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ASSESSMENT OF INDOOR AIR QUALITY IN ISLAMIC BOARDING SCHOOLS (PESANTREN) BASED ON ENVIRONMENTAL HEALTH QUALITY STANDARDS (EHQS) IN INDONESIA

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Abstract

Introduction: *Islamic boarding schools needs to take the conditions of the environment into consideration. The standardization of a healthy environment is still neglected in some Islamic boarding schools. This study serves an overview of the importance of evaluating indoor air quality in Islamic boarding school environments. It is in line with the Government Regulation Number 28 of 2024 regulating Environmental Health governance.* ***Methods:*** *A non-experimental quantitative survey-based design is used to systematically assess the indoor environmental health conditions in dormitories. Temperature, lighting-intensity, relative-humidity, ventilation-rate, and particulate-matter-concentrations (PM_{10} and $PM_{2.5}$) based on EHQS became environmental variables. Four Islamic boarding schools representing different environmental and infrastructural characteristics Darul Muttaqien, Nur Azkia (Bogor), Al Amanah Al-Gontory, and Jam'iyyah Islamiyyah (South Tangerang) were the places where the study was conducted. It was based on The Ministry of Religious Affairs of the Republic of Indonesia in 2023 information stating that West Java ranks first in terms of the number of Islamic boarding schools.* ***Results and Discussion:*** *Every Islamic boarding school environment had different environmental quality characteristics. The measurement of temperature, humidity, PM_{10}, and $PM_{2,5}$ was found not to be in EHQS. Meanwhile, lighting, humidity in one of the boarding schools and the ventilation rate in the boarding schools fulfilled the requirement stipulated by the regulation.* ***Conclusion:*** *The quality of indoor air in Islamic boarding schools associated with the requirements stipulated in Government Regulation No. 28/2024 concerning Environmental Health showed that not all rooms met the standards of the environmental health quality.*

INTRODUCTION

The Government Regulation Number 66 of 2014 regulates Environmental Health. The regulation has been revised by the Government Regulation Number 28/2024. The revision involves Part Thirteen which aims to realize a healthy environmental quality. The matters the regulation manages comprise the responsibilities and authorities of the government, environmental health quality standards, health requirements, environmental health implementation, waste environmental health is an effort to prevent disease and/or health disorders from environmental risk factors to realize a healthy environmental quality from physical, chemical, biological, and social aspects.

The environmental health regulations aim to realize a healthy environmental quality. The quality is associated with the physical, chemical, biological, and

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social aspects and these aspects allow everyone to achieve the highest level of health (1–5). Furthermore, Article 8 of the regulation states that environmental health quality standards and health requirements are set for environmental media which include water, air, land, food, facilities and buildings, as well as vectors and disease-carrying animals (6–7). The environmental health quality standards are, indeed, a set of parameters used to ensure (a) environmental quality and (b) whether water, air, soil, or the workplace, does not negatively impact human health. The standards are considered crucial for controlling pollution and maintaining the ecosystem balance. The two things are closely associated with the efforts of preventing the public health risks.

The previous regulations were arranged in the Government Regulation No. 41 of 1999 concerning Air Pollution Control. In addition, the Minister of Health Regulation No. 32 of 2017 regulates water quality standards for daily use. The application of the quality standards covers various aspects, such as the content of hazardous chemicals in drinking water, ambient air quality, and hygiene standards for workplaces and public places (8–10). The standards were designed based on the epidemiological studies which link the exposure to certain contaminants to the risk of disease or health problems. The levels of heavy metals, like lead (Pb) and mercury (Hg) in water or soil, should be limited to prevent the phenomenon of poisoning or the phenomenon of developmental disorders in children. Furthermore, sustainable monitoring and routine evaluation of the standards are essential to adapt. The adaptation is associated with the enhancement of science and technology and the emerging new pollution patterns (10–14).

