CHAPTER I
INTRODUCTION

1.1.Background

Indoor air quality (IAQ) has become a critical concern worldwide, not only in developing countries but also in developed nations (Gilbey et al., 2023a,b; Morino-Rangel et al., 2020). This concern largely stems from its strong association with significant impacts on human health (Tahir et al., 2023; Kaewrat et al., 2021). According to the World Health Organization (WHO), more than 7 million people die annually due to air pollution, with a large portion of these deaths linked to indoor air exposure (Kuehn, 2014). Alarmingly, over 2 million of these cases occur in Southeast Asian (SEA) countries, most of which are classified as developing nations, including Indonesia (Kuehn, 2014). A majority of these cases are found in rural areas of low- and middle-income countries (Azad et al., 2014; Krishnamoorthy et al., 2018). In fact, indoor air pollution poses a major public health threat, yet it often remains under-studied and poorly regulated (Carslaw and Mihucz, 2022; Holden et al., 2023). To the best of the authors' knowledge, there is currently no universally accepted national standard for indoor air pollution, although efforts to establish such standards have recently increased (Morawska et al., 2024). The issue is particularly pressing in regions where households still rely on traditional cooking methods using biomass fuels such as firewood, which are commonly used in rural areas (Rajper et al., 2020; Mannan and Al-Ghamdi, 2021). Moreover, in many of these households, cooking takes place indoors without proper ventilation (Lee et al., 2023; de la Hoz-Torres et al., 2022) . This leads to the accumulation of airborne pollutants, especially particulate matter (PM), which can remain suspended in the indoor environment for hours or even days. These pollutants can reach hazardous levels and spread to other parts of the home, including bedrooms, thereby increasing the risk of chronic exposure for all household members.

Particulate matter (PM), which includes coarse particles (PM10, particles with a diameter ≤10 μm), fine particles (PM2.5, ≤2.5 μm and PM1, ≤1 μm), is among the most critical parameters of indoor air pollution due to its direct link to various health issues such as respiratory and cardiovascular diseases (Yun et al., 2025; Roy et al., 2023). The size of PM is a major factor affecting its ability to penetrate the human body. The smaller the particle size, the deeper it can penetrate into the human respiratory system, increasing its potential to cause harm (Muoth et al.,

2017). Size-segregated PM is often categorized based on specific diameter ranges, such as 0.3–0.5 µm, 0.5–1 µm, 1–2.5 µm, 2.5–5 µm, 5–10 µm, and >10 µm, depending on the capability of the monitoring equipment. However, size-segregated analysis of PM is still rarely discussed in indoor air pollution studies, despite its importance. These particles can be generated both naturally and through human activities. In indoor environments, one of the main sources of PM is the incomplete combustion of organic materials, such as firewood, which is commonly used for traditional cooking in rural areas (Nassikas et al., 2024, Bennet et al., 2019). As previously mentioned, the smaller the particle size, the deeper the potential penetration into the human body (Manigrasso et al., 2017). For example, while PM10 can be trapped in the upper respiratory tract, finer particles such as PM2.5 and PM1 can reach the alveolar region of the lungs and, in some cases, even enter the bloodstream. Even short-term exposure to high concentrations of PM can lead to various health problems, including acute lower respiratory infections, chronic obstructive pulmonary disease (COPD), cardiovascular diseases, lung cancer, and even premature death (Zhu et al., 2023; Wang et al., 2022; Sui et al., 2020). The health risk is even greater when PM contains toxic chemical components such as polycyclic aromatic hydrocarbons (PAHs), which are known carcinogens (Singh and Agarwal, 2022; Feng et al., 2022).

