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Social and environmental impacts of traditional charcoal production: a case study in Hau Giang province, Viet Nam

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Abstract. This study investigated the status, environmental health risks and assessed contaminant concentrations of flue gas and ambient air quality in traditional charcoal production kiln areas in Hau Giang province. In total, 284 charcoal producers, 160 charcoal workers, and 160 neighbors were interviewed using structured questionnaires. Additionally, the concentration of carbon monoxide (CO), nitrogen dioxide (NO_2), particulate matter (PM), and sulfur dioxide (SO_2) from traditional kilns and ambient air samples were analyzed. The results showed that the average number of kilns owned by each charcoal producer was 3.13 kilns per household, of which the average volume of each kiln was 59.07 m^3 $kiln^{-1}$, with an annual charcoal yield of around 80.71 t $kiln^{-1}$. The profitability of charcoal producers was annually approximately 133 million VND per household. Charcoal workers predominantly reported suffering from eye irritation issues (41.6 %), while adjacent neighbors frequently experienced respiratory problems (87.5 %). The interviewees obviously recognized the negative impacts of charcoal production activities on community health (63.1 % respondents) and local fruit production (79.4 % respondents), yet only the minority of residents (8.11 % respondents) required a change from the current charcoal-based livelihood. The CO, PM, and SO_2 in flue gas compositions exceeded the maximum permissive levels of the National Technical Regulation on Industrial Emission of Inorganic Substances and Dusts (QCVN 19:2009/BTNMT), while the ambient quality of around charcoal production surpassed the maximum permissive level of PM and SO_2 (QCVN 05:2013/BTNMT). This indicates a very high risk to those who are regularly exposed to air pollutants. The study suggested that technological solutions and responsible policies should be enforced to promote the sustainability of charcoal production and minimize the negative impacts on human health as well as the environment.

Keywords: charcoal production, community health, environmental and social issues, traditional kilns.

Classification numbers: 3.4.5, 3.6.2, 3.8.2.

1. INTRODUCTION

Charcoal is a vital fuel produced by the carbonization of firewood under high temperatures and a low-oxygen environment [1], providing domestic energy for both rural or urban households. Over the years, the global demand for charcoal consumption has increased in relation to population growth and migration [2]. The peculiarity of charcoal production through traditional brick bell-sharped kilns is associated with the generation of smoke, particles, and toxic organic compounds [3]. The flue gas produced from the anoxic pyrolysis process contains a wide range of pollutants comprising particle matter (PM), polycyclic aromatic hydrocarbon (PAHs), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrogen oxides (NOx), sulfur oxides (SOx), and volatile organic compounds (VOC) [4 - 7]. Occupationally exposed workers suffer respiratory-related health problems. The accumulation of particulate matter in the respiratory system can increase the risks associated with heart-lung and cardiovascular illnesses. While, long-term exposure to particulate matter has been reported to cause mental retardation, attention deficit disorders, hyperactivity, and cancer [8 - 10]. In the elderly, frequent contact could influence declined lung capacity, asthma, and acute myocardial infarction [11]. Additionally, intensive CO exposure released from kilns affects children’s physical and mental growth [12].

In Hau Giang province, traditional charcoal production, with currently 869 traditional brick bell-sharped kilns, has been established and developed over several decades [13]. Major hubs of charcoal production are located in Phu Tan commune – Chau Thanh district and Tan Thanh and Dai Thanh commune – Nga Bay city. Charcoal production offers a stable income for households in rural areas. Moreover, it also creates regular employment for approximately 4.000 manual workers in Hau Giang and adjacent provinces as well [14]. In addition to the well-documented air pollution causing current social, environmental, and health problems [7], the large charcoal production areas also face workplace safety, gender division, children’s engagement, and high risks related to spontaneous combustion [5]. This negative impact has been recently highlighted by scientists, managers, and the media. However, the local community's consciousness of environmental concerns seems neglectable. Charcoal production activities in Hau Giang are characterized by spontaneous, non-synchronizing, and a shortage of environmental commitment and protection. Flue gas emitted from the firewood pyrolysis process directly affects the living environment and quality of life of approximately 1,660 local residents and indirectly disturbs local household agricultural-based livelihoods in surrounding areas [14]. However, the characteristics of charcoal production status, its impacts on environmental background are poorly understood. Thus, the study aims to (i) investigate the status of traditional charcoal production risks related to health and the environment, and (ii) assess air pollutant concentration in the flue gas and surrounding areas of traditional charcoal production kilns.

2. MATERIALS AND METHODS

2.1. Study area

The survey was carried out in 3 communes of Hau Giang Province, (i) Phu Tan commune – Chau Thanh district, (ii) Tan Thanh commune, and (iii) Dai Thanh commune – Nga Bay city, Vietnam (Figure 1) from September to December 2020. Most small-scale household charcoal producers are located alongside rivers and canals, which facilitates the transportation of firewood and charcoal products.