The requirements relevant to this study are the Environmental Health Quality Standards and Health Requirements for Air (Article 16). It consists of quality standards and health requirements for indoor air and ambient air directly exposed to humans. It contains the following measurement indicators: (a) temperature (air) measuring the hotness or coldness of the air expressed in degrees Celsius (°C) or Fahrenheit (°F) (15–19), (b) lighting indicating something that provides light (light) or illuminates, (c) lighting includes natural and artificial lighting, (d) humidity confirming the amount of water contained in the air, usually expressed as a percentage (20–24); it is related to or influenced by air temperature, and is directly related to temperature (25–29), (e) ventilation rate being the absolute amount of incoming air per unit of time (litres per second or l/s, cubic meters per hour or m^3/h) and the air exchange rate as the relative amount of incoming air per unit of time (30–32), (f) dust particles microscopic solids or liquids suspended in the air which is also called particulate matter (PM), or microscopic solids or liquids that are in the air and can be dust, smoke, or vapor, (g) dust particles are a form of air pollution that can come from natural or man-made sources (33–35). PM_{10} are airborne particles having a diameter of less than 10 micrometres (microns), or about 1/7 the width of a human hair. The particles are small enough to be inhaled into the human respiratory tract, but they are larger than $PM_{2.5}$ (particles with a diameter of less than 2.5 micrometres). PM_{10} includes various types of particles like dust, dirt, smoke, and other pollutants originating from natural and man-made sources, such as motor vehicles, factories, biomass burning, and construction activities.

Excessive exposure to PM_{10} can cause health problems like the irritation of the nose, throat, and lungs, especially for those who have sensitive respiratory conditions such as asthma (36–37). WHO and many countries are committed to setting PM_{10} levels as an effort to prevent the possibility of disease and minimize the spread of these particles so as not to be dangerous and maintain air quality (38–40). $PM_{2.5}$ exists as fine particles in the air measuring approximately 2.5 micrometres or smaller. The size is illustrated as 30 times smaller than the size of a piece of human hair. As a consequence, the particles are able to easily enter the respiratory system. In addition, they are also able to enter the bloodstream. The bigger number accumulations of the particles can be seen in the form of dust, dirt, soot and other chemical compounds as a side effect of combustion. The primary source of $PM_{2.5}$ pollution is generally obtained from human activities like the use of motorized vehicles and residue of burning. In addition, it can also occur from forest fires (41–43).

A Threshold Limit Value (TLV) is the maximum concentration of a substance allowed in air, water, or the environment; and is considered safe for human health over a specific period of time. TLVs are established based on scientific research analysing the effects of both short-term and long-term human exposures. The determination was set by the WHO and it is agreed by many countries. It applies not only to $PM_{2.5}$ but also to chemical compounds like ozone, NO_2, and SO_2 (44–47). WHO determines the TLV of $PM_{2.5}$ at a concentration of 10 μg/m³ based on the reference data of the annual average and 25 μg/m³ for 24-hour exposure. It means that if the $PM_{2.5}$ level is above the specified standard value, it will potentially undergo higher health risks, especially in the age groups of children and the elderly as well as the groups of people who are detected to have diseases of the respiratory system and heart. Based on Government

Regulation Number 41 of 1999, the TLV of $PM_{2.5}$ in Indonesia is 15 μg/m³ for the annual average and 65 μg/m³ for the daily average. TLV plays an important role in the environmental regulations and the public health policies. It is due to the fact that it provides supporting data for governments and industries in controlling pollution and protecting the public from health risks (46–48).

Many Islamic boarding schools (*pesantren*) patch a large number of students. Some of them exceed the ideal ratio of room size to occupancy. In other words, the dormitory rooms are often found to be overcrowded or exceed the ideal capacity. The situation results in such unfavourable social interactions like the phenomenon of close physical proximity. This situation mentioned above has potential to increase the rapid disease transmission. The worse situation happens if one of the occupants contracts an infectious disease. The poorly-functioning air circulation system also contributes to the unfavourable situation. Closed windows and doors made it difficult for the occupants to breath fresh air, especially in the morning. The situation leads to an increased incidence of acute respiratory infections.

Similarly, diarrhea is also a potential risk factor. The diseases seem to stem from unhygienic sanitation and food practices, as well as delayed disposal of indoor trash. The situation allows the trash to decompose before being transported. Scabies is caused by the practice of sharing personal belongings like towels and clothing. The things are unknowingly placed in close proximity, allowing dirt and sweat to adhere to each other and contaminate the skin. The crowded environment and close interaction increase the risk of tuberculosis transmission in Islamic boarding schools. It is getting worse if the infected students are undiagnosed or untreated (49–51).

