

Cadre-Led Sanitation Counseling and Maternal Stunting-Prevention Practices in Sigi Regency, Indonesia: A Cross-Sectional Study

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ABSTRACT

Introduction: Stunting remains a major public health problem in Indonesia, particularly in high-burden areas such as Sigi Regency, Central Sulawesi. Poor sanitation and hygiene practices contribute to environmental enteric dysfunction (EED), which may impair nutrient absorption and child growth. Indonesia's Community-Based Total Sanitation (STBM) program promotes sanitation-related behavior change through cadre-led interventions across five sanitation pillars.

Methods: A cross-sectional design was used involving 80 mothers of stunted children under two years old, selected through proportional stratified random sampling across high-burden villages. Data were collected using a structured and validated 25-item questionnaire measuring behaviors aligned with the five STBM pillars. A score of ≥ 75 ($\geq 75\%$ of the maximum score) was categorized as "adequate," while a score < 75 was classified as "inadequate." analysis was performed using Chi-square was conducted to determine associations between exposure to cadre-led activities and maternal sanitation and hygiene practices, with particular attention to behaviors followed by logistic regression analysis.

Results: Bivariate analysis showed significant associations between maternal stunting-prevention practices and counseling on open defecation elimination ($p < 0.00$), handwashing with soap ($p < 0.001$), and water and food management ($p = 0.001$). However, multivariate analysis revealed that only handwashing-with-soap counseling remained significantly associated with good maternal stunting-prevention practices (Adjusted OR = 63.00; 95% CI for OR: 15.61–254.12; $p < 0.001$).

Conclusion: Handwashing-with-soap counseling was the strongest predictor of maternal stunting-prevention practices. These findings suggest that hygiene-focused behavioral interventions targeting fecal–oral transmission pathways may play a critical role in reducing stunting risk. Strengthening cadre-based handwashing promotion should be prioritized in community-based stunting prevention strategies.

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INTRODUCTION

Stunting refers to a reduced height relative to age, identified by length/height falling below -2 Standard Deviations (SD) according to the World Health Organization (WHO) growth standards. This phenomenon arises from permanent damage inflicted by insufficient nutritional consumption and frequent or long-lasting infections during the initial 1,000 days of life (1). Environmental enteric dysfunction (EED) is a developed subclinical condition of the small intestine frequently observed in low-income communities. This disorder is thought to stem from prolonged exposure to enteropathogens, resulting in mucosal inflammation, villous shortening, compromised intestinal barrier integrity, and diminished nutrient absorption efficiency. Furthermore, this mechanism suggests that prolonged exposure to poor sanitation environments may contribute to child growth faltering through intestinal dysfunction and nutrient malabsorption mediated by EED (2).

In Indonesia, progress toward reducing stunting has been uneven. National survey data indicate a stunting prevalence of 19.8% in 2024 (3), yet substantial disparities persist across regions. Central Sulawesi Province continues to report elevated rates exceeding 27% (4)(5), and Sigi Regency remains among the most affected areas with an estimated prevalence of 33% in 2024—far above the national average (6). A growing body of empirical evidence indicates that Water, Sanitation, and Hygiene (WASH) interventions contribute to reducing stunting risk through interconnected biological and environmental pathways. A 2023 individual-participant data meta-analysis reported that WASH interventions significantly reduce children's exposure to enteropathogens and fecal contamination, thereby interrupting fecal–oral transmission pathways underlying environmental enteric dysfunction (EED) and impaired nutrient absorption (7). Therefore, sanitation-related behavioral interventions may influence child growth not only through improvements in environmental conditions but also through biological mechanisms related to intestinal integrity and nutrient utilization. These findings are reinforced by studies conducted in Indonesia, which demonstrate that specific household practices—such as consistent latrine use, handwashing with soap, and safe water and food handling—work synergistically to reduce infection-related growth faltering (8). In this context, mothers play a central role as primary decision-makers in household sanitation practices, family food management, and daily hygiene behaviors that directly influence children's risk of infection exposure. Indonesia's Community-Based Total Sanitation (STBM) strategy was developed to promote behavior change through five integrated sanitation pillars, positioning community cadres as key agents in facilitating behavioral change at both household and community levels (9). However, the effectiveness of cadre-based approaches is determined not only by the availability of sanitation facilities but also by cadres' ability to establish interpersonal communication, strengthen community engagement, and sustain the adoption of healthy behaviors over time. Program evaluations have revealed substantial variability in cadre performance, particularly regarding the quality of counseling, consistency of health message delivery, and intensity of community support activities. These findings indicate that the primary challenge in STBM implementation lies not only in the provision of sanitation infrastructure but also in sustaining behavioral change at the household level.

