



Outdoor Activity and Dietary Vitamin D Intake as Moderators of Caries Risk Factors in Preschool Children

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Abstract

Dental caries remains a major public health problem among preschool children and is strongly influenced by behavioral risk factors, particularly frequent sugar consumption and inadequate toothbrushing. Outdoor activity and dietary vitamin D intake may contribute to oral health through their potential roles in vitamin D status and dental mineralization. This study examined whether outdoor activity and dietary vitamin D intake moderate the association between caries risk factors and dental caries status among preschool children. An analytical cross-sectional study was conducted among children aged 5–6 years in the Kedungdoro Community Health Center area, Surabaya. From a target population of 393 children, 200 participants were selected using simple random sampling. Data on sugary food and beverage consumption, toothbrushing habits, outdoor activity, and dietary vitamin D intake were collected using parent-administered questionnaires, while dental caries status was clinically assessed using the dmft index. Spearman's rank correlation and hierarchical moderated regression analyses were performed. Among the 200 children, sugary food and beverage consumption ($r = 0.737$, $p < 0.001$) and poor toothbrushing habits ($r = 0.744$, $p < 0.001$) were strongly and positively associated with dental caries status. Outdoor activity was inversely associated with caries status ($r = -0.355$, $p < 0.001$), whereas dietary vitamin D intake was not significantly associated with caries status ($r = -0.069$, $p = 0.333$). In the final regression model, sugary food and beverage consumption ($\beta = 0.401$, $p < 0.001$) and poor toothbrushing habits ($\beta = 0.350$, $p < 0.001$) remained significant predictors, while outdoor activity showed an inverse association ($\beta = -0.147$, $p = 0.009$). Neither outdoor activity nor dietary vitamin D intake significantly moderated the associations between caries risk factors and dental caries. These findings highlight the importance of behavioral factors in preventing dental caries among preschool children.

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1. INTRODUCTION

Dental caries remains one of the most prevalent chronic diseases among preschool children and continues to be a major global public health concern because of its high prevalence and adverse effects on children's growth, nutrition, and quality of life. Early Childhood Caries (ECC) is defined as the presence of one or more decayed, missing due to caries, or filled primary teeth in children younger than 71 months (Adugna et al., 2024). According to the World Health Organization, approximately 43% of children worldwide experience caries in their primary dentition, with substantially higher prevalence reported in low- and middle-income countries than in high-income countries (World Health Organization, 2022). In Indonesia, the Indonesia Health Survey 2023 reported that dental caries affects 78.3% of children aged 3–4 years and 84.8% of five-year-old children, with mean dmft indices of 4.9 and 6.7, respectively (Kementerian Kesehatan Republik Indonesia, 2023). Likewise, a local study conducted in Gubeng District, Surabaya, found that approximately 90% of preschool children had ECC with a mean decayed, extracted, and filled teeth (def-t) index of 4.79 (Sya'bania, 2024). Furthermore, the 2024 Annual Report of the Surabaya Health Office identified Kedungdoro Community Health Center as the area with the highest number of pediatric dental caries cases in Surabaya (1,617 cases), highlighting the urgent need to identify determinants of dental caries in this population.

Dental caries is a multifactorial disease resulting from complex interactions among cariogenic microorganisms, fermentable carbohydrates, susceptible tooth structures, saliva, and time (Featherstone, 2008; Pitts et al., 2017). Among these determinants, behavioral factors are considered the most modifiable and therefore represent the primary target for preventive interventions. Frequent consumption of sugary foods and beverages, prolonged bottle-feeding before bedtime, and inadequate toothbrushing practices have consistently been identified as major behavioral risk factors for ECC (Mathur & Dhillon, 2018; Tahir & Nazir, 2018). Frequent sugar intake provides fermentable substrates for *Streptococcus mutans* and *Lactobacillus*, leading to acid production and enamel demineralization, whereas poor oral hygiene promotes biofilm accumulation and sustained colonization by cariogenic bacteria (Pitts et al., 2017). Although these behavioral determinants have been extensively investigated, they do not fully explain the variability in caries occurrence among children exposed to similar oral health behaviors, suggesting that additional protective factors may modify this relationship.