METHODS

This study is designed as a non-experimental, survey-based quantitative one. The population of the study refers to the official data from the Ministry of Religious Affairs of the Republic of Indonesia in 2023. It was reported that West Java Province has the largest number of Islamic boarding schools (*pesantrens*) 12,121 units. Therefore, the purposive selection of the locations of the study was represented by the ones located in Bogor (the Darul Muttaqien (DM) Islamic Boarding School), which is recognized as the Islamic boarding school with the best environmental management model.

Banten Province was determined as a comparison location, specifically in South Tangerang City and it was represented by the Al Amanah Al Gontory (AA) Islamic Boarding School. The school was identified to implement the optimal environmental management practices. Both DM and AA have *Pos Kesehatan Pesantren*. Two other schools, i.e. Nur Azkia (NA) and Jam'iyyah Islamiyyah (JI), became the comparative boarding schools which did not have *Pos Kesehatan Pesantren.*

The boarding schools consisted of the bed rooms, the hall, the mosque, the classrooms, and the corridors. The size of bed rooms varied. The smallest one was taken by 3 dots, while the largest one was taken by 27 dots. Measurements (as one of the efforts of data collections) were conducted during the day-time, i.e. when the students were engaged in their normal activities especially in the afternoon. It was due to the availability time of permitting to enter the boarding schools not more than after-school times. Meanwhile, sampling for temperature, lighting, humidity, ventilation rate, airborne particles, and noise was conducted in the designated room from various points. It was conducted according to the technical sampling procedures. How the measuring was used and how they work are shown by Table 1. This descriptive analysis of indoor air quality measurements was obtained. It was compared to the results of field inspections with the threshold values determined by Government Regulation No. 28/2024, Part Thirteen, concerning Environmental Health. The average value of the measurements was then calculated by comparing the area of the rooms.

Table 1. Measuring Instruments, Functions and How They Work for Measuring Indoor Air Quality

Instruments	Functions	Steps	Pictures
Termohygrometer (11)	Measuring temperature and humidity	• Put the instrument in the location where the temperature and humidity will be measured. • Wait 3-5 minutes. • Observe the scale displayed on the instrument. • The top panel displays the air temperature, and the bottom panel displays the humidity.	
Anemometer	Measuring ventilation rate	• A gust of wind hits the propeller on the device. • The rotation of the propeller is converted into a quantity. • After the propeller rotates, it will move a device that will measure the wind speed.(12)	

Instruments	Functions	Steps	Pictures
Dust meter	Measuring $PM_{2,4}$ and PM_{10}	• Collects air samples through its inlet, which directs dust particles into the detection area.(13)	
Soundlevel meter	Measuring noise	• A microphone converts sound signals into equivalent electrical signals.	
Lux meter	Measuring exposure	• Turn on the device by pressing the power button. • Select the measurement range according to your needs. Measurement ranges typically consist of A, B, and C. Range A has a lux count of up to 2000, range B has a lux count of up to 20,000, and range C has a lux count of up to 100,000. • Put the sensor on the light source or surface whose intensity will be measured. • Read the measurement results on the LCD panel. • Turn off the device by pressing the power button.	

RESULTS

The following was a description of indoor air quality assessments. They were measured at several locations in the four boarding schools studied (Table 2). The study revealed that the indoor environmental quality in the observed Islamic boarding schools generally did not meet the requirements of the Environmental Health Quality Standards (EHQS). The temperature measurements at all four study locations were above the recommended range of 18–30°C.

The measurements were conducted particularly in semi-open spaces such as corridors. The bedroom temperature was within the tolerance range. Lighting measurements in most rooms met the minimum standard of ≥ 60 lux. In addition, it met the optimal conditions for learning, except in the corridors (which are exposed to direct sunlight). The tropical climates often result in humidity levels, i.e. the ones exceeding the threshold of 40–60%, especially in bedrooms and corridors. Ventilation rates varied across rooms. Good air circulation was essential for room design; and it took the layout of doors/windows, and ventilation into account. The particular matter measurements both at 10 and 2.5 exceeded tolerance limits. The greater the number of students (exceeding the room's capacity) were, the higher the particulate concentration was. Halls and classrooms functioning for the indoor activities were used by a significant number of students. Therefore, the findings suggested that the research location was not in optimal environmental conditions.