These national and provincial patterns are also reflected in Sigi Regency, where stunting prevalence remains alarmingly high despite the region being prioritized within the national STBM implementation framework. Preliminary assessments indicate persistently low adoption of essential WASH behaviors at the household level, including latrine use, handwashing with soap, and safe water and food handling practices (9).

Therefore, this study aims to evaluate the effectiveness of STBM cadre interventions across the five sanitation pillars in shaping maternal stunting-prevention practices in Sigi Regency. Specifically, this study seeks to identify which pillar-specific interventions are most strongly associated with household-level stunting-prevention behaviors, thereby providing deeper insight into the mechanisms of behavior change mediated by community cadres. In addition, the findings of this study are expected to strengthen the scientific evidence base regarding behavior-based sanitation interventions in high stunting-burden settings and to inform policy enhancement and optimization of community-based STBM strategies in Indonesia.

METHOD

This study employs a clear and systematic approach to ensure the reliability and validity of the findings. Below are the components of the methodology:

Research Type

Quantitative study: This study employed a quantitative cross-sectional design to assess the association between sanitary behavior interventions delivered by Community-Based Total Sanitation (STBM) cadres and mothers' stunting prevention practices in Sigi Regency, Indonesia. A cross-sectional approach was selected because it enables the simultaneous measurement of exposures and outcomes within the same timeframe, allowing for efficient identification of population-level patterns. This design is widely recommended for early-phase public health investigations aimed at detecting associations rather than causal inferences, especially in community-based sanitation and nutrition research ([1](#)).

Population and Sample/Informants

The target population consisted of 101 mothers of children diagnosed with stunting under the age of two years. Employing the Slovin formula with a 5% margin of error, a final sample of 80 respondents was obtained. The sample size is adequate to achieve acceptable statistical power for detecting medium effect sizes in chi-square and logistic regression analyses.

A proportional stratified random sampling technique was implemented to ensure that respondents were selected proportionally from the various community health center (*Puskesmas*) service areas. Stratification was necessary to account for geographical, environmental, and service-delivery differences that could influence sanitation exposure and maternal practices. Randomization within strata reduces the risk of selection bias and strengthens the external validity of the findings.

Research Location

The research was conducted in Sigi Regency, Central Sulawesi Province—an area with persistently elevated stunting prevalence compared with national averages. The setting is scientifically relevant because STBM implementation and community nutrition initiatives have been prioritized in this region, offering natural variation in cadre performance and maternal practices. Conducting the study in this context enhances ecological validity since the population is directly affected by the sanitation–nutrition nexus targeted by STBM policies.

Instrumentation or Tools

This study employed a structured questionnaire consisting of 25 items to assess the preventive efforts undertaken by Community-Based Total Sanitation (STBM) cadres in reducing stunting risk. The instrument comprised five domains aligned with the national STBM framework, namely: Stop Open Defecation, Handwashing with Soap, Household Water and Food Management, Household Waste Management, and Household Liquid Waste Management. Each pillar was operationalized into five items, yielding a total of 25 questions. All items were dichotomous (Yes/No), with a correct response (reflecting recommended sanitation and hygiene practices) scored at 20 and an incorrect response scored at 0. Consequently, the maximum score per pillar was 100. The total score obtained was used to classify maternal knowledge and practices related to stunting prevention. A score of ≥ 75 ($\geq 75\%$ of the maximum score) was categorized as "adequate," while a score < 75 was classified as "inadequate." This scoring approach enables standardized evaluation of sanitation and hygiene practices across all STBM pillars.

Data Collection Procedures

Data collection was conducted from July to September 2025 through structured face-to-face interviews. Enumerators underwent intensive training to minimize interviewer bias, standardize question delivery, and ensure adherence to ethical protocols. Respondents were informed about the study objectives, confidentiality procedures, and their rights as participants before signing informed consent. All data were anonymized to reduce risks to participants. Interviews were conducted either at respondents' homes or local health facilities following uniform operational procedures to enhance data reliability.