One potential protective factor that has received increasing attention is vitamin D, which plays a critical role in calcium and phosphate homeostasis and is essential for the mineralization of enamel and dentin (Gül Aydın & Özdemir, 2021; Botelho et al., 2020). Vitamin D deficiency has been associated with enamel hypomineralization, reduced salivary secretion, and impaired expression of antimicrobial peptides such as cathelicidin (LL-37), thereby increasing susceptibility to cariogenic bacterial colonization (Gyll et al., 2018; Alhelfi & Hoobi, 2023). A meta-analysis of 24 randomized controlled trials further demonstrated that vitamin D supplementation reduced dental caries incidence in children by approximately 47% (Hujoel, 2013). Because approximately 80% of vitamin D is synthesized in the skin following ultraviolet-B (UVB) exposure, while the remainder is obtained through dietary intake and supplementation (Benedik, 2022), children's outdoor activity and dietary consumption of vitamin D-rich foods may represent important behavioral determinants of oral health. Natural dietary sources include fatty fish, eggs, liver, and fortified foods (Gül Aydın & Özdemir, 2021; Botelho et al., 2020). Nevertheless, despite abundant sunlight throughout the year, vitamin D insufficiency remains common among Indonesian children due to limited outdoor activity, increased indoor lifestyles,

sunscreen use, and clothing habits that reduce effective UVB exposure (Pulungan et al., 2021).

The relationship between vitamin D-related behaviors and dental caries may be understood through the behavioral health determinant framework, which emphasizes that health status is influenced by environmental, behavioral, health service, and hereditary factors, with behavior representing the most modifiable component. Within this framework, outdoor activity and dietary vitamin D intake may strengthen enamel mineralization and improve host resistance against cariogenic processes, thereby reducing the impact of established behavioral risk factors on caries development. Rather than acting solely as independent protective factors, these behaviors may also modify the magnitude of the association between conventional caries risk factors and caries outcomes. However, evidence regarding this potential moderating role remains limited, particularly among preschool children living in tropical countries where sunlight availability is abundant but vitamin D deficiency persists.

Although numerous studies have examined the direct effects of oral hygiene practices, sugar consumption, or vitamin D status on dental caries, few have investigated whether outdoor activity and dietary vitamin D intake modify the relationship between behavioral caries risk factors and dental caries among preschool children. This research gap is particularly evident in Indonesia, where studies integrating oral behavioral risk factors with vitamin D-related behaviors remain scarce. Therefore, the present study aimed to analyze the moderating roles of outdoor activity and dietary vitamin D intake in the association between behavioral caries risk factors and dental caries status among preschool children in the Kedungdoro Community Health Center area, Surabaya. The findings are expected to provide evidence for developing integrated behavioral and nutritional strategies to improve oral health and reduce the burden of early childhood caries.

2. METHODS

This analytical observational study employed a cross-sectional design to examine the association between behavioral caries risk factors and dental caries status among preschool children, as well as to investigate the moderating roles of outdoor activity and dietary vitamin D intake in this relationship. A cross-sectional approach was considered appropriate because all variables were measured simultaneously, enabling the assessment of associations between exposure and outcome variables within the study population. The research was conducted from February to March 2026 in several kindergartens located within the service area of the Kedungdoro Community Health Center, Surabaya, East Java, Indonesia, an urban tropical area characterized by a high burden of childhood dental caries and year-round ultraviolet-B (UVB) exposure.

The study population consisted of all preschool children aged 5–6 years enrolled in kindergartens within the Kedungdoro Community Health Center area. Based on school registration records, the target population comprised 393 children. The required sample size was calculated using the Slovin formula, yielding a minimum sample of 199 participants. Participants were selected through simple random sampling to ensure that every eligible child had an equal opportunity to be included in the study. Children were eligible if they were 5–6 years of age, enrolled in one of the selected kindergartens, in good general health, and had written informed consent provided by their parents or legal guardians. Children who were absent during data collection or whose parents or guardians declined participation or failed to cooperate throughout the study procedures were excluded.

The dependent variable was dental caries status, which was clinically assessed using the decayed, missing, and filled primary teeth (dmf-t) index. The independent variables comprised behavioral caries risk factors, specifically the frequency of sugary food and beverage consumption and toothbrushing habits. The moderating variables included outdoor activity and dietary vitamin D intake. Data on behavioral risk factors, outdoor activity, and dietary vitamin D intake were collected using structured questionnaires completed by parents or legal guardians. Outdoor activity was assessed based on the child's average duration of daily outdoor exposure, whereas dietary vitamin D intake was evaluated from the reported frequency of consuming vitamin D-rich foods. Clinical oral examinations were performed by trained and calibrated examiners following standardized examination procedures to determine the dmf-t scores of all participants.