In Indonesia, one of the developing countries in SEA, a significant percentage of rural households still rely heavily on solid fuels, such as firewood, for cooking (Arcenas et al., 2010; Sulistyorini et al., 2022, Syamsiro et al., 2019) . Several factors contribute to this continued practice, including cultural traditions, economic constraints, and the limited availability of alternative clean energy sources like liquefied petroleum gas (LPG). In some cases, villagers are hesitant or even fearful of using LPG due to a lack of experience or knowledge about how to operate it safely. Although the government has introduced programs to promote the use of LPG in rural areas, these efforts have not been fully successful, mainly because of this fear and lack of familiarity. The adoption rate of LPG varies across regions, depending on factors such as affordability, accessibility, and user preferences. In reality, many rural families now use a combination of gas and wood, adjusting their fuel choice based on the type of food being cooked, the time of day, or the availability of firewood. For example, wood is often used to boil water for tea or coffee, while gas may be used to cook meals. However, previous studies have shown that cooking with wood produces significantly higher levels of air pollutants, including particulate

matter (PM), carbon monoxide (CO), and volatile organic compounds (VOCs), compared to cooking with LPG (Chen et al., 2021; Jagger et al., 2024; Kashtan et al., 2023).

Furthermore, the impact of indoor air pollution is exacerbated by the typical kitchen design in rural homes. In many cases, ventilation systems in Indonesian rural households are inadequate or entirely lacking. Essential features such as chimneys, exhaust fans, or windows located near the cooking area are often absent. As a result, smoke and pollutants generated during cooking tend to linger indoors for extended periods, leading to a persistent buildup of airborne contaminants. This situation poses a significant health risk, especially to vulnerable groups such as women and young children, who typically spend more time indoors and are thus more likely to experience prolonged exposure to PM (Maung et al., 2022; Zhou et al., 2022; Tolis et al., 2021) . The lack of effective ventilation increases the concentration of pollutants in the living environment, intensifying the risk of both short-term and long-term health problems associated with indoor air pollution (Basile and Bloch, 2012; Fasola et al., 2021; Bozzola et al., 2024).

Despite the serious concerns described earlier, studies on indoor air quality in Indonesia remain limited. Even research on ambient PM is still largely focused on urban areas, with rural regions receiving far less attention (Amin et al., 2024). Most existing studies in Indonesia have concentrated on outdoor air pollution, particularly in cities, while indoor air pollution—both in rural and urban settings—has been relatively under-researched (Amin et al., 2024). In particular, data on PM concentrations indoors, especially during cooking activities in kitchens, is crucial for understanding the potential health impacts on household occupants. One major challenge contributing to the lack of research in this area is the limited availability of affordable and accessible air quality monitoring equipment. Additionally, power supply issues—such as frequent electricity outages or even a complete lack of access in certain villages—pose significant obstacles to conducting indoor air pollution monitoring in rural areas. These limitations have historically hindered efforts to assess and address indoor air quality in these communities.

Recent advancements in sensor technology—particularly the rapid development of low-cost optical particle counters—have made monitoring indoor air quality much more accessible. These sensors allow for relatively high temporal and spatial resolution and typically offer real-time measurements. Many of them can even be operated using a power bank, making it possible to conduct monitoring in areas without access to electricity. Additionally, these devices are user-friendly and do not require specialized training to operate. In the broader context of environmental

health and sustainable development, efforts to improve indoor air quality align closely with the United Nations Sustainable Development Goals (SDGs). Specifically, they contribute to SDG 3 (Good Health and Well-being) and SDG 7 (Affordable and Clean Energy). Therefore, addressing indoor air pollution in rural Indonesia is not merely an environmental science issue; it is also a crucial aspect of promoting social equity and improving public health. Understanding the patterns of PM concentrations during cooking activities and assessing their associated health risks is essential. Such insights are vital for developing effective mitigation strategies, promoting the use of clean cooking practices, and ultimately fostering healthier indoor environments in rural households.

1.2. Study objectives

This study seeks to fill the existing research gap by monitoring and analyzing indoor PM levels during cooking activities in rural households in Indonesia. The specific objectives of the study are:

1. To characterize the mass and number concentrations of particulate matter during cooking activities in rural Indonesian households
2. To estimate the possible health risks associated with PM exposure during typical cooking times, particularly focusing on vulnerable household members such as women and children who are more frequently exposed to indoor pollutants.
3. To compare the observed PM concentrations with existing national and international air quality standards (such as those set by the WHO and Indonesian Ministry of Environment and Forestry) and to evaluate the results in the context of previous studies conducted in similar rural environments.

By achieving these objectives, the study aims to contribute new knowledge to the field of indoor air pollution in Indonesia and support evidence-based strategies for improving household air quality in rural areas especially in the kitchen.