Data Analysis

Data were processed through coding, cleaning, and double-entry verification prior to analysis using SPSS version 22.0. Univariate analyses summarized variable distributions using frequencies, percentages, means, and standard deviations.

Bivariate analysis was conducted using the Chi-square test with a significance level of $p < 0.05$. Fisher's Exact Test was employed when Chi-square assumptions were violated (expected cell count < 5), ensuring statistical validity. Significant variables in the bivariate test were continued in the logistic regression test to find out the most influential significant variables

Ethical Approval

This research has received approval from the Palu Ministry of Health Polytechnic Research Ethics Commission No.001622/KEPK POLTEKKES KEMENKES PALU/2025.

RESULTS

The results showed that distribution of respondent characteristics.

Table 1. Distribution of respondent characteristics

Characteristic	Category	n	%
Age (years)	26–30	27	33.6
	31–35	35	43.8
	36–40	9	11.3
	41–45	9	11.3
Education level	Elementary/Junior High	37	46.3
	Senior High School	41	51.3
	College	2	2.5
Occupation	Housewife	68	85.0
	Cadre	12	15.0

The characteristics of the respondents are presented in Table 1. Most mothers were aged 31–35 years (43.8%), indicating that the majority were in a mature reproductive age group, which is commonly associated with greater caregiving responsibility and decision-making autonomy. Only small proportions.

Table 2. Associations between the five STBM pillars and maternal stunting-prevention practices

Variables	Maternal Stunting-Prevention Practices Following Cadre Intervention				P -Value
	Adequate		Inadequate		
	n	%	n	%	
Families receive counseling for defecation	32	40.0	8	10.0	<0.001
Families not receive counseling for defecation	14	17.0	26	33.0	
Families receive Handwashing counseling	36	45.0	4	5.0	<0.000
Families not receive Handwashing counseling	5	6.0	35	44.0	
Families receive counseling on how to treat water and food	32	40.0	8	10.0	0.001
Families not receive counseling on how to treat water and food	7	8.7	33	41.3	
Families receive waste security counseling	30	37.5	10	12.5	0.062
Families not receive waste security counseling	21	26.3	19	23.7	
Families receive wastewater security counseling	33	41.2	7	8.8	0.293
Families not receive wastewater security counseling	28	35.0	12	15.0	

Table 2 shows that three STBM pillars were significantly associated with maternal stunting-prevention practices. Respondents who received open defecation counseling were more likely to have adequate (40.0%) and inadequate (10.0%) practices compared to those who did not receive counseling adequate (17.0%) and inadequate (33.0%) ($p < 0.001$). A stronger pattern was observed for handwashing with soap, where most respondents who received counseling were categorized as adequate (45.0%) and inadequate (5.0%) compared to those who did not receive counseling adequate (6.0%) and inadequate (44.0%) ($p < 0.001$). Similarly, for household water and food management, counseling was significantly associated with adequate (40.0%) and inadequate (10.0%) practices compared to those who did not receive counseling adequate (8.7%) and inadequate (41.3%) ($p=0.001$).

In contrast, solid waste management showed a distribution of adequate (37.5%) and inadequate (12.5%) among those receiving counseling compared to adequate (26.3%) and inadequate (23.7%) among those not receiving counseling, but the association was not statistically significant ($p=0.062$). Likewise, household wastewater management showed adequate (41.2%) and inadequate (8.8%) among those receiving counseling and adequate (35.0%) and inadequate (15.0%) among those not receiving counseling, with no significant difference ($p=0.293$). Overall, STBM pillars directly related to fecal–oral transmission pathways demonstrated stronger associations with stunting-prevention practices.