Data were analyzed using a computerized statistical software package. Descriptive statistics were used to summarize participant characteristics and the distribution of study variables. Categorical variables were presented as frequencies and percentages, whereas continuous variables were described using the mean, standard deviation, median, minimum, and maximum values, depending on data distribution. The associations between behavioral caries risk factors, outdoor activity, dietary vitamin D intake, and dental caries status were initially examined using Spearman's rank correlation test, as several study variables did not meet the assumption of normal distribution.

To evaluate the moderating effects of outdoor activity and dietary vitamin D intake, Moderated Regression Analysis (MRA) was performed using hierarchical multiple linear regression. Prior to constructing interaction terms, all continuous independent and moderator variables were mean-centered to reduce multicollinearity. Three regression models were developed sequentially. The first model included the primary behavioral predictors, namely sugary food and beverage consumption and toothbrushing habits. The second model incorporated outdoor activity and dietary vitamin D intake as moderator variables. The final model added four interaction terms, consisting of sugary food and beverage consumption $\times$ outdoor activity, toothbrushing habits $\times$ outdoor activity, sugary food and beverage consumption $\times$ dietary vitamin D intake, and toothbrushing habits $\times$ dietary vitamin D intake. A moderator was considered significant when the interaction term demonstrated a p-value of less than 0.05. In addition, changes in the coefficient of determination (R^2) across successive models were examined to determine the additional explanatory contribution of the moderator variables and their interaction effects.

Prior to regression analysis, all assumptions of linear regression were evaluated to ensure the appropriateness of the statistical model. Multicollinearity was assessed using tolerance and variance inflation factor (VIF) values, autocorrelation was evaluated using the Durbin–Watson statistic, normality of residuals was examined through histograms and normal probability (P–P) plots, and heteroscedasticity was assessed using scatterplots and the Glejser test. The regression model was considered acceptable when tolerance values exceeded 0.10, VIF values were <10 , the Durbin–Watson statistic approached 2.0, residuals were approximately normally distributed, and no evidence of heteroscedasticity was observed.

Ethical approval for this study was obtained from the Health Research Ethics Committee, Faculty of Dental Medicine, Universitas Airlangga (Approval No. 0335/HRECC.FODM/III/2026). Written informed consent was obtained from all parents or legal guardians before participation. All study procedures complied with the ethical principles outlined in the Declaration of Helsinki, and the confidentiality and anonymity of participants were maintained throughout the research process.

3. RESULTS AND DISCUSSION

A total of 200 preschool children aged 5–6 years and their parents or legal guardians participated in this study. Parents or guardians completed the questionnaires regarding behavioral risk factors, outdoor activity, and dietary vitamin D intake, while children's dental caries status was assessed clinically using the dmft index.

Table 1. Characteristics of participants and distribution of study variables (n = 200).

Variable	Category	n	%
Parents' educational level	Elementary school	18	9.0
	Junior high school	21	10.5
	Senior high school	129	64.5
	Diploma	12	6.0
	Bachelor's degree	20	10.0
Parents' occupation	Housewife	124	62.0
	Employee	38	19.0
	Self-employed	24	12.0
	Civil servant/Military/Police	7	3.5
	Others	7	3.5
Child age (years)	5	61	30.5
	6	139	69.5
Sex	Male	92	46.0
	Female	108	54.0
Sugary food and beverage consumption	Low	25	12.5
	Moderate	61	30.5
	High	114	57.0
Poor toothbrushing habits	Low	24	12.0
	Moderate	51	25.5
	High	125	62.5
Outdoor activity	Insufficient	133	66.5
	Sufficient	67	33.5
Dietary vitamin D intake	Inadequate	161	80.5
	Adequate	39	19.5

Table 1 summarizes the demographic characteristics of the participants and the distribution of the main study variables. Most parents or guardians had completed senior high school (64.5%), while 62.0% were housewives, indicating that the majority of respondents had a secondary education and were primarily responsible for childcare. Among the preschool children, 69.5% were 6 years old and 54.0% were female, demonstrating a relatively balanced sex distribution with a predominance of older preschool children. Regarding behavioral risk factors, more than half of the children (57.0%) were classified as having a high frequency of sugary food and beverage consumption, and 62.5% exhibited poor toothbrushing habits, suggesting that unfavorable oral health behaviors were common in the study population.

