INTERNATIONAL JOURNAL OF SUSTAINABLE CONSTRUCTION ENGINEERING AND TECHNOLOGY
ISSN: 2180-3242 e-ISSN: 2600-7959

IJSCET

Vol. 15 No. 3 (2024) 21-30
https://publisher.uthm.edu.my/ojs/index.php/ijscet

Analyzing Factors of Environmental Pollution from Construction Sites and Proposing Solutions

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DOI: https://doi.org/10.30880/ijscet.2024.15.03.003

Article Info

Received: 25 February 2024
Accepted: 11 December 2024
Available online: 22 December 2024

Keywords

Environmental pollution, pollution factor, sustainable development, construction site

Abstract

Amid accelerating modernization, environmental degradation has become increasingly prevalent across various industrial sectors, with the construction industry emerging as a significant contributor. In Vietnam, construction-related pollution has reached alarming levels in both acceleration and severity. Despite regulatory measures, current mitigation efforts remain inadequate and have shown limited effectiveness in addressing pollution caused by the construction sector. This study aims to identify, analyze, and evaluate key factors contributing to environmental pollution at construction sites through a survey of industry professionals. Using SPSS software for data analysis, the research identifies five principal factors among 36 independent causes of environmental pollution. Based on these findings, the study proposes targeted interventions to reduce construction-related pollution and foster sustainable development within Vietnam's construction sector.

1. Introduction

In developing countries, the construction sector is regarded as a cornerstone of national development, playing a critical role in shaping both the scale and technological advancement of the economy. In Vietnam, the construction industry has been pivotal not only in developing infrastructure but also in catalyzing the growth of other sectors, thereby facilitating broader socioeconomic development. Additionally, it has made a substantial contribution to the national economy. However, despite the significant benefits provided by the construction industry, the environmental pollution resulting from its activities poses a major challenge to sustainable development in both Vietnam and the construction sector itself. This issue is most prominently manifested through pollution caused by dust, emissions, wastewater, solid waste, excessive noise, and intense lighting during various stages of construction.

Numerous studies have analyzed environmental pollution in the construction industry and proposed solutions to address this issue. A comprehensive review by Yan (2018) examined global literature on construction site environmental impacts and sustainable building practices. The analysis identified five primary categories of construction-related environmental degradation, including noise pollution, light pollution, water pollution, solid waste pollution, and dust pollution. Based on these findings, the study proposed a framework for ecological stewardship in construction, including systematic sustainability protocols, enhanced regulatory oversight mechanisms, refined site management practices, and standardized guidelines for environmental technology management [20]. Zuo et al. (2017) explored the behavioral aspects of the dust pollution equation to identify issues and challenges associated with its control. The analysis yielded pragmatic interventions for optimizing particulate matter management in construction environments, while providing strategic recommendations to enhance managerial cognition and risk perception, thereby facilitating behavioral modifications in operational practices [21]. Another study related to fine dust by Cheriyan and Choi (2020) employed content analysis combined with deductive reasoning and a concept-based review methodology to synthesize a comprehensive understanding within the study's scope. Their findings emphasize the importance of investigating areas such as real-time monitoring of construction dust, considering the distributional characteristics of particles, and developing a standardized particulate matter inventory tailored for construction activities [3]. Cao and Zhang (2019) conducted a study aimed at establishing a foundational framework for protecting the ecological environment, mitigating environmental pollution in construction zones, and minimizing health risks to construction workers. Focusing on large-scale construction and demolition sites, which generate significant amounts of construction dust. The researchers utilized simulation techniques and actual measurements to gain an in-depth understanding of the patterns of dust distribution and diffusion [2]. Hong et al. (2020) implemented data-mining techniques to establish real-time monitoring metrics for construction generated contaminants. Their methodological framework aimed to optimize the management of on-site pollutant emissions while minimizing ambient contamination levels in proximate residential zones [7].

A notable research gap in the factors of environmental pollution from construction sites lies in the lack of comprehensive studies that synthesize various pollution factors within projects. While previous studies have primarily concentrated on analyzing and proposing solutions for specific pollution issues (dust, noise, emissions, etc.), there is limited literature that combines these factors in a holistic approach, particularly for the construction environment in Vietnam. To address the aforementioned issues, this study aims to identify the key factors contributing to environmental problems at construction sites, assess their respective impacts, and categorize these factors. Based on this analysis, the paper will propose targeted solutions and strategies to mitigate the pollution resulting from construction activities, while also contributing to the promotion of sustainable development within Vietnam's construction industry.