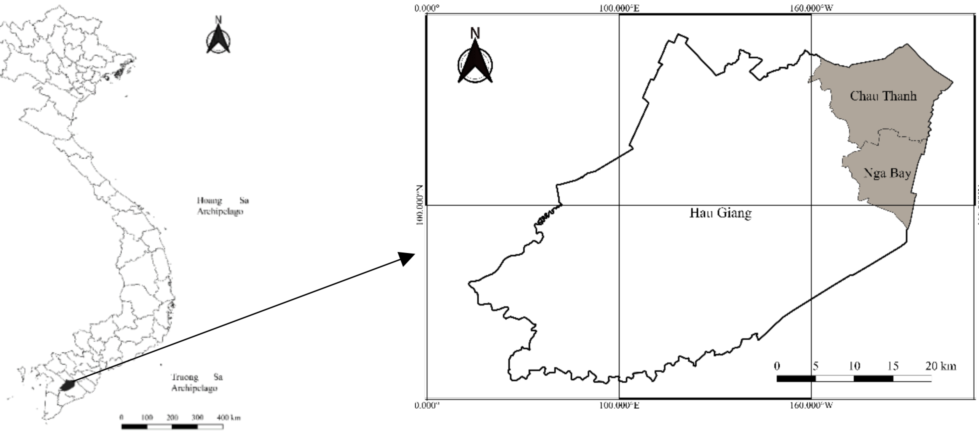

Figure 1. Location of the study area, Hau Giang province, Viet Nam.

2.2. Stakeholder survey

We organized six in-person meetings with the attendance of the Heads of (i) the Department of Environmental Protection in Hau Giang province, (ii) the Division of Environment and Resources in Chau Thanh district and Nga Bay city, and (iii) People's Committee of the three communes. We collected general information on the status of charcoal production activities, their impacts on community health, and background information on socio-economic, environmental, and agricultural production.

2.3. Community survey

A structured questionnaire was designed to investigate the status of household charcoal production activities in accordance with the results of previous studies. In total, 284 household small-scale charcoal producers, 160 charcoal workers who were occasionally exposed to the air-toxicological environment from charcoal-making kilns, and 160 neighbors who live nearby, adjacent to the charcoal production area, were interviewed. In the case of those who owned several kilns, the survey was carried out for all kilns separately. In the charcoal producer group, we collected the characteristics of traditional charcoal kilns, operational costs and profitability, confirmation of their key livelihood, the expectation of shifting from a charcoal-based livelihood, and agreement to invest in a flue gas treatment system. In the neighbor group, we investigated their engagement in charcoal production, confirmed their key livelihood, the average income from charcoal production activities, charcoal-based livelihood expectation, and critical issues of health and the environment. In the worker group, we also surveyed the seniority, the average income, individual protective equipment, the expectation to change livelihood, and critical health and environmental issues.

2.4. Characteristics and protocol of traditional charcoal production kiln

Figure 2a shows a traditional kiln typically made from baked bricks, clay, and sand mortar. The structure of each traditional kiln includes (i) a bell-shaped pyrolysis chamber that carbonizes firewood, (ii) a door that is used for wood loading and charcoal unloading, (iii) a combustion chamber that provides heat for the carbonization process, and (iv) 4 chimneys that release flue gas from the heating chamber. A traditional charcoal production process could be briefed as follows (Figure 2b): (i) firewood is fully loaded in the chamber according to each layer; the lowest layer is kept 5 - 10 cm away from the pyrolysis chamber base to ensure the air convection inside the chamber, (ii) the door is completely sealed after fully firewood loading to commence the pyrolysis process, (iii) the whole firewood inside the kiln is carbonized by providing heating via a combustion chamber; air heating slowly transfers to the inner heating chamber to kick off the carbonization progression; firewood experiences a series of decomposition/conversion mechanisms under thermal reaction conditions in a poor-oxygen environment, (iv) after 25 days of pyrolysis, the heating was switched off, and the combustion chamber was blocked off for an additional 15 days to cool to ambient temperature, and (v) the charcoal is unloaded and transported out of kilns to sell for local traders, and a new cycle will be ongoing.

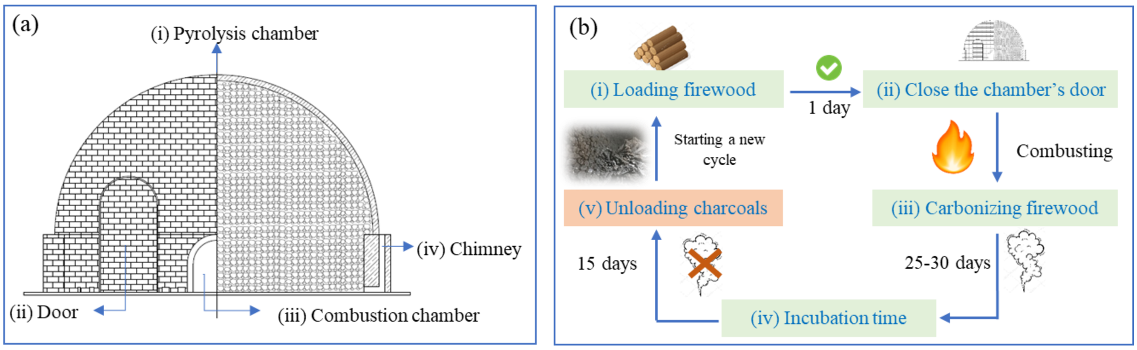

Figure 2. Structure (a) and protocol (b) of a traditional charcoal production kiln.