Tabel 2. Measurement of Environmental Health Quality Standards in Four Islamic Boarding School

Parameter	EHQS	Boarding Schools							
		DM		NA		AA		JI	
		Sampling location	Results	Sampling location	Results	Sampling location	Results	Sampling location	Results
Temperature	(18–30 C)	Bed room	28.92*	**Bed room**	**33.48****	Bedroom	32**	Bedroom	30.9**
		Hall	31.26**	**Hall**	**34.54****	Hall	30.7**		
		Class room	31.99**	**Classrom**	**32.91****	Classroom	32**	Classroom	32**
		Corridor	32.71**	**Corridor**	**33.31****	Corridor	29.5*	Corridor	32.7**
Lighting	(Min. 60 Lux)	Bed room	80.3*	Bed room	32.48***	**Bedroom**	**82.2***	Bedroom	75.13*
		Hall	69.23*	**Hall**	**649.74***	Hall	132.3*		
		Class room	371.3*	classroom	282.78*	Classroom	172.5*	Classroom	160.75*
		Corridor	11386.65*	Corridor	1267.21*	Corridor	403.5*	Corridor	797.71*
Humidity	40–60 %	Hall	70.7**	Bed room	55.7*	Bedroom	76.3**	Bedroom	79.8**
		Hall	65**	Hall	49.1*	Hall	78.2**		

Parameter	EHQS	Boarding Schools							
		DM		NA		AA		JI	
		Sampling location	Results	Sampling location	Results	Sampling location	Results	Sampling location	Results
		Class room	62.4**	classroom	52.5*	Classroom	73.8**	Classroom	74.1**
		Corridor	61.6**	Corridor	52.9*	Corridor	74.3**	Corridor	71.9**
Ventilation Rate	0.15–0.25 m/s	Bed room	0.24*	Bed room	0,.6*	Bedroom	0.30**	Bedroom	0.20*
				Hall	0.14***	Hall	0.6**		
		Classroom	0.46**	classroom	0.13***	Classroom	0.20*	Classroom	0.31**
						Corridor	0.21*	Corridor	1.98**
PM_{10}	70 ug/m^3	Bed room	155**	Bed room	119**	Bedroom	127**	Bedroom	96**
		Hall	211**	Hall	74**	Hall	81**		
		Class room	191**	classroom	165**	Classroom	103**	Classroom	77**
		Corridor	155**	Corridor	79**	Corridor	77**	Corridor	65*
$PM_{2,5}$	25 ug/m^3	Bed room	76**	Bed room	48**	Bedroom	79**	Bedroom	56**
		Hall	99**	Hall	36**	Hall	47**		
		Class room	84**	classroom	83**	Classroom	59**	Classroom	48**
		Corridor	69**	Corridor	38**	Corridor	42**	Corridor	42**

DISCUSSION

Indoor Environmental Quality (IEQ) was a critical factor and it was shaping both the comfort and daily function of the dormitories for the students who stayed there. Most activities took place indoors in bedrooms, classrooms, mosques, and multipurpose halls. Consequently, managing indoor air conditions should be set as a priority. Existing literature has consistently shown that poor indoor air quality caused respiratory problems (52). The situation reduced students' attention and lowered their academic outcomes. Conversely, healthier indoor environments were associated with the improved the students' attendance and their greater learning efficiency (53–54).

This study found that several IEQ indicators in Islamic boarding schools (*pesantren*) remained below recommended environmental health standards. The findings were particularly dealing with temperature, humidity, and concentrations of particulate matter (PM_{10} and $PM_{2.5}$). The variation observed across different locations highlighted the influence of factors: building layout, ventilation effectiveness, and occupant behaviour on indoor environmental conditions. Thermal conditions, especially air temperature, was found to play a central role in determining occupant comfort. Measured temperatures ranged from 28.92 to 32.71°C; the corridors had the highest values and the bedrooms had the lowest values. The figures exceeded the recommended comfort range of 18–30°C in most areas. The elevated temperatures could be attributed to direct solar exposure, limited airflow, and intense indoor activity.