2. Research Methodology

2.1 Designing Questionnaire, Building a 6-level Likert Scale

A systematic review of international and domestic literature addressing construction-induced environmental pollution, combined with a contextual analysis of Vietnam's operational conditions, enabled the study to synthesize critical causative factors and develop a preliminary assessment instrument. This initial questionnaire underwent rigorous validation through a structured consultation process with domain experts. The expert panel evaluated the contextual relevance and potential impact of the identified factors within the framework of Vietnam's construction industry. The validation protocol included an assessment of the instrument's comprehensiveness and measurement precision, facilitating the elimination of irrelevant variables and the incorporation of additional critical factors. Subsequently, the preliminary questionnaire was iteratively refined based on aggregated expert feedback, resulting in modifications to enhance the validity and reliability of the official survey questionnaire [13].

The survey questionnaire was conducted from September 2022 to October 2022 using two methods: direct (distributing survey forms in person) and indirect (sending the Google Form via email, etc.). The survey participants are individuals working in the construction sector in Vietnam. Based on the evaluation indicators, the results show that the survey participants are diverse, covering various professional levels and work environments in the construction field. Therefore, the survey data are reliable and relevant to the research (as shown in Table 1).

Table 1 *The analysis results of survey participants' composition*

Evaluation criteria		Frequency	Rate (%)	Evaluation criteria		Frequency	Rate (%)
Working time	Less than 3 years	84	42	Qualification	Bachelor	4	2
	From 3-5 years	60	30		Engineer	180	90
	From 5-10 years	36	18		Master	12	6
	Over 10 years	20	10		Doctor	4	2
Occupation	Architect	12	6	Project type	Civil and industrial	168	84
	Construction management	40	20		Bridges and roads	24	12
	Engineer	140	70		Irrigation, water supply and drainage	4	2
	Supervision consultant	8	4		Others	4	2
Work unit	Investor	44	22	Company size	Less than 50 people	80	40
	Supervision consulting	8	4		50-100 people	44	22
	Design consulting	44	22		100-200 people	24	12
	Project management consulting	12	6		Over 200 people	52	26
	Construction unit	84	42				
	Others	8	4				

2.2 Processing and Analyzing Data Using SPSS

Statistical Product and Services Solutions (SPSS) software was used for data analysis, screening, and evaluation, as well as for verifying the reliability of the scales, ensuring the uniformity and objectivity of the data before analyzing and evaluating the results. The research flowchart is shown in Figure 1.

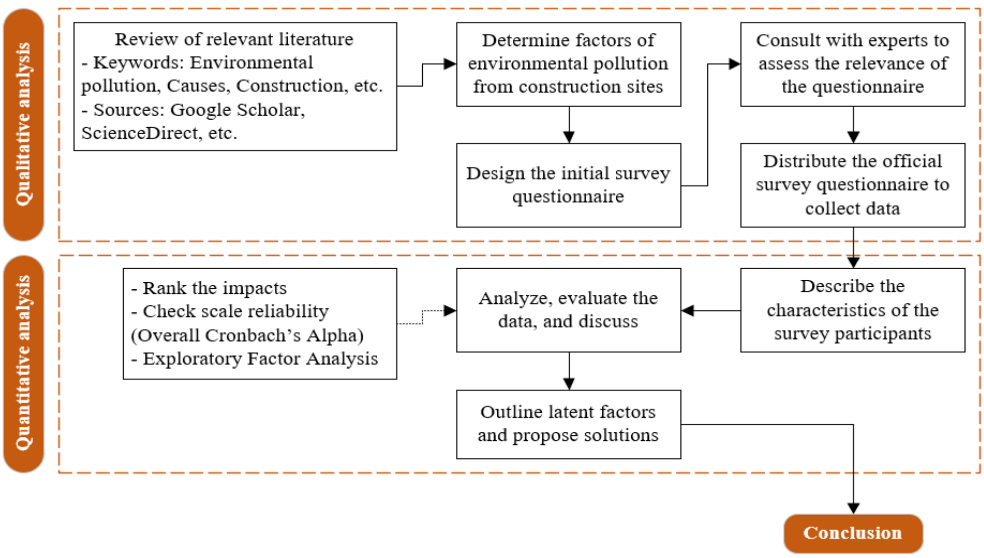

Fig. 1 *Research diagram of environmental pollution factors from construction sites*

2.3 Checking Scale Reliability

The factors mentioned in the survey questionnaire were evaluated based on the Likert 6-level scale, as follows: (0) – No influence, (1) – Very little influence, (2) – Little influence, (3) – Moderate influence, (4) – Much influence, (5) – Very much influence.