2.5. Air quality assessment

Flue gas was directly analyzed from 9 operational kilns in Chau Thanh district and Nga Bay city. At each kiln, flue gas samples were taken four times inside a kiln chimney in accordance with the 4 phases of the carbonization reactions. This includes (i) 5-day startup phase (wood drying), (ii) initial carbonization (pre-carbonization) phase – the charcoal primarily formed from the summit of pyrolysis kilns after 10-day pyrolysis; (iii) midterm carbonization phase – approximately 50 % of charcoal production (20 days), and (iv) final carbonization phase - hydrolysis processes seemly over in all the kilns (30 days).

The parameters of flue gas samples, including CO, NOx (based on NO_2), SO_2, and PM, were detected during the hydrolysis process. In which CO, NO_2, SO_2 were determined using a portable emission analyzer (Testo 350, Germany). The analyzer was calibrated before use and during the period of monitoring by zeroing at regular intervals. The method to determine the concentration of gas flue contaminants by the analyzer was as follows - (i) measuring the diameter of the charcoal kiln chimney, (ii) entering the value to the analyzer determining the flue gas flow rate that emitted from the kiln, (iii) placing machine's probe inside the chimney kiln with a fixed angle of 90 ^{o}C, (iv) pumping flue gas automatically to the analyzer via the probe with a constant flow rate of 0.5 L min^{-1} for a 15-minute duration to detect the concentration of contaminants.

PM samples were collected by the isokinetic method and detected by the US EPA Method 5 [15]. A high-volume air sampler (Tecora G4, Italy) was used to take the PM from flue gas at the sampling port (Figure 3). The high-volume air sampler automatically maintained the isokinetic sampling rate during the sampling run, which is greater than 90 %. PM was collected at one point on the chimney because the chimney diameter was lower than 30 cm (Circular

24/2017/TT-BTNM; US EPA method 1A). A total volume of flue gas was taken by 1.5 m^3 through a 47 mm glass-fiber filter paper. Collected filter papers were dried in an oven at 105 °C for 3 h. It was then put in a desiccator at least 24 h before weighing. PM was detected based on the increase in filter paper weight compared to the initial weight. All measured values were converted to standard temperature and pressure according to Circular 24/2017/TT-BTNM dated September 01, 2017, of the Ministry of Natural Resources and Environment on environmental monitoring techniques.

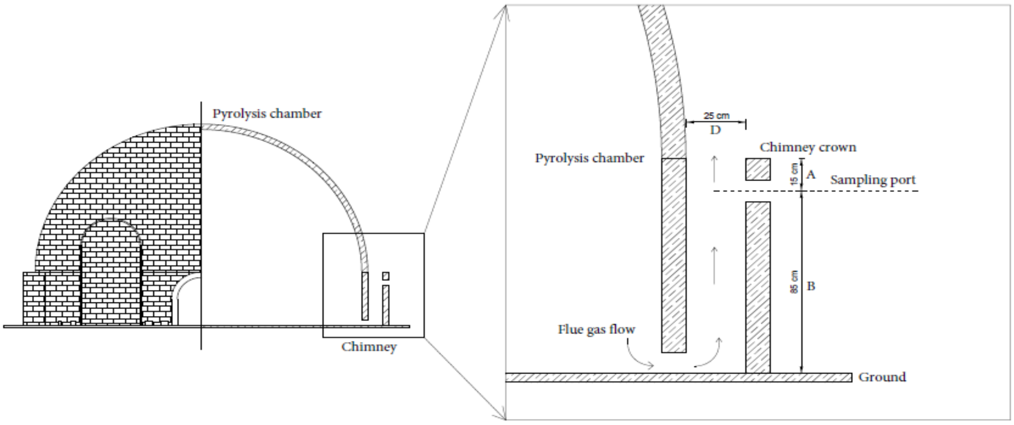

Figure 3. Diagram of chimney, flue gas flow and sampling port.