Semi-open areas, like corridors, were particularly vulnerable to the heat gain. It is due to their exposure to sunlight. Meanwhile, enclosed spaces tended to maintain slightly lower temperatures. The findings were consistent with the prior research on educational facilities in tropical regions. The naturally ventilated buildings often struggled to maintain thermal comfort. It has also been established that temperature conditions directly affect students' comfort levels and cognitive performance (55–56). For example, the studies conducted in Australia indicated that students generally felt most comfortable with a temperature range of 23–27°C. Meanwhile, the temperature range above might lead to discomfort and reduced students' focus/concentration (2). These results suggested that the improvements in ventilation design and climate-responsive building strategies were needed in *pesantren* environments.

Lighting conditions also contributed significantly to the visual comfort. In this study, illumination levels across all observed spaces were within recommended standards. The corridors showed the highest brightness levels due to abundant daylight. Meanwhile, the halls and bedrooms relied on the combination of natural and artificial lighting; and it resulted in comparatively lower illumination. The previous studies emphasized that adequate natural lighting not only supported visual comfort but also enhanced health and academic productivity. The well-lit learning spaces were reported to enable students to perform visual tasks more effectively. Therefore, it created better academic outcomes (3). In addition, optimizing the use of daylight in building design was reported to reduce dependence on artificial lighting and improve overall energy efficiency (56).

Indoor environmental quality (IEQ) significantly impacted the students' comfort and the activities of dormitory residents (students). They were able to do many activities indoors, including in bedrooms, classrooms, the mosque, and the hall. Therefore, indoor air quality should be the priority of management. The previous study showed that poor indoor air quality could impact students' respiratory health, their concentration levels, and their academic performance. A healthy learning environment could also reduce students' absentee-ism and increase their learning productivity (53–54). The results of this study indicated that several indoor environmental quality parameters in Islamic boarding schools still did not meet the environmental health standards, particularly air temperature, humidity, and PM_{10} and $PM_{2.5}$. Differences in values across study locations indicated that building characteristics, natural ventilation, and occupant activity were the main factors that influenced the indoor environmental conditions.

Air temperature was one of the main parameters that determined the thermal comfort of building occupants. The results of this study showed that air temperatures in several locations within Islamic boarding schools ranged from 28.92 to 32.71°C, with the highest values found in corridors and the lowest in bedrooms. Compared to environmental health standards (18–30°C), most study locations observed in this study exhibited temperatures exceeding the recommended limits. The high temperatures were likely influenced by several factors: exposure to solar radiation, suboptimal natural ventilation, and high activity levels. Semi-open spaces, like corridors, underwent higher temperatures due to the direct exposure to solar radiation, compared to enclosed spaces such as bedrooms.

The findings were aligned with the various previous studies on educational buildings which showed that classroom temperatures often exceeded comfort standards, especially in buildings with natural ventilation in tropical climates. The studies on classroom thermal comfort indicated that air temperature has a direct impact on student comfort and learning performance (55–56). Another study on classrooms found that students perceived a comfortable operating temperature in the range of 23–27°C, while higher temperatures could cause thermal discomfort and reduced students' learning concentration (54). Therefore, the relative high air temperatures in some rooms in Islamic boarding schools (*pesantren*) indicated the need for strategies to improve ventilation and building designs that are more adaptive to tropical climates.

Lighting was believed to be a crucial factor in achieving a comfortable visual environment. Good lighting levels, which were in line with recommended standard values, were found at all study locations. Corridors exhibited very high lighting levels due to the dominance of natural sunlight, while spaces, like halls and bedrooms, had lower light intensity. It is due to the fact that they relied on a combination of natural and artificial lighting. A previous study showed that natural lighting had significant benefits for students' health and their visual comfort it could also increase students' learning productivity. Classrooms with adequate lighting allowed students to read and write more comfortably; so their academic performance was improved (21). Furthermore, educational building designs maximizing natural lighting could also improve the energy efficiency and reduce the use of artificial lighting (56). Therefore, adequate lighting in Islamic boarding schools could be considered a positive factor in supporting students' learning and their *ibadah* (worship activities).

Air humidity was an important parameter related to thermal comfort and the growth of microorganisms indoors. The results of this study showed that air humidity levels across all study locations ranged from 61.6–70.7%, exceeding the recommended humidity standard of 40–60%. High indoor humidity was likely influenced by the humid tropical climate conditions, suboptimal ventilation, and high occupant activity. Bedrooms exhibited the highest humidity levels due to the prolonged occupant activities and the relatively limited ventilation. The previous study showed that the high humidity promoted the growth of microorganisms such as fungi and bacteria indoors. It could potentially lead to respiratory problems (4). Another study suggested that high humidity in enclosed spaces was linked to poor ventilation and inadequate occupancy rates (5). Therefore, improving natural and mechanical ventilation systems is considered significant to reduce indoor humidity levels.