The overall Cronbach's Alpha for the group of factors "Air pollution" is 0.888, which is greater than 0.7, indicating good reliability [11]. The variable-total correlation coefficients for each factor are greater than 0.3, suggesting a good correlation between the observed variables in the scale. Similar analyses for the remaining groups of factors are presented in Table 2. Based on these results, the collected data has high reliability, no variables were excluded, and it can be used for subsequent analysis.

Table 2 *Overall Cronbach's Alpha of factor groups*

Group	Cronbach's Alpha	N of Items
Air pollution (A)	0.888	11
Noise pollution (N)	0.855	5
Water pollution (W)	0.838	6
Solid pollution (S)	0.890	11
Other factors (O)	0.757	3

2.4 Ranking Impacts

The causes of air pollution are ranked by their level of influence from high to low, and are presented in Table 3.

Accordingly, the highest ranking is "Demolition or blasting of construction structures" (mean value = 3.98).

Table 3 *Group of air pollution factors*

Code	Factor	No. of samples	Mean value	Standard deviation	Rank
A.5	Demolition or blasting of construction structures [14]	200	3.98	0.972	1
A.7	Fuel combustion in construction and transportation activities (construction materials, prefabricated materials, waste, and soil) [9, 12, 14]	200	3.78	0.947	2
A.10	Emissions from materials, accumulation of construction waste at the site, and waste generated during demolition [9, 14, 19]	200	3.58	1.024	3
A.11	Construction waste disposal process [14]	200	3.40	1.116	4
A.9	Resource and energy-intensive building construction processes [14, 19]	200	3.32	1.069	5
A.6	On-site material production and processing operations [14, 19]	200	3.28	1.080	6
A.1	Construction-phase earthworks (excavation, backfilling, and ground leveling) [14, 20, 21]	200	3.24	1.229	7
A.2	Performing pile works (piling, driving, drilling, etc.) [14]	200	2.90	1.066	8
A.3	Transporting materials, machinery, equipment, construction waste, loading, unloading, and storing goods [12, 14, 18-20]	200	2.86	1.098	9
A.4	Transportation means for workers to the construction site [12, 19]	200	2.36	1.112	10
A.8	Maintenance of construction machinery and equipment [14]	200	2.10	1.047	11

The causes of noise pollution are ranked by their level of influence from high to low, and are presented in Table 4.

Accordingly, the highest ranking is "Heavy construction vehicles and equipment (concrete breakers, pneumatic and internal combustion engine-driven equipment, pile drivers, excavators, bulldozers, trucks, cranes, etc.)" (mean value = 3.98).

Table 4 *Group of noise pollution factors*

Code	Factor	No. of samples	Mean value	Standard deviation	Rank
N.1	Heavy construction vehicles and equipment (concrete breakers, pneumatic and internal combustion engine-driven equipment, pile drivers, excavators, bulldozers, trucks, cranes, etc.) [6, 10, 14, 16, 20]	200	3.98	1.051	1
N.2	Manual construction activities such as erection, welding, knocking, hammering, drilling, grinding, material handling, or even blasting [4, 6, 14]	200	3.68	1.088	2
N.5	Construction activities occurring in the vicinity of existing buildings or in environments with echo-reflective materials [20]	200	3.04	1.151	3
N.4	Construction, processing, and material handling activities at temporary facilities on the construction site [10, 14]	200	2.86	1.080	4
N.3	Workers and employees exchanging information, shouting or loud loudspeakers on the construction site [16]	200	2.48	1.007	5

The causes of water pollution are ranked by their level of influence from high to low, and are presented in Table 5.

Accordingly, the highest ranking is "Illegal dumping of materials into canals, rivers, seas, and other water bodies" (mean value = 3.96).