Ambient air samples were measured in the working environment of kiln laborers and neighbors' living environment surrounding charcoal production sites. Air samples were collected at a radius of 10 m from kilns, as this is the common distance for workers, and at a radius of 200 m for a background environment surrounding charcoal production sites, based on local household distribution and consultation with local authorities. Measurements were carried out four times in accordance with the time of flue gas measurements. At each time, we monitored three repetitions a day, comprising the early morning, noon, and late afternoon in order to elucidate the fluctuation amplitude of quantitative data results in a day. We detected CO, NO_2, SO_2, and PM in air samples. Ambient air samples were collected at selected sites and analyzed at the laboratory. The methods used to detect the ambient air parameters were completely different from flue gas. The PM was measured by the weighing method (TCVN 5067:1995) [16]. CO was analyzed by the gas chromatographic method (ISO 8186:1989) [17], SO_2 was determined by Pararosaniline Method (ISO 1667:1990) [18], and NO_2 was measured mass concentration by the modified Griess-Saltzman method (ISO 6768:1998) [19].

2.6. Data processing

Data obtained from interviews were entered and processed by using Microsoft Excel 2019. Flue gas was evaluated based on the National Technical Regulation on Industrial Emission of Inorganic Substances and Dusts (QCVN 19:2009/BTNMT, column B). We used one-way ANOVA analysis to evaluate a statistically significant difference in the concentration of air pollutants over the 4 phases of the pyrolysis processes. Ambient air quality results were compared to the National Technical Regulation on ambient air quality (QCVN 05:2013/BTNMT). We applied a one-way ANOVA analysis to evaluate a statistically significant difference in the concentration of contaminants over the 3 times (early morning, noon, and late afternoon). We carried out the statistical analysis using Sigmaplot 14.0. If the dataset passed the normality test ($P > 0.05$), Shapiro-Wilk analysis was carried out. In contrast, if the dataset failed the normality test ($P < 0.05$), Kruskal-Wallis analysis was performed. The results were presented in tabular form with the values including mean ± standard deviation (SD) and the different symbols with a confidence level of 95 %.

3. RESULTS AND DISCUSSION

3.1. Status of charcoal production

Table 1 shows the status of charcoal production activities in Hau Giang province. Currently, the number of charcoal producers was around 284 households with 890 kilns which quantified equivalent of 3.13 kilns per household. The mean charcoal yield of each kiln reached 80.71 tons per year. It is noticed that the charcoal yield relies heavily on the type of firewood feedstock, kiln size, and operation frequency. For the capacity of kilns, the average volume of each kiln was 59.07 m^3 and varied from 57 to 61 m^3 (accounted for 50 % of the number of kilns in this area). According to charcoal producer's responses, the charcoal production kilns were built recently with a higher capacity than previous kilns. In the traditional kiln carbonization process, 40 tons of ordinary firewood produces 13 tons of charcoal which means that 3.07 kg of fuelwood was required to produce 1 kg of charcoal; the wood-to-charcoal conversion rate was 32.57 %. On the other hand, each kiln approximately annually needs around 248 tons of firewood which align with previously reported results [20].

As can be seen from Table 1, the operational time needed to complete a batch of carbonization was roughly 38.06 days, with a common variation of between 35 and 41 days. The process comprises firewood preparation, wood loading, carbonization, incubation time, and charcoal unloading. The investigation showed that the performance of each kiln universally obtained around 6.26 batches per year. Yet, the operation of kilns depends on the readiness of firewood sources and consumption markets, either domestically or overseas.

Data confirms that charcoal production activities are currently the critical livelihood for the majority of small-scale charcoal producers. Charcoal production accounted for 95 % of total household income, which worked out to approximately 42.6 million VND $kiln^{-1}$ per year and was annually equivalent to 133 million VND per household. This level of income was relatively satisfactory for charcoal producers. Therefore, only 11.6 % of interviewed charcoal producers expected to shift their current business activities to gain a higher income.

Among surveyed charcoal producers, the proportion of non-investment households was 85.2 %, while the percentage of investment households was identically low (Table 1), which indicated that the majority of households are against installing the flue gas treatment systems. Here, financial limitations and ineffective technological solutions were detected as the primary concerns. Furthermore, 8.5 % of households suggested that synchronization of policies needs to be established and applied for all the neighboring charcoal producers.

It can be observed that charcoal-based livelihood plays a vital role for residents. In total, 64.2 % of the surrounding neighbors were directly involved as hired workers at kilns, which accounted for 70.8 % of total household income. Each household had ~2 members to take part in the manual jobs at kilns earning 5.04 million VND per capita monthly. In the case of charcoal workers, the seniority of charcoal-production workers was 10.06 years of experience. Charcoal production offered a stable income for workers, which was a monthly 5.68 million VND per capita.

Table 1. Status of charcoal production.