Ventilation was a key factor in maintaining indoor air quality because it plays its role in reducing pollutant accumulation and increasing air exchange. The results showed that ventilation rates varied across several study locations, with the highest values found in mosques with more open building structures. The differences in ventilation levels between rooms indicated that a building's architectural design played a significant role in determining air circulation patterns within a space. Rooms with larger ventilation openings generally allowed for higher air exchange compared to rooms with limited ventilation. Several previous studies showed that adequate ventilation was a key factor in maintaining indoor air quality and preventing the build-up of pollutants (6). Furthermore, increased ventilation in classrooms showed to significantly reduce air pollutant levels and improve indoor air quality (7). Other studies also showed that good ventilation contributed to increased thermal comfort while reducing the risk of airborne disease transmission, particularly in educational settings (8). Therefore, optimizing ventilation is an important strategy for enhancing indoor environmental quality in Islamic boarding schools.

PM_{10} and $PM_{2.5}$ concentrations were the key indicators of indoor air quality because the particles could enter the human respiratory system and cause various health problems. The results of the study showed that PM_{10} and $PM_{2.5}$ concentrations at all study sites exceeded recommended environmental health standards. The high particulate matter concentrations were likely caused by a combination of indoor human activity, dust resuspension from floors, and infiltration of air pollution from the outdoor environment (57–59). The previous study showed that particulate matter concentrations in classrooms often increased during the learning activities because the students' movement could cause dust on the floor re-emerged into the air (43).

Another study showed that most particulate matter pollution in the classrooms originated from the outdoor air pollution entering through natural ventilation or building infiltration (60–62). A recent study on classroom air quality in China also showed that indoor $PM_{2.5}$ concentrations could be influenced by the ventilation levels and the outdoor air pollution conditions (58). Therefore, this study recommends that controlling air pollution sources and improving ventilation systems are good first steps in reducing particulate matter concentrations at the research site. It provides awareness and important insights to Islamic boarding school administrators that indoor air quality can be improved and maintained in synergy with building design, ventilation, and environmental management, thus creating a healthy learning environment.

The previous studies showed that improving indoor air quality could provide significant benefits for students' health and their learning performance. A healthy learning environment could improve students' concentration, reduce their health symptoms related to air pollution, and increase their academic productivity (53,63). Therefore, efforts to improve indoor environmental quality in Islamic boarding schools could be achieved by increasing natural ventilation, controlling dust, and optimizing building design to adapt to tropical climates.

CONCLUSION

Indoor air quality in Islamic boarding schools as set in Government Regulation No. 28/2024 concerning Environmental Health showed that not all rooms in the boarding schools met environmental health quality standards. The potential for air quality that meets the quality standards could be enhanced into eco-Islamic boarding schools. Therefore, it will globally support the achievement of the SDGs goals, especially related goals, i.e. a healthy and prosperous life. It will clean water and proper sanitation. It will provide sustainable cities and settlements. It will provide responsible consumption and production. In addition, it will handle climate change and terrestrial ecosystems.

This study was limited by its small sample of four boarding schools in Java. The measurements were daytime-only and without 24-hour monitoring. The observation focused on selected IAQ parameters (temperature, humidity, lighting, ventilation rate, PM_{10} and $PM_{2.5}$). The observations were excluding the assessing of other pollutants or biological contaminants. The study also excluded the direct health outcome data, and potential short-term environmental variability during single-session measurements, which together may limit causal inference and generalizability of the findings.

This study recommended that remedial measures – like ensuring good ventilation, reducing the use of smoke-producing fuels, encouraging outdoor smoking, and planting trees around the Islamic boarding school – can help us to improve air quality. The educational dissemination about the importance of clean air and maintaining respiratory health is also crucial in Islamic boarding schools.

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AUTHORS' CONTRIBUTION

FR: conceptualization, data collection, data analysis, manuscript drafting, editing, and revision. AS, DS, and G: conceptualization, and supervision. JJ, SNA and SN: data analysis, manuscript drafting, and supervision. All authors have reviewed and approved the final version of the manuscript.

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