Table 5 *Group of water pollution factors*

Code	Factor	No. of samples	Mean value	Standard deviation	Rank
W.5	Illegal dumping of materials into canals, rivers, seas, and other water bodies [8]	200	3.96	0.918	1
W.2	Toxic substances from sewage discharge and construction waste seep into soil and water sources, causing pollution through physical, chemical, and biological reactions [8, 9, 14, 20]	200	3.80	1.061	2
W.3	Heavy metal content in water increases due to biochemical reactions affecting metals in construction waste and rainwater [9, 14]	200	3.74	1.019	3
W.4	Rainwater runoff, spills of liquids, oils, debris, paints, solvents, and other hazardous chemicals from drainage during construction operations [1, 8, 14, 16, 20]	200	3.60	1.022	4
W.1	Land clearing activities erode the soil, leading to runoff carrying a large amount of dirt and forming sediment pollution [1, 14, 16]	200	3.20	1.061	5
W.6	Waiting time and delays during excavation, earthworks, site plan development, and changes in construction progress [1]	200	2.66	1.109	6

The causes of solid pollution are ranked in order of influence from high to low, and are presented in Table 6.

Accordingly, the highest ranking is "Cement mixes, waste bricks, burning tires, packaging, bitumen barrels, paints and varnishes contain organic solvents or other hazardous substances" (mean value = 3.40).

Table 6 *Group of solid pollution factors*

Code	Factor	No. of samples	Mean value	Standard deviation	Rank
S.1	Cement mixes, waste bricks, burning tires, packaging, bitumen barrels, paints and varnishes contain organic solvents or other hazardous substances [14, 20]	200	3.40	1.042	1
S.5	Source of construction waste from material handling [14]	200	3.18	1.036	2
S.10	Lack of waste management planning or inappropriate planning [14, 15]	200	3.14	1.236	3
S.11	Ineffective labor productivity and a lack of experienced technical manpower [15]	200	3.12	1.110	4
S.3	Asphalt materials [14]	200	3.04	0.850	5
S.6	Source of construction waste from construction activities (errors and rework) [14, 15]	200	3.02	1.194	6
S.2	Workers' domestic waste negatively impacting the surrounding environment [20]	200	2.94	0.860	7
S.7	Attitude, behavior, capacity of contractors and stakeholders (lack of coordination and slow information flow between parties) [14, 15]	200	2.92	1.250	8
S.4	Source of construction waste by design (errors or changes in design, specifications) [14, 15]	200	2.64	1.112	9
S.8	Effect of weather (outside) [14, 15]	200	2.36	1.112	10
S.9	Ordering error [14]	200	2.16	1.192	11

The pollution impacts due to other factors are ranked in order of influence from high to low and are presented in Table 7.

Accordingly, the highest ranking is "Improper sand and stone exploitation, leading to the destruction of sand dunes, alteration of natural terrain, and direct environmental impacts" (mean value = 3.60).

Table 7 *Group of pollution impacts due to other factors*

Code	Factor	No. of samples	Mean value	Standard deviation	Rank
O.2	Improper sand and stone exploitation, leading to the destruction of sand dunes, alteration of natural terrain, and direct environmental impacts [8]	200	3.60	0.982	1
O.1	Construction activities such as the production of cement, aggregates, concrete, steel require a lot of fossil fuels and lead to the destruction of non-renewable resources [8]	200	3.50	0.946	2
O.3	Excessive use of high-intensity lighting devices at night [20]	200	2.76	1.144	3

2.5 Exploratory Factor Analysis (EFA)

In contrast to conventional analytical methodologies that focus on the discrete examination of causal relationships between independent and dependent variables, Exploratory Factor Analysis (EFA) adopts a holistic approach that emphasizes variable intercorrelations [17]. This statistical technique is used to identify the underlying structure within a set of observed variables by uncovering latent constructs or "factors" that explain their interrelationships. It serves as a data reduction method, simplifying large datasets into a smaller number of meaningful dimensions while retaining critical information. The identification of inherent factor groupings is conducted through factor extraction, while the determination of the number of these underlying groupings is facilitated by factor rotation [5]. Furthermore, the retention of factors is guided by multiple empirical criteria, including eigenvalue thresholds, scree plot analysis, and proportions of explained variance.