The distribution of vitamin D–related behaviors also revealed suboptimal conditions. Approximately 66.5% of the children had insufficient outdoor activity, while 80.5% had inadequate dietary vitamin D intake. These findings indicate that a large proportion of preschool children had limited exposure to behaviors that may support adequate vitamin D status.

The descriptive findings suggest that preschool children in the Kedungdoro Community Health Center area were characterized by a high prevalence of modifiable behavioral risk factors for dental caries, accompanied by inadequate outdoor activity and low dietary vitamin D intake. These baseline characteristics provide an important context for subsequent analyses examining the associations between behavioral risk factors, vitamin D–related behaviors, and dental caries status.

Table 2. Spearman correlation between study variables and dental caries status among preschool children (n = 200)

Variable	Spearman's <i>r</i>	<i>p</i> -value
Sugary food and beverage consumption	0.737	<0.001
Poor toothbrushing habits	0.744	<0.001
Outdoor activity	−0.355	<0.001
Dietary vitamin D intake	−0.069	0.333

Table 2 presents the bivariate associations between the study variables and dental caries status. Sugary food and beverage consumption ($r = 0.737$, $p < 0.001$) and poor toothbrushing habits ($r = 0.744$, $p < 0.001$) demonstrated strong positive correlations with dental caries status, indicating that children with more frequent sugar consumption and poorer oral hygiene practices tended to have higher dmft scores. Conversely, outdoor activity was moderately and negatively associated with dental caries ($r = -0.355$, $p < 0.001$), suggesting that greater outdoor activity was related to lower caries severity. No significant correlation was observed between dietary vitamin D intake and dental caries status ($r = -0.069$, $p = 0.333$).

Table 3. Hierarchical moderated regression analysis predicting dental caries status among preschool children.

Model Summary					
Model	R^2	Adjusted R^2	ΔR^2	ΔF	Δp
Model 1: Behavioral risk factors	0.556	0.552	0.556	123.473	<0.001
Model 2: + Moderator variables	0.568	0.559	0.012	2.717	0.069
Model 3: + Interaction terms	0.583	0.566	0.015	1.690	0.154
Regression Coefficients (Final Model)					
Variable	B	β	t	<i>p</i>	
Sugary food and beverage consumption	0.421	0.401	5.753	<0.001	
Poor toothbrushing habits	0.349	0.350	5.042	<0.001	
Outdoor activity	−0.022	−0.147	−2.642	0.009	
Dietary vitamin D intake	−0.001	−0.007	−0.137	0.892	
Sugar × Outdoor activity	0.002	0.061	0.923	0.357	
Toothbrushing × Outdoor activity	−0.004	−0.116	−1.765	0.079	
Sugar × Vitamin D intake	−0.003	−0.121	−1.933	0.055	
Toothbrushing × Vitamin D intake	0.003	0.113	1.847	0.066	

Note: Model significance: Model 1: $F = 123.473$ ($p < 0.001$); Model 2: $F = 64.171$ ($p < 0.001$); Model 3: $F = 33.385$ ($p < 0.001$).

Table 3 summarizes the hierarchical moderated regression analysis. In Model 1, behavioral risk factors explained 55.6% of the variance in dental caries status ($R^2 = 0.556$, $p < 0.001$). Adding outdoor activity and dietary vitamin D intake in Model 2 increased the explained variance only slightly ($\Delta R^2 = 0.012$), and this improvement was not statistically significant ($p = 0.069$). Likewise, incorporating the interaction terms in Model 3 produced

a marginal increase in explanatory power ($\Delta R^2 = 0.015$), which also failed to reach statistical significance ($p = 0.154$). These findings indicate that neither outdoor activity nor dietary vitamin D intake significantly improved the prediction of dental caries beyond the behavioral risk factors.

In the final regression model, frequent sugary food and beverage consumption ($\beta = 0.401$, $p < 0.001$) and poor toothbrushing habits ($\beta = 0.350$, $p < 0.001$) remained significant positive predictors of dental caries status. Outdoor activity showed a significant inverse association with dental caries ($\beta = -0.147$, $p = 0.009$), whereas dietary vitamin D intake was not significantly associated with dental caries ($p = 0.892$). Furthermore, none of the interaction terms reached statistical significance ($p > 0.05$), indicating that outdoor activity and dietary vitamin D intake did not moderate the relationship between behavioral risk factors and dental caries status.

