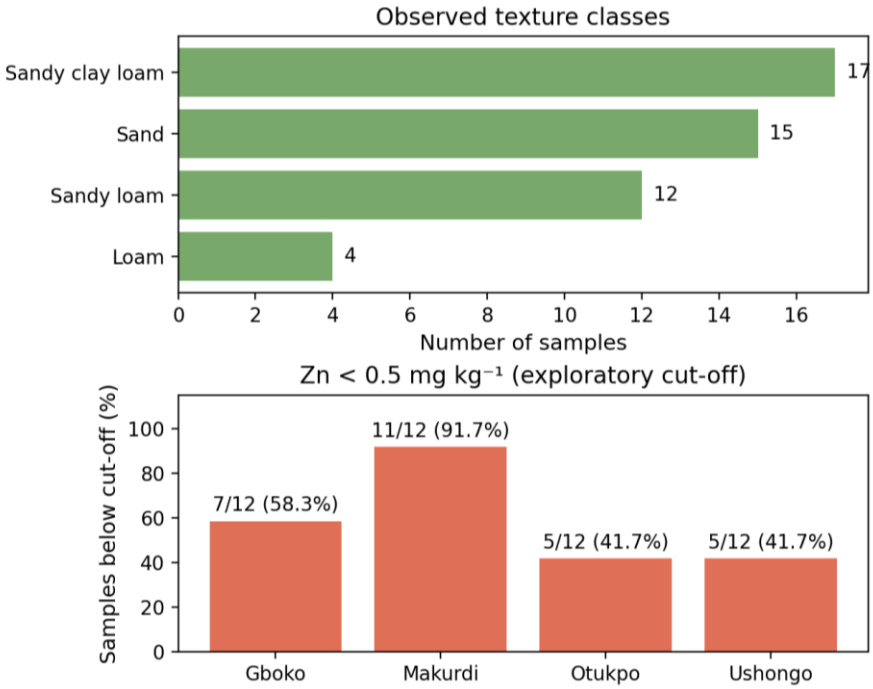


Figure 3. Texture-class frequencies and counts below the exploratory Zn cut-off by LGA; the cut-off is not a validated critical limit.

can inform hypotheses about retention and mobility, none of the eight tested correlations was statistically significant after adjustment, and texture was analyzed only descriptively. The data therefore do not demonstrate a texture- or CEC-driven mechanism. This caution matters because clay and organic matter may retain some nutrient forms while also increasing sorption, and field-scale availability depends on the extraction method and soil conditions. Previous work in Benue documents sandy topsoils and spatial variation in fertility, but those findings cannot substitute for missing site-level measurements in the present sample (Agada *et al.*, 2023;2024). Although regional studies identify cassava, maize, and yam as important crops, the sampled farms' crop identities, tissue concentrations, and yields were not supplied (Abah & Petja, 2016; Apelebiri *et al.*, 2024). No crop-specific fertiliser recommendation is justified from the present soil data alone.

4.3 Management implications

The principal management implication is diagnostic rather than prescriptive. Soil testing should be interpreted using extraction- and crop-appropriate calibration, and any suspected micronutrient limitation should be checked with crop-tissue analysis and, where feasible, field response trials. This recommendation is consistent with local evidence favouring site-specific rather than blanket fertiliser advice in Makurdi (Agada *et al.*, 2024;2026).

4.4 Strengths and limitations

The study includes smallholder fields from four LGAs and reports soil measurements for four micronutrients alongside pH, CEC, and texture. However, important limitations constrain interpretation: farm and fertilizer histories, organic carbon, available phosphorus, drainage, crop tissue, and yield were not available. These omissions prevent assessment of representativeness, causal attribution, and prediction of crop nutrient uptake or yield response(s).

5. Conclusion

Extractable micronutrient concentrations and soil properties varied across the 48 sampled fields in Gboko, Makurdi, Otukpo, and Ushongo. Omnibus tests indicated LGA differences for Zn, B, pH, and CEC, but not for Cu or Fe; the data do not support pairwise rankings. Twenty-eight samples (58.3%) were below the exploratory Zn cut-off of 0.5 mg kg^{-1}, which is not a validated critical limit and should not be interpreted as the prevalence of crop deficiency. No micronutrient sufficiency or deficiency classification is made because the available critical thresholds are not compatible with the reported extraction procedures. The findings justify further, site-specific investigation, not a blanket fertiliser recommendation.Future work should document the site-selection process and farm history, confirm laboratory methods and extraction protocols, include crop-specific tissue and yield measurements, and test calibrated nutrient recommendations in replicated field trials.

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Conflict of Interest

The authors declare no conflict of interest.

Generative AI Statement

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) and Claude (Anthropic) to assist with analytical script development, manuscript drafting, language refinement, grammar correction, and improvement of clarity. All AI-assisted outputs were critically reviewed, verified, and edited by the authors. The authors take full responsibility for the accuracy, originality, interpretation, and integrity of the final manuscript, including the analytical procedures and reported results.

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