Key information	Unit	Value
Charcoal producers		
Age	year old	43.3 ± 10.8
Male	%	82
Number of kilns owned by a charcoal producer *(n =284)*	kiln household^{-1}	3.13 ± 2.03
Charcoal production kiln volume *(n = 980)*	m^3	59.07 ± 28.74
Charcoal yield *(n = 980)*	ton kiln^{-1} year^{-1}	80.71 ± 39.20
Time of a pyrolysis cycle *(n = 980)*	Day	38.06 ± 10.40
Wood-to-charcoal conversion rate	%	32.57 ± 6.72
Number of charcoal production batches *(n = 980)*	batch year^{-1}	6.26 ± 1.79
Operational costs for a batch *(n = 980)*	million VND kiln^{-1} batch^{-1}	95.60 ± 70.50
Profitability *(n = 980)*	million VND kiln^{-1} batch^{-1}	42.60 ± 28.50
Key livelihood *(n =284)*	%	94.7†
Expect to change from the charcoal-based livelihood *(n =284)*	%	11.6†
Investment in flue gas treatment system *(n =284)*		
Non-investment	%	85.2
< 30 million VND	%	4.2
30 - 50 million VND	%	0.7
50 - 70 million VND	%	1.4
Others	%	8.5
Surrounding neighbors *(n =160)*		
Age	year old	42.4 ± 8.7
Male	%	59
Time of settlement	year	39.1 ± 18.7
Charcoal production engagement	%	64.2†
Key livelihood	%	70.8†
Mean income of each household member from charcoal production	million VND month^{-1}	5.04 ± 2.36
Number of household members working in charcoal kilns	member household^{-1}	1.84 ± 1.19
Expecting to change from charcoal-based livelihood	%	7.20†
Charcoal workers *(n =160)*		
Age	year old	37.4 ± 9.5
Male	%	74
Seniority (working years)	year	10.06 ± 9.11
Mean income	million VND month^{-1}	5.68 ± 1.75
Fully equipped personal protective equipment	%	6.80†
Expecting to change from charcoal-based livelihood	%	1.80†

Note: "†" was statistically calculated based on the percentage of total respondents with the answer of yes.

However, it is recognized that the figure of workers who were fully equipped with personal protective equipment was low (6.8 % respondents), which suggests health risks as a consequence of long-term exposure. There was a strong possibility that charcoal production generated many job opportunities for many people in the study area. Hence, the probability of conveying surrounding neighbors and charcoal workers switching from their charcoal-based livelihoods was only 7.2 % and 1.8 %, respectively.

3.2. Flue gas quality assessment of released via carbonization phases

The mean concentration of air pollution (CO, SO_2, NO_2, and PM) from charcoal kilns is shown in Table 2, and their variation amongst sampling times and charcoal kilns is displayed in Figure 4. The result showed that the average CO values generally increased with the carbonization process. The highest mean values of CO concentration were detected in the middle phases (20,017 mg Nm^{-3}). In comparison to the National Standard, the CO values were consistently higher than that of the QCVN 19:2009/BTNMT (column B) over the entire carbonization phases, especially in the middle and final phases. However, there was no significant difference in CO values during the middle and final phases ($P > 0.05$). Figure 4a illustrates that CO largely varied among measurable times and charcoal kilns. The highest concentration touched 50,571 mg Nm^{-3} during the thermochemical decomposition of firewood. In total, 29 out of 36 samples (80 %) transcended the QCVN 19:2009/BTNMT (column B), which related to the initial, middle, and final phases.

Table 2. Characteristics of flue gas from carbonization phases.

Unit: mg Nm^{-3}

Parameters	Carbonization phases				Reference[†]
	Start-up	Initial	Middle	Final	
CO	1,019 ± 628[a]	8,038 ± 8,909[ab]	20,017 ± 16.47[c]	17,010 ± 12,625[bc]	1000
SO_2	1.34 ± 3.02[a]	747 ± 1,210[b]	44.1 ± 122.5[a]	3.55 ± 10.65[a]	500
NO_x	102 ± 82.8	106 ± 60	115 ± 21.7	135 ± 67.10	850
PM	44.3 ± 15.8[a]	65.1 ± 45.3[a]	126.9 ± 81.4[b]	233.4 ± 137.7[c]	200

Note: notations indicate significant differences among carbonization phases with a confidence level of 95 % (One-way ANOVA method). "†" indicates a reference to the permissible maximum concentration limits of the QCVN 19:2009/BTNMT (column B) in 1 hour.

A similar trend was also seen in mean NO_2 concentrations, with NO_2 increasing through the carbonization process. The highest mean concentration was 135 mg Nm^{-3} which occurred in the final phase. There was no significant difference in the average NO_2 concentration among the carbonization processes. Table 2 and Figure 4c show that recorded NO_2 in all samples was under the QCVN 19:2009/BTNMT threshold (column B).

Similarly, it can be observed that SO_2 formed during the carbonization process substantially varied amongst sampling times and charcoal kilns. The highest concentration was seen in the initial phase compared to the remaining phases ($P < 0.05$). In total, 3/36 samples surpassed the QCVN 19:2009/BTNMT (column B), which focused on the initial phase (Figure 4b).

Furthermore, the results show that the mean of PM tended to increase with the pyrolysis process. PM varied from 44.3 to 233.4 mg Nm^{-3}, with the highest concentration recorded in the final phase ($P < 0.05$). Figure 4d shows that 7/36 samples exceeded the QCVN 19:2009/BTNMT (column B), only recorded in the second phase.