Table 3. Multivariate analysis The Effect of STBM Counseling on Stunting Prevention Measures

Variables	*(adjusted OR)	** 95% CI for OR	p-Value
Open defecation counseling	11.33	0.72 – 178.38	0.163
Handwashing counseling	63.00	15.61 – 254.12	<0.001
Water and Food treat counseling	2.56	2.10 – 131.60	0.106

*OR Adjusted Odds Ratio; **CI for OR = Confidence Interval 95%

Table 3, the results of the analysis showed that only the variable of handwashing with soap had a significant effect on stunting prevention practices ($p<0.001$). Mothers who received soapy hand washing counseling were 63 times more likely to have good stunting prevention practices compared to those who did not receive counseling (Adjusted OR = 63,000; 95% CI for OR: 15,61–254,12). Meanwhile, bowel counseling (Adjusted OR = 11.33; 95% CI for OR: 0.72 – 178.38; $p = 0.163$) and water and food management counseling (Adjusted OR = 2.56; 95% CI for OR: 2.10 – 131.60; $p = 0.106$) did not show a statistically significant association, although they tended to increase the likelihood of better stunting prevention practices

DISCUSSION

The discussion section interprets the findings of this study within the context of existing research, explores their practical implications, evaluates the strengths and limitations, and provides recommendations for future research.

Interpretation of Key Findings

The results of this study show that the three main pillars of sanitation, hygiene, and water management—namely elimination of open defecation, handwashing habits with soap, and safe drinking water management—have a significant relationship with stunting prevention practices by mothers. However, in the multivariate analysis of logistic regression, only the variable of handwashing with soap counseling still showed a significant influence on stunting prevention practices ($p<0.001$). Mothers who received counseling on handwashing using soap were 63 times more likely to have good stunting prevention practices than mothers who did not receive such counselling (Adjusted OR = 63.00; 95% CI for OR: 15.61–254.12). Meanwhile, counseling related to the elimination of open defecation (Adjusted OR = 11.33; $p = 0.16$) and water and food management (OR = 2.56; $p = 0.10$) did not show a statistically significant association, although it still showed a tendency to increase the chances of better stunting prevention practices.

The study's bivariate findings are in line with previous studies that showed that improved sanitation facilities and personal hygiene practices correlated with a reduction in the incidence of stunting in children. For example, research in rural India showed that access to toilets was associated with a 16–39% reduction in the chances of stunting

(10). Similarly, in Ethiopia, poor sanitation and open defecation were associated with higher stunting rates, emphasizing the critical role of WASH interventions in child nutrition (11)(12). Conversely, solid waste and wastewater management did not demonstrate significant associations with stunting prevention, suggesting that the focus should remain on the aforementioned core pillars for effective interventions (13)(14).

The strong associations between open defecation elimination and handwashing with soap in stunting-prevention practices underscore the critical role of fecal–oral transmission pathways in exacerbating environmental enteric dysfunction (EED) and child growth impairment. The findings in this study show that mothers who practice the practice of eliminating open defecation and consistently washing their hands with soap tend to have better stunting prevention practices, which indicates that reduced exposure to fecal pathogens in the household environment plays a role in lowering the risk of developing EDs in children. In other words, the significant relationship found in the two pillars can be explained through biological mechanisms in which reduced exposure to enteropathogens helps maintain the integrity of the intestinal mucosa, improves nutrient absorption, and reduces the activation of chronic inflammation that contributes to child growth disorders.

Studies indicate that poor sanitation and hygiene practices significantly correlate with stunting, as evidenced by findings from rural Ethiopia, where open defecation was linked to a threefold increase in stunting risk (14). Similarly, research in Indonesia demonstrated significant correlations between stunting incidents and both open defecation and inadequate handwashing practices (15). The underlying mechanisms involve microbial exposure leading to gut dysfunction, which impairs nutrient absorption and promotes chronic immune activation, ultimately diverting resources from growth to infection response (16). Furthermore, interventions targeting water, sanitation, and hygiene (WASH) have shown promise in reducing stunting rates by disrupting these transmission pathways. Thus, enhancing sanitation and hygiene is vital for mitigating EED and promoting healthy growth in children (17).