Table 4. Regression diagnostic tests.

Assumption	Result	Interpretation
Multicollinearity	Tolerance >0.10 ; VIF <10	No multicollinearity
Autocorrelation	Durbin–Watson = 1.809	No autocorrelation
Residual normality	Histogram and Normal P–P Plot	Approximately normal
Heteroscedasticity	Glejser test ($p > 0.05$)	No heteroscedasticity

The regression diagnostic tests confirmed that all assumptions required for multiple linear regression were satisfied (Table 4). No evidence of multicollinearity was observed, as all predictors met the recommended tolerance and VIF thresholds. The Durbin–Watson statistic (1.809) indicated the absence of autocorrelation among residuals. Visual inspection of the histogram and normal probability plot suggested that the residuals were approximately normally distributed. In addition, the scatterplot and Glejser test showed no evidence of heteroscedasticity ($p > 0.05$). These findings support the validity and robustness of the moderated regression model used in this study.

This study demonstrated that behavioral caries risk factors, particularly frequent consumption of sugary foods and beverages and inadequate toothbrushing habits, were significantly associated with dental caries status among preschool children. These findings reinforce the well-established concept that dental caries is primarily a behavior-related disease in which repeated exposure to fermentable carbohydrates and poor oral hygiene promote biofilm acidification, enamel demineralization, and progressive carious lesions. The present findings are consistent with the ecological plaque hypothesis and the current understanding of dental caries as a multifactorial disease resulting from the interaction of dental biofilm, dietary sugars, host susceptibility, and time (Pitts et al., 2017; Kirthiga et al., 2020). Although biological factors contribute to disease progression, behavioral practices remain the most modifiable determinants and therefore constitute the primary target for preventive interventions in preschool children.

The significant association between inadequate toothbrushing habits and higher dmft scores further emphasizes the importance of effective plaque control during early childhood. In the present study, higher toothbrushing scores represented poorer oral hygiene practices, indicating that children with less favorable brushing behaviors experienced greater caries severity. This finding is biologically plausible because ineffective plaque removal prolongs bacterial colonization and acid production on tooth surfaces. Since preschool children generally lack sufficient manual dexterity to perform effective toothbrushing independently, parental supervision and assistance are essential for maintaining oral hygiene and reducing the risk of early childhood caries (Khan et al.,

2021). Therefore, preventive programs should target not only children's behaviors but also parental knowledge and involvement in daily oral hygiene practices.

Outdoor activity was inversely associated with dental caries status, indicating that children who spent more time outdoors tended to have lower dmf-t scores. One possible explanation is that greater outdoor activity increases exposure to ultraviolet-B (UVB) radiation, thereby enhancing endogenous vitamin D synthesis. Vitamin D contributes to calcium and phosphate homeostasis, promotes mineralization of enamel and dentin, and supports innate immune responses through the regulation of antimicrobial peptides within the oral cavity (Botelho et al., 2020; Pulungan et al., 2021). Beyond its physiological effects, outdoor activity may also reflect a healthier lifestyle characterized by greater physical activity, structured daily routines, and reduced sedentary behavior, all of which may indirectly contribute to improved oral health. Consequently, outdoor activity should be considered an indicator of broader health-promoting behaviors rather than an isolated determinant of dental caries.

In contrast, dietary vitamin D intake was not significantly associated with dental caries status (Li et al., 2023; Asante et al., 2024; Hung et al., 2024a; Hung et al., 2024b). This finding may be explained by the relatively limited contribution of dietary sources to total vitamin D requirements compared with endogenous synthesis through sunlight exposure, which accounts for approximately 80% of vitamin D production. Furthermore, dietary intake was assessed using parent-reported questionnaires, which are susceptible to recall bias and may not accurately capture portion size, food fortification, bioavailability, or long-term dietary patterns. These methodological limitations may have attenuated the observed association. Similar inconsistencies have been reported in previous nutritional epidemiology studies, suggesting that dietary vitamin D intake alone may not adequately reflect an individual's vitamin D status without biochemical assessment.