In this study, CO was also recognized as the prevailing gas emitted from the pyrolysis process of charcoal kilns. This can be explained by the incomplete combustion of hydrocarbon, anoxic pyrolysis, and the short-time exposure between firewood and heating [12, 21]. Besides, NO_2 and SO_2 emissions was generally relevant to the nitrogen and sulfur contents in different types of firewood feed-in materials and the presence of oxygen during the pyrolysis process [21]. However, in this study, we did not analyze the content of each element and recorded the oxygen concentration in the flue gas. Thus, the interdependence between composition and pollutant concentration in the flue gas was still uncertain. PM emissions from charcoal kilns were generally related to converting volatile gases, and vapors vented directly into the atmosphere [20]. Data obtained in this study showed that CO, SO_2, and PM parameters released from kilns were generally higher than the permissible limits of QCVN 19:2009/BTNMT (column B) and posed severe risks to human environmental health. Therefore, the results suggest that the health of charcoal workers and surrounding neighbors and the environmental protection in charcoal production areas should be considered as core priorities.

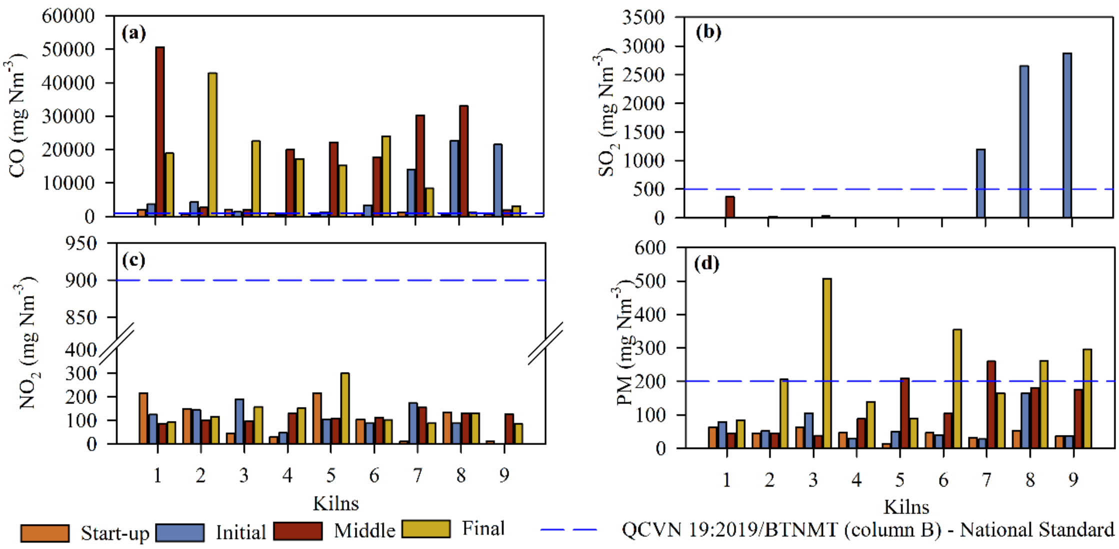

Figure 4. Variation of gaseous emissions among sampling times and charcoal kilns.

3.3. Ambient air quality assessment and its impact on health risks and agricultural production

Table 3 and Figure 5 illustrate the mean concentrations and fluctuation of ambient air contaminants according to time-of-day variation at kiln workplaces and surrounding areas. The mean concentration of CO values varied between 4,693 and 4,740 µg m^{-3} directly at the kiln workplaces (10 m distance from the kiln). Whilst, CO values in the surrounding areas ranged from 4,076 to 4,299 µg m^{-3} (200 m radius from the kiln), which was similar to previous values reported [21, 6]. Among the measured times, CO values at noon tended to be highest than those in the early morning and late afternoon. It could be partly explained by gas dynamic under higher temperatures, but measured values were insignificant ($P > 0.05$). It is apparent that higher CO concentration was found at charcoal kiln sites than in the adjacent areas. In all cases, the variation of CO was consistently lower than that of QCVN 05:2013/BTNMT (Figure 5), which indicates a safe level for short-term CO exposure.

As can be seen from Table 3, the average concentration of NO_2 varied from 43.8 to 48.2 µg m^{-3} at worker sites (a 10 m distance) and fluctuated between 38.3 and 40.5 µg m^{-3} in surrounding areas (~ a 200 m distance). A higher concentration of NO_2 varied between 190 and 490 µg m^{-3} within a 1 m radius of kilns was reported in a previous study [6]. Thus, data indicate that ambient air contaminant concentration levels rely on the monitoring distance from kilns. As observed data, there was no significant difference in NO_2 among time-of-day concentrations ($P>0.05$). All measured NO_2 values were lower than that of the QCVN 05:2013/BTNMT.