EFA was conducted to assess the degree of convergence for each scale. KMO = 0.763 > 0.5 and Sig = 0.000 < 0.05 indicate that the factor analysis is appropriate and the observed variables are correlated with each other in the factor.

Condition for the number of factors to be retained: Eigenvalue = 1.258 > 1. Only factors with the eigenvalue index ≥ 1 are included in the analytical model.

Total variance explained ≥ 50% indicates that the EFA model is suitable. In this analysis, the total variance explained is 72.3%, meaning the factors extracted after EFA account for 72.3% of the variation in all observed variables. Compared to the standard threshold of 50%, this confirms the suitability of the EFA model.

3. Research Results and Solutions

3.1 Impact Grouping Results

The first group of factors includes seven variables: A.5, W.1, W.2, W.3, W.4, W.5 and O.2, with factor loadings ranging from 0.665 to 0.913. These variables are associated with improper waste disposal, as well as the dumping of hazardous materials and chemicals into the environment. The authors have labeled this factor as “Improper waste disposal at the construction site” (see Table 8).

Table 8 *Latent factors of environmental pollution from construction sites*

Code	Impact categories	Factor loading				
		1	2	3	4	5
I	Improper waste disposal at the construction site					
W.3	Heavy metal content in water increases due to biochemical reactions affecting metals in construction waste and rainwater	0.913				
W.2	Toxic substances from sewage discharge and construction waste seep into soil and water sources, causing pollution through physical, chemical, and biological reactions	0.858				
W.5	Illegal dumping of materials into canals, rivers, seas, and other water bodies	0.772				
W.1	Land clearing activities erode the soil, leading to runoff carrying a large amount of dirt and forming sediment pollution	0.724				
A.5	Demolition or blasting of construction structures	0.680				
O.2	Improper sand and stone exploitation, leading to the destruction of sand dunes, alteration of natural terrain, and direct environmental impacts	0.666				
W.4	Rainwater runoff, spills of liquids, oils, debris, paints, solvents, and other hazardous chemicals from drainage during construction operations	0.665				
II	Pollution due to human and weather factors					
S.9	Ordering error		0.815			
S.8	Effect of weather (outside)		0.747			
W.6	Waiting time and delays during excavation, earthworks, site plan development, and changes in construction progress		0.743			
S.6	Source of construction waste from construction activities (errors and rework)		0.650			
N.3	Workers and employees exchanging information, shouting or loud loudspeakers on the construction site		0.630			
III	Pollution due to equipment and machinery at the construction site					
A.3	Transporting materials, machinery, equipment, construction waste, loading, unloading, and storing goods			0.803		
A.8	Maintenance of construction machinery and equipment			0.766		

A.2	Performing pile works (piling, driving, drilling, etc.)			0.756		
A.9	Resource and energy-intensive building construction processes			0.670		
IV	Project management plan at the construction site is inadequate					
S.11	Ineffective labor productivity and a lack of experienced technical manpower				0.894	
S.10	Lack of waste management planning or inappropriate planning				0.846	
V	Regulations on shielding and waste treatment at the construction site are not good					
A.11	Construction waste disposal process					0.778
S.2	Workers' domestic waste negatively impacting the surrounding environment					0.692
N.5	Construction activities occurring in the vicinity of existing buildings or in environments with echo-reflective materials					0.570

The second group of factors includes five variables: N.3, W.6, S.6, S.8 and S.9, with factor loadings from 0.630 to 0.815. These variables are associated with human errors during the implementation process and the effects of weather. The authors have named this group of factors as "Pollution due to human and weather factors".

The third group of factors includes four variables: A.2, A.3, A.8 and A.9, with factor loadings from 0.670 to 0.803. These variables are related to the operation and maintenance of construction and transportation equipment. The authors have named this group of factors as "Pollution due to equipment and machinery at the construction site".

The fourth group of factors includes two variables: S.10 and S.11, with factor loadings from 0.846 to 0.894. These variables are related to the lack of experienced human resources and the absence of a proper or effective management plan. The authors have named this group of factors as "Project management plan at the construction site is inadequate".

The fifth group of factors includes three variables: A.11, N.5 and S.2, with factor loadings from 0.570 to 0.778. These variables are related to waste management and efforts to mitigate the impact of construction activities on the surrounding environment. The authors have named this group of factors as "Regulations on shielding and waste treatment at the construction site are not good".