A major objective of this study was to determine whether outdoor activity and dietary vitamin D intake moderated the association between behavioral caries risk factors and dental caries status. However, the moderation analysis did not identify significant interaction effects for either variable. These findings indicate that although outdoor activity was independently associated with lower caries severity, it did not alter the strength of the relationship between behavioral risk factors and dental caries. Likewise, dietary vitamin D intake neither showed a direct association with dental caries nor modified the effects of sugary food consumption or toothbrushing habits. This suggests that the protective influence of outdoor activity operates independently rather than by buffering the detrimental effects of established behavioral risk factors.

Several explanations may account for the absence of significant moderation effects. First, dental caries is a highly complex disease influenced by numerous biological, behavioral, and environmental determinants, including fluoride exposure, salivary composition, oral microbiota, socioeconomic conditions, and access to dental care, many of which were not incorporated into the present analytical model. Second, outdoor activity and dietary vitamin D intake served as proxy indicators of vitamin D exposure rather than direct biological measurements. Without assessing serum 25-hydroxyvitamin D [25(OH)D] concentrations, it was not possible to determine the participants' actual vitamin D status. Third, the cross-sectional design precludes temporal inference and cannot establish whether sustained outdoor activity or long-term vitamin D sufficiency influences caries progression over time. These methodological considerations may partly explain why the hypothesized moderating effects were not observed.

The present findings highlight that behavioral risk factors remain the dominant determinants of dental caries among preschool children. While outdoor activity appears to provide a direct protective association with dental caries, it does not modify the influence

of dietary sugar consumption or toothbrushing behaviors. Consequently, public health strategies should continue prioritizing the reduction of free sugar intake and the promotion of supervised toothbrushing with fluoride toothpaste while encouraging outdoor activities as part of broader healthy lifestyle interventions. Integrating oral health promotion with child nutrition and physical activity programs may provide additional benefits for improving children's overall health and well-being.

Several limitations should be considered when interpreting the findings of this study. First, the cross-sectional design limits causal inference because exposure and outcome variables were measured simultaneously. Second, behavioral information, including sugary food and beverage consumption, toothbrushing habits, outdoor activity, and dietary vitamin D intake, was obtained through parent- or guardian-reported questionnaires, which may be affected by recall bias and reporting inaccuracies. Third, vitamin D status was inferred from behavioral indicators rather than confirmed through serum 25(OH)D measurements, preventing direct evaluation of the biological relationship between vitamin D status and dental caries. Fourth, several potentially important confounding variables including fluoride exposure, salivary characteristics, clinical oral hygiene status, overall dietary patterns, socioeconomic status, access to dental services, and previous dental treatment history were not included in the analysis. Finally, because the study was conducted in a single urban community health center in Surabaya, the findings should be generalized to other populations with caution. Future longitudinal studies incorporating objective biomarkers of vitamin D status and a broader range of biological and environmental determinants are warranted to further clarify the complex pathways linking behavioral factors, vitamin D, and dental caries in preschool children.

4. CONCLUSION

This study demonstrated that frequent consumption of sugary foods and beverages and inadequate toothbrushing habits were significant behavioral risk factors associated with dental caries status among preschool children, whereas greater outdoor activity was associated with lower caries severity. In contrast, dietary vitamin D intake was not significantly associated with dental caries status. Furthermore, neither outdoor activity nor dietary vitamin D intake significantly moderated the relationship between behavioral risk factors and dental caries status. These findings indicate that behavioral risk factors remain the primary determinants of dental caries among preschool children, while outdoor activity serves as a protective factor directly associated with caries status rather than functioning as a moderating variable.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Ryan Nanda Syahbana conceived and designed the study, collected and analyzed the data, interpreted the findings, and drafted the manuscript. Darmawan Setijanto contributed to the study design, supervised the research process, critically reviewed the methodology and data interpretation, and substantially revised the manuscript for important intellectual content. Taufan Bramantoro contributed to the conceptual framework, provided methodological and statistical guidance, interpreted the findings, critically revised the manuscript, and approved the final version for publication. All authors read and approved the final manuscript and agree to be accountable for all aspects of the work.

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DECLARATION OF ARTIFICIAL INTELLIGENCE USE

Generative artificial intelligence (AI) was employed only to enhance the linguistic quality, grammatical accuracy, readability, and overall structure of the manuscript. All aspects of the research, including study conception, methodological design, data acquisition, data analysis, interpretation of the findings, and final manuscript preparation, were undertaken solely by the authors. The authors are fully responsible for the accuracy, originality, and integrity of the content presented.

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