Table 3 shows the mean concentration of SO_2 at direct workplaces and surrounding places of kiln charcoal production. Accordingly, SO_2 concentration varied from 205 to 240 µg m^{-3} (a 10 m distance) at charcoal workplaces and ranged from 177 to 220 µg m^{-3} (a 200 m distance) at proximity sites. These results are lower than the 1-m distance from traditional kilns, with a variation between 1,740 and 2,930 µg m^{-3} reported by [6]. No significant difference was recorded among sampling times of day ($P < 0.05$). Figure 5 depicted that 15/36 samples at worker sites and 4/36 samples in adjacent areas surpassed the allowed limit of the QCVN 05:2013/BTNMT (350 µg m^{-3}). This indicates a higher health risk for workers.

Table 3. Characteristics of ambient air quality in surrounding areas.

Unit: µg m^{-3}

Parameters	Early morning	Noon	Late afternoon	Reference†
Air quality in charcoal worker sites				
CO	4,693 ± 1,220	4,850 ± 1,244	4,740±1,243	30,000
NO_2	47.4 ± 25.1	48.2 ± 28.5	43.8±26.8	200
SO_2	220 ± 137	240 ± 148	205±103	350
PM	84.6 ± 56.3^a	102.6 ± 100.9^a	79.9±86.5^b	300
Air quality in neighbour sites				
CO	4,076 ± 997	4,299 ± 1,126	4,286 ± 1,074	30,000
NO_2	40.5 ± 24.1	40 ± 28.9	38.3 ± 22.6	200
SO_2	177 ± 84	220 ± 114	190 ± 79	350
PM	35.1 ± 22.8	31.4 ± 19	28.3 ± 19.2	300

Note: notations indicate significant differences among sampling times with a confidence level of 95 % (One-way ANOVA method). "†" indicates a reference to the permissible maximum concentration limits of the QCVN 05:2013/BTNMT in 1 hour.

Comparing the mean of PM concentration, it is evident that there was no significant difference among sampling times ($P > 0.05$), although the higher PM concentrations were recorded at noon. The mean variation of PM values varied between 79.9 and 102.6 µg m^{-3} at the kiln workplaces, while surrounding sites fluctuated between 28.3 and 35.1 µg Nm^{-3}. Overall, 3/36 of the measured PM values at a 10 m distance from kilns surpassed the QCVN 05:2013/BTNMT, while surrounding sites were all under the safety level.

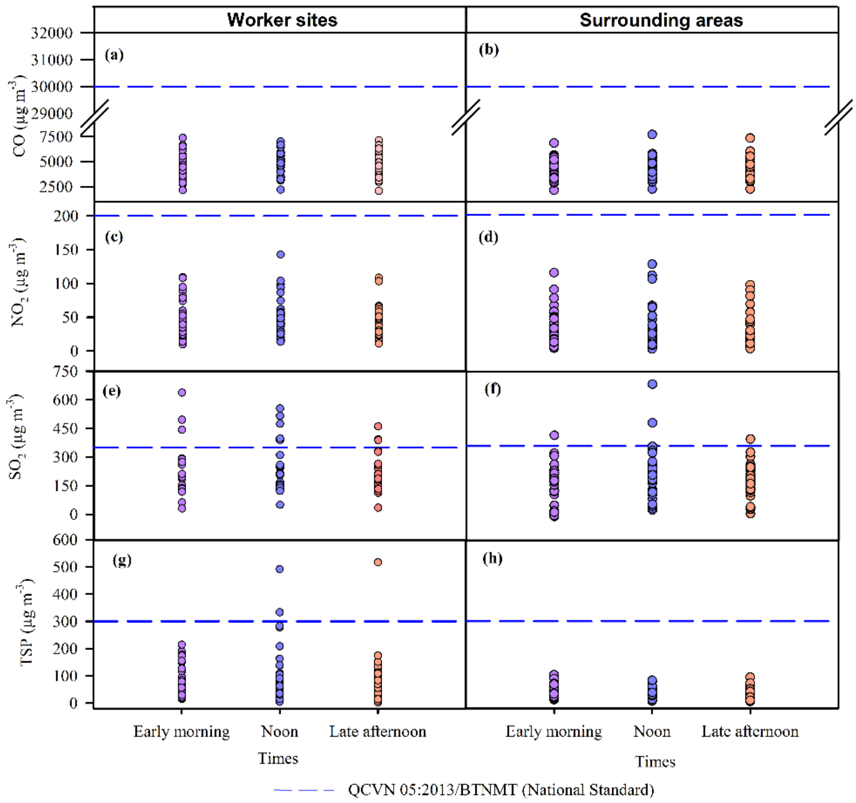

Figure 5. Variation in ambient air contaminant concentrations according to sampling times.