The relationship between safe drinking water, food management, and maternal preventive practices is critical for gastrointestinal health and nutrient absorption in children. Studies indicate that poor water quality and inadequate food hygiene significantly increase the risk of gastrointestinal diseases, such as gastroenteritis and enteric fever, particularly in low-income settings. For instance, infants with better nutrition and access to boiled water showed lower rates of gastroenteritis. In Malawi, a nutrition program integrating water, sanitation, and hygiene (WASH) messages improved dietary diversity among children, highlighting the importance of safe water and food practices (18). Furthermore, compromised WASH conditions in regions like Siaya County, Kenya, were linked to Environmental Enteric Dysfunction (EED), which impairs nutrient absorption and overall health. Additionally, in North India, the presence of contaminated drinking water was associated with a higher incidence of enteric fever, emphasizing the need for optimal food hygiene alongside safe water access (19). Overall, these findings underscore the necessity of integrating water quality and food hygiene into maternal and child health strategies to enhance child health outcomes (20). The multivariate results of this study reinforce this mechanism, where handwashing counseling using soap remains the strongest predictor of stunting prevention practices even though it has been controlled for other variables." This condition suggests that consistent changes in personal hygiene behavior may be more effective in breaking the fecal–oral transmission chain and lowering the risk of EED than other sanitation interventions that require broader environmental and infrastructure support." In addition, interventions focused on water, sanitation, and hygiene (WASH) have shown potential in reducing stunting rates through the disconnection of these transmission pathways

Although not significant in multivariate analyses, the trend of increased stunting prevention practices in the maternal group receiving water and food management counseling suggests that these interventions still have the potential to support child health, especially in reducing the risk of recurrent gastrointestinal infections." Overall, these findings confirm the importance of integrating water quality and food hygiene in maternal and child health strategies to improve child health outcomes The absence of a significant association on indiscriminate elimination counseling in a multivariate analysis is likely influenced by the local context of the community in Sigi Regency, where sanitation practices are still strongly influenced by environmental conditions and available household sanitation facilities. In some areas, bowel behavior may not be entirely determined by the knowledge or counseling received by the mother, but also by limited access to healthy latrines, community habits, and household socioeconomic conditions." In addition, the insignificance of the relationship on solid waste and liquid waste management suggests that the two factors work through more complex environmental pathways and take longer to affect the child's growth status in

addition, relatively homogeneous respondent characteristics in some sanitation practices likely limit data variation between respondents, making statistical relationships more difficult to detect in multivariate models. The use of cross-sectional research designs in this study also limits the ability to evaluate the causal relationship and long-term impact of sanitation interventions on children's growth status. Measurements taken at a single point in time may not have been able to capture the cumulative effects of environmental exposure that develop gradually through the mechanism of environmental enteric dysfunction (EED)

Therefore, a comprehensive, integrated, and behavior-change-based WASH strategy needs to be strengthened, especially through the optimization of handwashing counseling using soap as a priority intervention in stunting prevention efforts at the community level (21)(22).

Comparison with Previous Studies

The findings regarding the influence of sanitation behaviors on child nutritional outcomes are consistent with previous studies that emphasize the critical role of fecal contamination pathways. For instance, research in Burkina Faso indicates that a contaminated environment significantly contributes to stunting, suggesting that interventions targeting environmental contamination are essential for improving child growth outcomes (23). Similarly, the Global Enteric Multicenter Study highlights that inadequate sanitation and hygiene practices are linked to undernutrition, potentially accounting for half of all child stunting cases (24). Furthermore, studies in urban Ghana and Bangladesh reveal high levels of fecal contamination in environments where children play and eat, underscoring the importance of addressing specific exposure pathways to mitigate health risks (25)(26). Collectively, these studies reinforce the notion that targeted sanitation behaviors directly related to fecal contamination are more impactful on child nutrition than broader sanitation measures (27).

Inadequate sanitation and unsafe water significantly contribute to the exposure of children to enteric pathogens, which can lead to environmental enteric dysfunction (EED) and subsequent linear growth impairment. EED is characterized by intestinal inflammation and increased permeability, resulting from chronic pathogen exposure, particularly in settings with poor water, sanitation, and hygiene (WASH) conditions (28). Studies indicate that children suffering from EED exhibit markers of inflammation and gut damage, which correlate with stunting and reduced nutrient absorption (29). For instance, research in Uganda and Indonesia highlights that children with higher pathogen loads and altered gut microbiota profiles show significant growth deficits, emphasizing the role of enteric infections in stunting (29). Furthermore, interventions targeting WASH and nutrition have shown varying effectiveness based on individual pathogen and EED biomarker status, suggesting that tailored approaches are necessary to mitigate these health issues and improve child growth outcomes (30).