3.2 Solutions

Several methods are proposed to solve the problem of environmental pollution at construction sites. For addressing improper waste disposal at the construction site, the following solutions are proposed. Collecting and transporting construction waste at source to collection point, transfer station before putting it into treatment. Ensuring that the classification of wastes is carried out according to the correct process to have suitable treatment methods for each type. Construction sites need to arrange temporary wastewater treatment measures and sediment drainage systems to retain wastes such as garbage, excess construction materials before being discharged to the outside. Using new materials to replace old materials such as steel formwork systems that can be reused in various places in the project instead of wood formwork classified as waste after use. Solid waste can be significantly reduced during project planning with a sustainable nature, such as the selection of building materials from sustainable resources, the use of prefabricated components instead of fabrication at the construction site.

In the group of factors that cause pollution due to human and weather factors, the following solutions are proposed to solve this problem. Planning the purchase of supplies to ensure they meet the project's needs, avoiding situations where improper placement causes storage difficulties that could lead to damage. In the process of preserving materials, it is necessary to identify factors that may affect quality in order to propose solutions to solve situations when they arise. Identifying situations that can lead to mistakes in the construction process that generate a specific amount of waste, thereby proposing measures to limit certain situations. Additionally, raising awareness among workers about environmental pollution is crucial.

The group of factors of construction equipment and machinery, replacing old appliances with modern ones that use alternative energy and produce fewer emissions. Regularly inspecting and taking measures to maintain construction machinery and equipment periodically. Selecting equipment and machinery suitable for each stage of work, avoiding the use of equipment with excessive capacity for the required tasks. Rotating jobs using high-capacity equipment during construction.

Several methods can be used to meet and improve the project management plan on site. Training human resources to improve qualifications helps the project to be organized properly. Regularly check inventory to plan for timely storage, use and order. Selecting the dismantling option before demolition to make use of reused materials. Developing a comprehensive waste management plan prior to commencing construction, including potential waste sources, site map with designated areas for recycling and recyclable materials will benefit in the long run and reduce the total amount of waste generated.

For the group of factors related to regulations on shielding and waste treatment at construction sites, more effective measures are needed. Creating barriers around the work area and using auxiliary equipment corresponding for each type of main vehicle and machinery to limit the impact on the surrounding environment. Planting trees around the construction site to minimize noise during construction and to enhance landscaping efforts later.

4. Conclusion

A comprehensive methodology was employed to collect empirical data from construction industry professionals. The survey instrument was developed through a systematic literature review and expert consultation, enabling the identification of critical factors contributing to environmental pollution in construction activities within the Vietnamese context. The research methodology facilitated a comprehensive assessment of factor influence, taxonomical categorization, and source identification. The findings provide a robust foundation for developing targeted mitigation strategies, addressing underlying causal mechanisms, and promoting sustainable practices in the construction sector.

However, this study has several limitations that should be acknowledged. It focuses solely on individuals working within the construction industry, potentially excluding valuable perspectives from policymakers, environmental scientists, and affected communities. Additionally, the collected data was derived from survey questionnaires, which are inherently susceptible to respondent subjectivity. Furthermore, the research is region-specific to Vietnam, making its findings less generalizable to countries with different practices and environmental conditions.

Future research should broaden its scope by incorporating perspectives from a wider range of stakeholders to develop a more holistic understanding of construction-related pollution. Investigating strategies to incentivize stakeholders to adopt pollution mitigation measures is essential. Simultaneously, comparative analyses should be conducted between developed and developing economies to support knowledge exchange and identify best practices. Priority research areas should include empirical evaluations of the benefits of construction waste recycling, refinement of predictive models for waste generation, in-depth analyses of recycling protocols in developed countries, reviews of regulatory and legislative frameworks for waste management, and exploration of scalable industrialization strategies for construction waste recycling.

Acknowledgement

We acknowledge Ho Chi Minh City University of Technology (HCMUT), VNU-HCM for supporting this study.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contributions to the paper as follows: study conception and design, data collection, analysis and interpretation of results, draft manuscript preparation: Vu Hong Son Pham, Thuy Dung Dau. All authors reviewed the results and approved the final version of the manuscript.

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