Our study showed that the concentration of air contaminations at workplaces was higher than that of adjacent sites, which indicates that traditional charcoal production kilns are the key factor for the emission and spread of air contaminants. The SO_2 and PM concentrations exceed the QCVN 05:2013/BTNMT, indicating that the living and working environmental conditions remain unsafe for human health. Although CO and NO_2 were lower than the permissible limit of QCVN 05:2013/BTNMT, chronic exposure can result in health and environmental risks because charcoal production activities are conducted continuously amongst producers with no limitation on operational schedules. According to [10, 22], air pollutants can increase the symptoms of respiratory-related illnesses and impact the function of the lungs even at low concentrations. Moreover, long-term exposure to CO results in headache, exhaustion, dizziness, and nausea syndromes [12, 23]. Furthermore, the combination of CO and particulate matter results in sore throat and irritation [10], while accumulation of particulate matter concentration in the respiratory system can also cause mental retardation, attention deficit, hyperactivities, and cardiovascular disease [9]. Besides, regular SO_2 inhalation is more likely to result in breathlessness, wheezing, and impaired lung function [21]. Also, those who are regularly exposed to a high NO_2 concentration cause lung-related risks of function [24, 25].

Our study showed that charcoal production activities negatively influenced the health of neighbors and charcoal workers around kiln sites and the reproduction of fruit plants in the region. In which, the workers were detected as the highest affected group compared to surrounding neighbors (Table 4). This can be explained by the high-frequent exposure to air contaminants and the adverse working environment at charcoal kilns.

Table 4. Impact of charcoal production on health risks and agricultural production.

Key influences	Neighbor (n = 160)	Worker (n = 160)
Effects on health risks	42.3	83.8
Respiratory (n = 138)	87.5	2.8
Coughing	NA	17.4
Eye irritation (n = 7)	5.0	41.6
Insomnia (n = 8)	5.2	16.6
Ailment (n = 7)	5.0	15.3
Other	NA	6.3

Note: the data was statistically calculated based on the percentage of total respondents with the answer of yes. "NA" shows no symptoms were recorded during the survey.

The majority of neighbors (87.5 %) reported respiratory-related issues, while eye irritation, insomnia, and ailment symptoms were less reported (~5 % of respondents). In contrast, 41.6 % of workers reported eye irritation signs, whilst the respiratory symptom case was reported by only 2.8 % of workers. Coughing, eye irritation, insomnia, and ailment were all relatively universally reported between 15.3 and 17.4 % of respondents concerning these issues. Moreover, other symptoms such as dizziness, lightheadedness, and nausea while, and sometime after, engaging in production tasks were also expressed (6.3 %). These above-mentioned symptoms are common for those who regularly contact or live in charcoal production areas [3, 21]. As such, symptoms of the worker group were more diverse than that of the neighbors, which is suggestive of higher exposure. In addition, our study showed that the rate of the worker group with respiratory symptoms was much higher than that of the neighbor group. It could be partly attributed to the age and gender disparity displayed in Table 1. In which, the average age in the worker group was lower 5-year-old neighbor group; simultaneously, the gender ratio in the worker group appeared to be plateauing around 15 % higher in males.

It is noticed that adverse impacts on fruit plants resulted from charcoal production activities (Table 5). Commonly reported cases were limited plant growth and yield reduction, 38.9 and 33.9 %, respectively. The case of plant death was also considered relatively common by 16.3 % of respondents. Moreover, charcoal dust released from kilns significantly changes fruits' colors, resulting in a low selling price.

Table 5. Impact of charcoal production on agricultural production.

Key influences	Percentage (%)
Effect to fruit plants (n = 160)	*79.4*
Death of plants *(n = 26)*	16.3
Limited plant growth *(n = 62)*	38.9
Yield reduction *(n = 54)*	33.9
Low-price selling *(n = 14)*	8.6
Blacked fruits due to charcoal dust *(n = 4)*	2.35

Note: the data was statistically calculated based on the percentage of total respondents with the answer of yes.

4. CONCLUSIONS

This study outlined the status of small-scale traditional household charcoal production, health and environmental concerns, the quality of flue gas, and the ambient air quality surroundings of the traditional charcoal kilns in Hau Giang province, Vietnam. Charcoal production is the key livelihood of roughly 95 % of charcoal producers and 64 % of local inhabitants in the study area. The majority of workers experienced eye irritation symptoms, while adjacent residents suffered more respirational issues. Many interviewees were aware of the negative impacts of charcoal production activities on both health and environmental risks, yet only a small minority were willing to install a flue gas treatment system. For the flue gas, the middle and final phases of charcoal production released higher air contaminants into the atmosphere. Among them, CO was the main component, with more than 80 % of collected samples surpassing the permissible limit of QCVN 19:2009/BTNMT (column B). In terms of ambient air quality, PM and SO_2 transcended the permissible limit of QCVN 05:2013/BTNMT, which indicated that charcoal production was a key factor in air contamination. The study suggested that technological solutions and sustainable production policies should be promoted to minimize harmful human and environmental health impacts.

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Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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