The need to strengthen community-based behavior-change strategies led by cadres in Indonesia is underscored by the persistent high prevalence of stunting, which is significantly influenced by poor sanitation practices. Research indicates that interventions such as Community-Led Total Sanitation (CLTS) have effectively improved community knowledge and behaviors related to sanitation, thereby contributing to stunting prevention efforts (31). Additionally, enhancing the capacity of health cadres through training and collaborative interventions has been shown to increase their effectiveness in promoting high-impact sanitation behaviors (32). For instance, a study in Semarang demonstrated that active engagement of *posyandu* cadres, coupled with improved sanitation infrastructure, led to a notable decrease in stunting rates (33). Furthermore, behavior change approaches in training programs have empowered cadres to disseminate knowledge effectively within their communities, highlighting the critical role of these local leaders in stunting reduction initiatives (34). Thus, reinforcing cadre-led strategies is essential for enhancing the overall effectiveness of Indonesia's stunting reduction initiatives.

Limitations and Cautions

This study has several limitations that should be considered when interpreting the findings. The use of a cross-sectional design limits the ability to establish causal relationships between STBM counseling interventions and maternal stunting-prevention practices. In addition, the data were collected through self-reported responses, which may introduce information bias, including recall bias and social desirability bias. The relative homogeneity of several sanitation practice characteristics among respondents may also have reduced data variability, making certain associations more difficult to detect in the multivariate analysis.

The findings should also be interpreted within the social and environmental context of communities in Sigi Regency, where several sanitation practices are influenced by infrastructure conditions, community norms, and socioeconomic factors. Therefore, the non-significant findings for several variables do not necessarily indicate the absence of an effect on stunting prevention, but may instead reflect the complex interaction between environmental and behavioral factors. Furthermore, the large Adjusted Odds Ratio observed for handwashing-with-soap counseling should be interpreted cautiously, as it may have been influenced by data distribution and residual confounding factors that were not fully controlled.

Recommendations for Future Research

Future studies are recommended to employ longitudinal or cohort designs to provide stronger evidence regarding the causal relationship between STBM interventions and maternal stunting-prevention practices at the household level. Such approaches are important for evaluating the long-term effects of sanitation and hygiene interventions on behavioral changes and child growth outcomes, including the biological mechanisms associated with environmental enteric dysfunction (EED). In addition, future research should consider the use of direct observational methods or mixed-methods approaches to reduce the potential bias associated with self-reported data and to gain a deeper understanding of the social, cultural, and environmental factors influencing the effectiveness of cadre-based interventions (35). Future research should also explore the role of contextual factors, such as sanitation infrastructure access, socioeconomic conditions, and community norms, in shaping the effectiveness of each STBM pillar in stunting prevention. More detailed analyses examining the effectiveness of different cadre counseling approaches, intervention frequency, and the quality of interpersonal communication are also needed to identify the intervention components that most strongly influence maternal behavioral change. Furthermore, studies involving broader geographic coverage and more diverse population characteristics are necessary to improve the generalizability of findings across communities with a high burden of stunting.

CONCLUSION

This study demonstrates that behavior-based STBM interventions are associated with maternal stunting-prevention practices, particularly in the areas of open defecation elimination, handwashing with soap, and safe drinking water management. However, multivariate analysis showed that only handwashing-with-soap counseling had a significant effect on maternal stunting-prevention practices. Mothers who received handwashing-with-soap counseling were more likely to implement good stunting-prevention practices compared to those who did not receive such counseling.

These findings highlight that personal hygiene interventions focusing on disrupting fecal–oral transmission pathways may be more effective in supporting stunting prevention through reducing the risk of environmental enteric dysfunction (EED) and impaired nutrient absorption. Although the other STBM pillars did not show significant associations in the multivariate analysis, they may still contribute indirectly through broader environmental and community-level mechanisms. Therefore, strengthening cadre-based STBM interventions, particularly handwashing-with-soap education, should be prioritized as part of stunting prevention strategies in high-burden settings.

AUTHOR'S CONTRIBUTION STATEMENT

First author: Conceptualization, Methodology, data analysis Writing -Original drafts, Writing -Review & Editing, Supervision. Second author: Methodology, Writing -Original Drafts, Data Analysis. Third author: Writing -Original Draft, Writing -Review & Editing, Supervision. All authors have read and approved the published version of the manuscript.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

In compiling this manuscript, the author used AI tools, specifically Grammarly and QuillBot, solely to improve grammar, spelling, and sentence clarity. The author is fully responsible for the content and integrity of the manuscript.

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